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A Tool for Evaluating Domestic Ventilation Systems' Ability to Provide an Acceptable Indoor Air Quality

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Synopsis

This paper is describing the first results of the Annex 27 work aiming at developing simplified tools for evaluating domestic ventilation systems by using sofisticated simulation programs studying pollutant concentration either for each person or in an individual room. Assumptions based on previous research works are set up for a number of parameters. The total number of combinations are about 17 500 and have been reduced to 174 by the statistical method "fractional factorial analysis". With this reduction it is possible to make all the runs even with sofisticated multicell models. The result is presented as coefficients for the various pollutants.

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 the resident's pattern vary. This results in a varying need for supply air to obtain acceptable indoor 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 the IEA Annex 27 are: **to** develop tools to evaluate 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.

Introduction

With the above objectives and scopes of the three subtasks the Annex started in April 1993 and has today eight participants: Canada, France, Italy, Japan, Netherlands, Sweden, UK, and USA. Based on the subtask "State of the Art" assumptions have been set up to develop simplified tools for:

1. Indoor Air quality (reported in this paper)
2. Energy
3. Noise
4. Thermal Comfort
5. Life Cycle Cost
6. Reliability
7. Building and User aspects.

With the State of the Art Review, ref 1, 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. With these assumptions we can 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 14 OECD countries studied have 700 million inhabitants, 280 million dwellings with a floor space of 32 000 million m^2. The habitable space varys greatly 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.

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/bedroom. Moving frequency studies show, that after 35 years of age the family has settled and will remain living in there.

A very important trend is that the number of one-person household is increasing. Today it goes from 20 % (Japan) to 40 % (Sweden). This 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 % today to 30 % of the population.

A survey amongst the AIVC countries gave that the most frequent ventilation system is either stack or simply window opening. However, in new constructions in most countries a fan is installed either for central exhaust or for local extraction in bath and/or kitchen.

Method

In order to develop simplified tools for the indoor air quality, a set of assumptions had to be made. Here is also included family pattern both for weekdays and weekends. Such assumptions are time schedule at home and in the individual rooms, for taking showers, cooking, smoking, window airing. In table 1 can be found the parameters the simulations are made for. The common way to do parametric studies are to vary one parameter and keep all the others constant. By this you will not get the extreme combinations. By selecting a representative number of the total combinations out of nearly 17 500, it is possible to make simulations for a statistically representative number of combinations of the parameters, "multi variant parametric study". The combinations of the values of the parameters are selected by the method "fractional factorial analysis". The number of runs is given by chosing the IVth resolution, see ref 2. Then the regression analysis of the result is giving coefficients, which can be applied on that specific case you are interested in.

This paper describes the results from the first complete 174 runs made by the semi-multicell program called SIREN developed by CSTB, France, see ref 3. The aim is to do the same with the true multi-cell program COMIS.

Here follows a short description of some of the assumptions. See also table 1.

Example dwelling: A number of dwellings were assumed, typically for the participating countries. Two type dwellings were selected as the assumed number of persons in each dwelling have the same area per person for the crowded case. The dwelling types selected are a 4-room flat either on the ground floor in a 4-storey multifamily building or on the top floor (D4a) and a 4 room detached single family house (D4c).
Ventilation systems: The four main systems are: **1** adventitious or natural window airing (Airing), **2** natural passive stack (Stack or S), **3** mechanical exhaust (Exh), **4** mechanical supply and exhaust (SE). All systems can be combined with local fans.
Family types: Three cases crowded (5 persons), average (4 persons), spacious (2 persons)

Table 1. Links between factors and high, medium, and low values used in the simulations

Factor	**Level**			**Comments**
	+1	**0**	**-1**	
Dwelling A (DWA)				
Dwelling B (DWB)				
Leakage (LEA) dwell. D4a dwell. D4c	5 (5) h^{-1} 10 (5) h^{-1}	2.5 (2.5) h^{-1} 5 (2.5) h^{-1}	1 (1) h^{-1} 2.5 (1) h^{-1}	( )in brackets mech supply and exhaust
Occupancy (OCC)	Crowded	Average	Spacious	
Window airing (WIN)	Climate depending	50 % climate depending	Closed windows	
Climate (CLI)	Cold, Ottawa	Mild, London	Warm, Nice	
Supply area (SUP)	410 cm^2 400 cm^2	205 cm^2 200 cm^2	0 cm^2 0 cm^2	Vent. systems 1 Vent. systems 2 & 3
Flow rate (FLR)	60 l/s	45 l/s	30 l/s	Mech. ventilation
Local fan, kitchen hood (LKF)	On, 100 l/s		Off	
Local fan, bath (LKB)	On, 25 l/s		Off	

Leakage: Three cases are given with more airtight envelope if mechanical supply and exhaust ventilations system is used. Tighter for flats.
Window airing: Assumed to take place only in bedrooms. Three cases are given **1** closed window, **2** opening pattern depending on the outdoor temperature and wind speed, and **3** a medium case with 50 % of the opening area depending of the climate.
Clothes washing and drying: Base case with no water vapour.
Indoor temperature: +20 °C
Body washing: All residents are taking a 10 min shower every day in the morning
Tobacco smoking: The woman is smoking in the living room when at home after 13.00 h

In table 1 is indicated the level which is purely used when interpreting the combination given by the fractional factorial analysis and here **"+1"** indicates that the high value is to be used in the calculation, **"0"** the medium value, and **"-1"** the lower value. By combining columne DWA and DWB the type dwellings are selected to be D4a on ground floor or on top floor in a 4-storey building or the detached house D4c. In table 2 is given the number of factors for each parameter and the number of runs for each of the ventilation systems.

Table 2 Number of factors and how many levels

System	DWA	DWB	LEA	OCC	WIN	CLI	SUP	FLR	LKF	LKB	Factors	Number of runs.
Airing	2	2	3	3	3	3	3	-	2	2	9	$2^{9-4}+2\times5+1=43$
Stack	2	2	3	3	3	3	3	-	2	2	9	$2^{9-4}+2\times5+1=43$
Exh	2	2	3	3	3	3	3	3	2	2	10	$2^{10-5}+2\times6+1=45$
SE	2	2	3	3	3	3	-	3	2	2	9	$2^{9-4}+2\times5+1=43$
Total												Total 174 runs

Results

The regression analysis have given a set of coefficients for each of the indoor air quality factor and for each system. The first preliminary results for supply and exhaust ventilation systems have just been produced. The approach is illustrated in table 3.

The results of the complete simulations will give for each case the following indoor air quality and energy parameters.

1. Pollutant 1. Is a pollutant constantly emitted (eg. building material)
2. Pollutant 2. The number of hours that the most exposed person is exposed for a CO_2-level above 700 ppm or 1400 ppm. (Here 1400 ppm is never reached
3. Pollutant 3. Exposure for cooking products, e.g. water vapour, CO, NO_2
4. Pollutant 4. Exposure for tobacco smoke, passive smoking.
5. If the dwelling has a too high or too low pressure difference it might give a risk for radon, combustion spillage, and interstitial condensation.
6. Humidity. Relative humidity (RH) in each room, number of hours RH>75 % indicating a risk for mould growth. As it is nearly impossible to have water vapour content < 7g/kg all the time. We have checked if there is a 4 week period during the heating season with lower values giving a chance to recover from house dust mite.
7. Outdoor air change rate in the individual habitable rooms
8. Energy both for heating the outdoor air and for the fan energy

The pollutant production is assumed to be constant when smoking. The presence in the dwelling varys and is depending on which case that is selected. For the crowded and average cases is given41 h/week and for the spatious case only 27 h/week.

This first presentation of the results are given as factors for some some of the above parameters, see table 3. As the code, SIREN, is a semi-multicell computer code the result is given for all the habitable rooms together or the most exposed person. Both additative and multiplicative regression analysis has been tested and the best fitted is selected.

Discussion

This first presentation of some of the pollutants for one ventilation system is indicating the proceedure of the work within Annex 27 to predict the indoor air situation for a very large number of combinations. By using simulation technique it is possible to run a statistically selected number of combinations representing the total number of combinations. As it is too expensive to do a simulation run on an individual dwelling for each case with a number of assumptions, the final aim is to give possibilities to evaluate all ventilation systems in an easy way for a variety of pollutants.

The first analysis indicates that a regression based on multiplying or adding factors is a possible way. Runs with the code SIREN, that has a short running time for each combination, will be compared with the true multicell model COMIS. The results will also be compared with detailed measured dwellings in the participating countries.

Usually there is no time or money to make detailed computer simulations for ventilation systems in the residential sector during the design process. The simplified tools make it possible to predict the indoor air quality for a lot of different parameters for many ventilation systems. The tool can be used for proposing systems in new houses or when renovation is proposed. It can also be a tool for a first check if any complaint has been made by the residents.

References

1. Månsson L-G (ed). *Evaluation and Demonstration of Domestic Ventilation Systems. State of the Art.* A12:1996 Swedish Council for Building Research. ISBN 91-540-5731-0.
2. Montgomery D C. *Design and Analysis of Experiments*. 3rd edition 1991. Arizona State Univ. John Wiley & Sons. ISBN 0-471-52000-4
3. Millet J-R; Kronvall J; Holtsberg. *Simulation of IAQ. Simulation results and statistical analysis*. April 1996. Working document

Table 3. Factors for IAQ. Exhaust and supply air system

Parameter	Lev-el	CO2> 700 ppm. h	Cook h	Smok, h	Dry, h	Low press, Pa	Cond ens h	Energy kWh	Vent, ach
Basis value		**18**	**1692**	**936**	**813**	**-7.9**	**174**	**2250**	**0.93**
Add +/-; Mult *		+/-	*	*	+/-	*	+/-	*	*
Detached		0	1	1	0	1	0	1	1
Ground fl		-53	0.99	1.08	620	1.08	87	0.97	1.02
Top floor		-12	0.98	1.09	+654	1.51	+100	0.95	1.01
Leakage	Low	+22	1.00	1.03	+30	1.35	+22	0.81	0.91
	Ave	0	1	1	0	1	0	1	1
	High	-58	0.99	0.94	+65	0.88	-1	1.30	1.14
Occupancy	Low	-100	0.81	0.68	-102	1.21	-126	1.03	1.01
	Ave	0	1	1	0	1	0	1	1
	High	+186	1.19	1.00	-357	1.10	+67	0.99	0.99
Window	No	-30	1.01	0.99	+44	0.63	-6	0.90	0.96
airing	Ave	0	1	1	0	1	0	1	1
	High	-6	0.99	1.00	+41	0.71	+28	0.98	0.99
Climate	Mild	-44	0.69	0.66	-299	1.08	-66	0.58	1.04
	Ave	0	1	1	0	1	0	1	1
	Cold	+6	0.97	0.95	+187	1.92	-62	1.83	1.04
Air flow	Low	+273	1.09	1.19	-214	1.13	+104	0.77	0.72
rate	Ave	0	1	1	0	1	0	1	1
	High	-89	0.94	0.87	+218	1.18	-58	1.25	1.29
Kitchen fan	used	-5	0.68	0.99	+24	1.47	-63	1.05	1.07
	not	0	1	1	0	1	0	1	1
Bathr fan	used	-25	1.01	0.99	+18	1.16	-103	1.02	1.04
	not	0	1	1	0	1	0	1	1