TOOLS FOR EVALUATION OF DOMESTIC VENTILATION SYSTEMS

L-G Månsson
LGM Consult AB, Tullinge, Sweden

ABSTRACT
Within an International Energy Agency (IEA) project (Annex 27) experts from 8 countries (Canada, France, Italy, Japan, The Netherlands, Sweden, UK, and USA) have developed tools for evaluating domestic ventilation systems during the heating season. Building and user aspects, thermal comfort, noise, energy, life cycle cost, reliability, and indoor air quality (IAQ) tools were developed. The IAQ tool accounts for constant emission sources, CO_2, cooking products, tobacco smoke, condensation risks, humidity levels (i.e., for judging the risk for mould and house dust mites), and pressure difference for identifying the risk for radon or land fill spillage to enter the dwelling or problems with combustion appliances indoors.

An elaborated set of design parameters were worked out, that resulted in about 17 000 combinations. By using multi variat analysis it was possible to reduce to 174 combinations for IAQ. A sensitivity analysis was made for 990 combinations. The results from all the runs were used to develop a simplified tool and a set of equations.

The results can be used both for dwellings to be constructed and existing dwellings. The tools give immediate answers and indications, when discussing with the client about the consequences of different choices. Within this project also a computerised energy tool has been developed taking into account air tightness, climate, window airing pattern, outdoor air flow rate, heat exchange efficiency.

This paper presents an introduction of the tools and demonstrate their applications.
Keywords: Air infiltration, air tightness, natural ventilation, outdoor air, residences, thermal comfort, ventilation, window,

1. INTRODUCTION

During the lifetime of a building the resident's pattern vary. This results in a varying need for supply air to obtain an acceptable indoor climate and to avoid degradation of the building fabric. Emissions from building materials are also time dependent. In standards and codes the outdoor air needed in a dwelling often is based on the maximum number of persons living in the dwelling, defined by the possible number of beds contained therein.

Dwellings consume about 25 – 30 % of all energy used in OECD countries. In the near future conditioning of domestic ventilation air will be responsible for 10 % of the total energy use. Thus even relatively small reductions in overall ventilation levels could represent significant savings. 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.

The **objectives** of this IEA project were: to develop tools to evaluate domestic ventilation systems; to validate these tools with data obtained from measurements; to demonstrate the use of these tools for different climates, building types, and use of dwellings; and to draft a handbook on tool usage and application.

2. TOOLS

The simplified tools are intended to provide an easy tool for the quick evaluation of existing, renovated, or new dwellings, ranking systems and weighing different factors for specific situations and the consequences. These tools are to be used for dwellings in climates that need to be heated and is valid during the heating season.

The simplified tools give the user a possibility to weigh the importance of different parameters and see the links between them. The consequences of different choices can be seen very easily and quickly. They also provide the means to evaluate suggestions during a building process. The tools have been developed both from existing computer codes and from new. The tools provide mainly qualitatively output but quantitative results are also given. IAQ evaluation is based on a statistical analysis. The tools developed are:

- Building and User Aspects (used as checklists, not further described)
- Thermal Comfort
- Noise: Outdoor and System Noise
- Indoor Air Quality: Constant emission sources, metabolically generated CO_2, cooking products, tobacco smoke, water vapour and condensation in wet and habitable rooms, dryness sensation, the risk of house dust mite growth, pressure differences indicating risk for radon and landfill spillage introduced indoors or problems with combustion appliances
- Reliability: Flow Stability and Performance Over Time
- Energy: heat needed for the ventilation and electricity for fan energy
- Life Cycle Cost (LCC)

All the tools have been developed for three climates: cold, moderate, and mild. The tools can be applied for four common ventilation systems and can also be expanded to other systems by adding one or two extra fans. The four common ventilation systems considered are:

1. Natural Window Airing (NWA)
2. Passive Stack Ventilation (PSV)
3. Mechanical Exhaust Only (MEO)
4. Mechanical Supply and Exhaust (MSE)

The tools have originally been developed for three type dwellings:

1. A four room apartment on the ground floor of a four story building.
2. A four room apartment on the top floor of a four story building.
3. A two storey detached single family house with four rooms.

The tools have limitations. Not all cases have been covered and simplifying approximations have been made. To consider other input data than that used in the development of the tools, detailed computer analysis or the equations based on statistical analysis must be used. The background reports provide guidance. Costs are given for some of combinations. Those are to be taken as an indication and also as a ranking. Background material for cost is usually more tricky to find than pure measured data.

4. THERMAL COMFORT

Inlet devices for location in the external wall or in the window frame have been tested. The tool was developed from experimental data, obtained in a climatic chamber. There are a number of factors that determine the risk of draughts occurring, in particular the vertical temperature profile, air velocity, turbulent intensity and surface temperature of the surroundings are very important. The results were used to provide a simplified tool, giving a rating of five categories. The score for each set of input parameters can be obtained by referring Table 1. The score "+ +" means the smallest impact on thermal comfort, and the score "- -" means the severest impact on thermal comfort.

The experiments showed that the lower part of the room is most critical for the draught risk. By raising overall room temperature, draught risk for the lower part of the room can be avoided. It means that the heat supply is one of the most important factors of the draught risk. Criteria for scoring the percentage of lattice points satisfying thermal comfort conditions: 100-95% "**+ +**"; 95-85% "**+**"; 85-75% "**0**"; 75-50% "**-**"; 50-0% "**- -**".

Table 1 Thermal comfort impact of outdoor air, 10l/s								
Type of inlet (vent)		**Outdoor temperature °C**						
Generic	**Specific**	**-15**	**-10**	**-5**	**0**	**5**	**10**	**15**
High induction	Upward directed flow	-	-	0	+	++	++	++
	Radiant flow	--	--	-	-	0	++	++
	Horizontal straight flow	--	--	--	--	-	+	++
Low in-duction or window ajar	Horizontal opening high position	--	-	-	0	+	+	++
	Vertical opening middle height	--	-	--	--	--	-	-
	Horizontal opening, low position	--	--	--	--	--	-	-
Back-ground leakage	n50 = 1.5 ach, (high infiltration velocity)	--	-	-	-	-	0	0
	n50 = 2.6 ach, (low	--	--	--	-	-	+	++

5. NOISE

Table 2. Indoor noise; the sound power level L_W **= 70 dB(A)**						
Duct length ⇒	< 5 meter			≥ 5 meter		
Number of branches ⇒	0	1	2	0	1	2
No silencer		--	--	--	--	--
Silencer 1000 mm	-	0	0	0	0	0
Silencer 1000 mm and cross-talk absorber 500mm	0	+	+	0	+	++

Noise in relation to ventilation systems can be divided into three categories:

- Outdoor noise through ventilation openings, cracks, etc
- Noise generated by components of the ventilation system;
- Sound transported within or between dwellings by the ventilation system.

Table3. Judging the outdoor noise reduction. Exposed facade area $S_{facade} = 5 - 10\ m^2$																
Ventilation system		$G_{a;c}$ **= 35 dB(A)**														
		Inferior soundproofed constructions, % of facade														
		0 %					< 50 %					≥ 50 %				
		Surface area A net [cm^2]														
		0-50	50-100	100-200	200-400	≥400	0-50	50-100	100-200	200-400	≥400	0-50	50-100	100-200	200-400	≥400
Natural supply	Vent. opening no sound-proofing R_a = -5 dB(A)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Soundproofed ventilation opening: R_a = 0 dB(A)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Soundproofed ventilation opening: R_a = 10 dB(A)	++	-	-	-	-	0	-	-	-	-	-	-	-	-	-
	Soundproofed ventilation opening: R_a = 15 dB(A)	++	++	++	-	-	0	0	0	-	-	-	-	-	-	-
Mechanical supply and exhaust		++	++	++	++	++	0	0	0	0	0	0	0	0	0	0

The judgement of the influence the outdoor noise can have depending of the chosen ventilation system matrices are made for different cases. Here shown by one case, table 3. To use the matrices the following has to be considered:

1. Estimate the surface area of the facade, S_{facade} in m²
2. Estimate the required characteristic noise reduction $G_{a,c} = L_o - L_i$ dB(A)
3. Estimate percentage of inferior sound proofing construction in the exposed facade
4. Estimate the net surface area A [cm²] of the ventilation opening (MSE A = 0)
5. Select the possible system and required sound proofing

In table 3 the following rating is chosen: "-" not applicable; "0" applicable with excellent sound proofing; "+" applicable with normal sound proofing; "++" applicable without extra sound proofing.

6. IAQ

This tool estimates the effects of the choice of ventilation system together with the air-tightness of the dwelling on the indoor air quality. The user selects values for basic input parameters related to the ventilation system, building envelope and climate. The user then refers to simple, easy-to-use matrices to obtain a rating of:

- IAQ (material, hours with too high CO_2, tobacco smoke, cooking emission)
- The level of condensation
- The energy required to heat the indoor air

Warning flags are also given for:

- Dryness feeling, warning if RH < 30 % more than 800 h during wintertime
- Winter high RH: Warning if no 4 week period with water vapour content < 7 g/kg is found giving an increase risk for house dust mites growth.
- Pressure difference: Warning if the difference indoor/outdoor is more than 20 Pa >200 h.

Table 4 IAQ and high relative humidity wintertime. Climate Ottawa, no window airing

Dwell	n50	NWA				PSV				MEO												MSE					
ing		Supply area cm2																				-					
		0		410		0		400		0						100						-					
		Exhaust Flow Rate l/s																									
		-								15		30		45		15		30		45		15		30		45	
		Additional fan																									
		N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
D4a	1	--	--	-	0	--	--	0	0	-	--	0	-	+	0	-	-	0	0	+	+	-	-	0	+	+	++
top	2.5	--	-	-	0	-	-	0	+	-	-	0	-	+	0	-	-	0	0	+	+	0	0	0	+	+	++
apartm	5	-	-	-	+	0	0	0	++	0	0	0	0	+	+	0	0	0	+	+	+	0	+	0	++	+	++
D4a	1	--	--	-	0	--	--	0	+	-	--	0	-	+	0	-	-	0	0	+	+	-	-	0	+	+	++
ground	2.5	--	-	-	0	-	-	+	++	-	-	0	-	+	0	-	-	0	0	+	+	0	0	0	+	+	++
apartm	5	-	-	-	+	+	+	+	++	0	0	0	0	+	+	0	0	0	+	+	+	0	+	0	++	+	++
D4c	1	--	--	0	0	--	--	+	+	-	--	0	--	+	-	-	-	0	-	+	0	-	-	0	+	+	++
house	2.5	--	--	0	+	-	-	+	++	-	-	0	-	+	0	-	-	0	-	+	0	0	0	0	+	+	++
	5	-	-	0	+	-	-	+	++	-	-	0	-	+	0	0	0	0	0	+	0	0	0	+	++	+	++
	10a	0	+	+	++	+	+	+	++	0	+	+	+	+	+	+	++	+	++	+	+	+	++	+	++	+	++
	10b	-	-	+	+	-	-	+	++	-	-	-	-	-	-	0	0	0	0	0	0	0	0	+	++	+	++

Assumptions have been made for nine different parameters for the four main ventilation systems. Either 2 or 3 values have been selected. Both a multi variat analysis and a sensitivity have been made by 990 simulations. The results gave both equations and simplified matrices, where "- -" corresponds to the higher exposures, "+ +" to the lower ones. An example is given in table 4. A detailed residential pattern had to be assumed.

7. RELIABILITY

Table 5 Flow rate stability. Climate Ottawa

System	Inlet area	Ffan flow rate	Extra fan	Dwelling: Apartment, Top, n50 = 1	Apartment, Top, n50 = 5	Apartment, Ground, n50 = 1	Apartment, Ground, n50 = 5	House, n50 = 2.5	House, n50 = 10
PSV	100	-	N	0	0	0	0	-	0
	100	-	Y	0	0	0	0	-	0
	400	-	N	+	+	0	0	0	0
	400	-	Y	+	+	0	0	0	0
MEO	0	15	N	- -	0	- -	0	-	0
	0	15	Y	- -	+	-	0	-	0
	0	45	N	0	+	0	+	-	0
	0	45	Y	+	+	0	+	0	0
	100	15	N	0	+	0	0	0	0
	100	15	Y	0	+	0	+	0	0
	100	45	N	+	+	+	+	0	0
	100	45	Y	+	++	+	+	0	0
MSE	-	15	N	0	+	0	+	0	+
	-	15	Y	0	+	0	+	0	+
	-	30	N	++	++	++	++	++	++
	-	30	Y	++	++	++	++	++	++
	-	45	N	++	++	++	++	++	++
	-	45	Y	++	++	++	++	++	++

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 for reliability as indicated by:

1. Flow rate stability as a function of situational factors, based on the assumption that the flow rate in the bedrooms should exceed 4 l/s,person, exemplified by table 5
2. Performance over time i. e. systems and components reliability.

The qualitative ratings here are:

+ + Excellent reliability > 0.5 ach
+ Good reliability 0.25 – 0.5 ach
0 Fair reliability 0.12 – 0.25 ach
- Poor reliability0.06 – 0.12 ach
- -Very poor reliability < 0.12 ach

Technical quality of ventilation systems is divided into three categories poor, average and best practice. The maintenance is also given in three levels where the high is up to doubled the normal while the low is 1/3. By estimating the probabilities for different faults in a system a graph can be given for the flow rate over time. Depending on maintenance intervals including duct cleaning, filter exchange different graphs are given.

8. ENERGY

The energy use due to ventilation and infiltration can be divided into two parts:

1. The energy to heat the infiltration and ventilation air
2. The energy to be used for the transport of air through the ventilation system

Important parameters for energy calculations are: flow rate, heat recovery efficiency, air tightness, supply air opening, climate (wind velocity, wind direction, temperature)
The interaction between infiltration and ventilation thus giving the energy need is calculated by a single zone computer model and shown in a nomogram (not shown). The tool is now an interactive computer program called Enervent.

The final output is given as: The average heating power needed in W, The amount of fuel used expressed in a unit you have defined, The annual cost in units you have defined, The annual energy consumption in GJ, Net present values for the energy cost during 30 years, Flow rate and fan pressure, Fan efficiency, Time of the day the system is in use.

9. LIFE CYCLE COST (LCC)

With the developed tool the maintenance costs by different maintenance activities can be found for the ventilation systems MEO. MSE, and MSE-X for a considered period of 30 years. The design of the tool is as follows:

The basic quality of system and building as well as the system loading need to be determined by qualitative descriptions. Then the maintenance class and the accompanying cost ranges must be read from a graph. Finally the expected maintenance costs and the planned maintenance activities can be determined using some tables. The cost for energy is dealt with separately. In total 7 different ventilation systems have been given values in 5 steps. Each system is presented on 4 pages. The steps are given in table 6.

Table 6 Steps to estimate the maintenance costs

Step 1	Estimate the basic quality and initial costs. The basic quality is determined by some qualitative descriptions of the installation and building qualities and properties.
Step 2	Estimate system loading. The users influence or system loading is determined by qualitative descriptions.
Step 3	Estimate for the situation, most suitable maintenance class. The maintenance class is estimated in a graph as a function of the basic quality and system loading. Also some cost ranges for maintenance (planned and complaints/failures) are given.
Step 4	Estimate the expected maintenance costs and the planned maintenance activities. The expected costs, expressed as Net Present Value for planned maintenance and for complaints and failures, can be estimated by using tables. Recommended maintenance activities and cycles are given. Special attention is needed for level "low". Some of the maintenance activities are carried out by the users (as a result of a conscious behaviour, resulting in a "low system loading") and some maintenance activities don't have to be carried out at all as a result of the basic quality of installation components. (Note: The costs are given in steps of 25 ECU)
Step 5	Estimate the total LCC by summarising initial costs from step 1 and costs for maintenance from step 4.

10. CONCLUSION

The tools developed is giving the user a possibility to a very quick evaluation, a comparison, showing the consequences of different choices and strategies. The application on specific cases is just engineering practice. In this paper only parts of the simplified tools can be given. Application tests made by independent experts in a non-participating country showed that the evaluation could be made within reasonable time frame for practical use.

11. ACKNOWLEDGEMENT

The funding organisations and companies in the participating countries and in particular the experts involved in the tool development: Millet (F), Villenave (F), De Gids (NL), Pfaff (NL), Op't Veld (NL), Sawachi (J), Yoshino (J), Giorgiantoni (I), Kronvall (S), Ruud (S), Feustel (USA), Reardon (CAN), Ross (UK), Orme (AIVC)

12. REFERENCES

1. Månsson L-G. (1995) Evaluation and demonstration of domestic ventilation systems. State of the Art. Swedish Council for Building Research. Report A12:1995. ISBN 91-540-5731-0.
2. Background material to be published on CD by AIVC, UK
3. Månsson L-G (editor). (1999). Simplified Tools for Evaluation of Domestic Ventilation Systems – Handbook. Manuscript to be published on CD by AIVC, UK