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A METHODOLOGY TO ASSESS THE IAQ PERFORMANCES OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS

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ABSTRACT

Until now, there is no widely accepted way to express any index for this purpose and taking into account the large variety of possible pollutants. Things can be simplified if the aim is to compare different systems and strategies rather than to give an absolute value of quality.

For the study of a pollutant source, the main important point for comparison is the pattern of its production, whatever this pollutant is. For human feeling and health we defined 5 main generic pollutants: constant emission related to the room area; human metabolism (using CO2 as a tracer); emission due to cooking activities; passive smoking; indoor humidity related to the dryness feeling.

The detailed data for each inhabitant is the curve of the number of hours above a pollutant level concentration Ci : Nh (Ci). A condensed one is calculated as the cumulated value above a threshold limit Cimax. This is the basis for the results presented here. Other parameters are also calculated as pressure difference between outdoor and indoor, room related parameters (humidity, condensation hazards), and energy parameters (heat needs and fan energy).

This methodology was defined and used in the framework of IEA annex 27 "domestic ventilation". Typical climates, dwellings and family patterns were also defined in order to compare the ventilation systems used in the different countries on the same basis.

The application was made by using to ventilation codes: COMIS, developed by an international group of researchers at LBL and SIREN, developed by CSTB. We defined 4 main types of widely used ventilation systems. Two sets of simulations were performed, the first one (174 runs) made it possible to compare the results between the 2 codes, and can be used as a basis for a statistical analysis. The second one (990 runs) was performed by SIREN and will be used for producing paper tools. We presented here the main corresponding results. Agreement between COMIS and SIREN proved to be close enough to give confidence in the ranking of the different ventilation system assessment.

KEYWORDS

ventilation system, IAQ index, ventilation heat losses, ventilation codes,

INTRODUCTION

A methodology to compare the performances of ventilation systems has been defined within the IEA annex 27 project.

After a presentation of the different parameters taken into account, we describe the methodology and we compare the results given by the codes COMIS and SIREN95.

THE STUDIED PARAMETERS

In the IEA annex 27 project ventilation systems are study : nine dwellings (3 plans and 3 airthightness), three occupancy (spacious, average, crowded), three climates (cold, mild, warm). [1]

Results are given in term of indoor air quality (pollutant exposure for each inhabitant) and energy.

Dwellings : three dwellings have been considered :

- D4A : four rooms flat located on ground floor in a four-storey building.
- D4B : four rooms flat located on top floor in a four-storey building.
- D4C : 4 rooms single family house

The climates are related to meteorological data from :

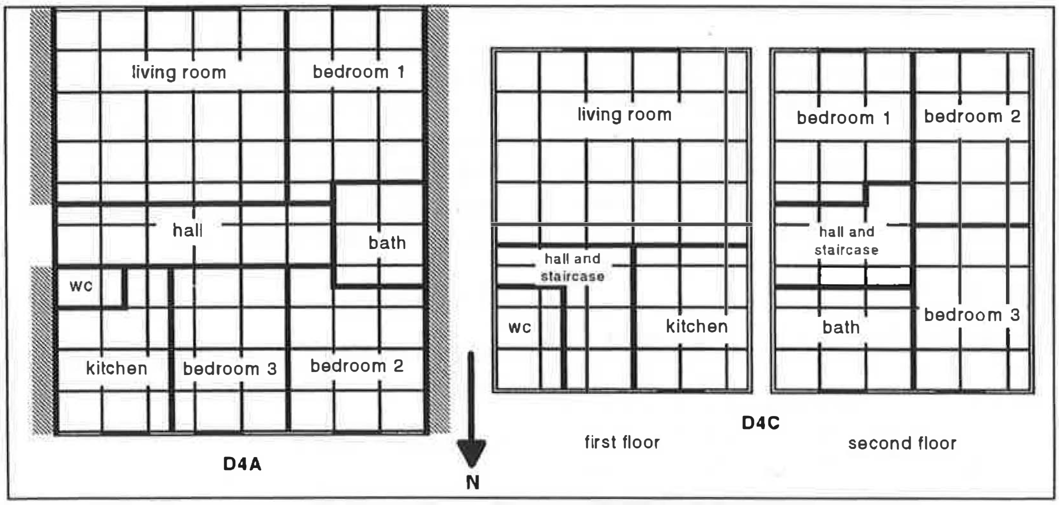
- cold : Ottawa (Canada).
- mild : London (United Kingdom).
- warm : Nice (France).

Four ventilation systems are designed :

- natural airing
- passive stack
- mechanical exhaust
- mechanical exhaust and supply

Dimensioning make use of inlets or outlets size and airflows (extract and supply)

For each system an alternative consists in additional fans in kitchen and bathroom, opening windows in bedrooms,



Leakage values are given hereafter :

	n50 (ach)		
D4A	1	2.5	5
D4C	2.5	5	10

Half of the cracks are located at 0.625 m from the floor and the other half 1.875 m from the floor for the leakage 1 , 2.5 and 5. For leakage 10, the additional cracks are located at the floor and at the ceiling.

Indoor air quality for people

For the study of a pollutant source, it can be noticed that the main important point for comparison is the pattern of its production (level versus time and place), whatever this pollutant is . Therefore, it is possible to define some generic pollutants, which will be defined only by their pattern.

For human feeling and health we propose at first to base the comparisons on five main generic pollutants :

- Pltl : constant emission related to the room area. It could be related to pollutant emission by the rooms themselves.
- Plt2 : human metabolism. It is based on the CO2 production.
- Plt3 : cooking activities. It is based to the water evaporated during cooking and could be related to odours production, as to CO or NOx production in case of gas appliance.
- Plt4 : passive smoking . It is based on a production of pollutant for the hours and place when and where people are smoking (production 20 U4/h in the living when woman is present between 13 - 24 o'clock).
- Indoor humidity : this one is here only related to the dryness feeling. It is not a generic pollutant as it can be expressed directly in terms of indoor relative humidity.

A weekly schedule of the dwelling occupancy has been defined by IEA annex 27 [1].

The production of pollutants by occupants metabolism is given hereafter (by person) :

		CO_2 (l/h)	H_2O (g/h)
Adult (≥15 years)	awake	18	55
	sleeping	12	30
Children (10 and 13 years)	awake	12	45
	sleeping	8	15
Child (2 years)	awake	8	30
	sleeping	4	10

Water vapour production by occupants activities is given hereafter (by person):

Cooking (g/h)			Shower (g)
breakfast	lunch	dinner	
50	150	300	300

Results :For each inhabitant we give the curve of the number of hours above a pollutant level concentration Ci : Nh (Ci). These results are also given in a condensed form based on the calculation of the cumulated value above a threshold limit. For CO2, the limits are 700 and 1400 ppm : the condensed outputs are expressed in ppm.h above these two levels.

The energy needs must be split into heat needs and electrical needs for fan.

The heat needs is calculated knowing the airflows to the outdoor and the temperature difference between outdoor and indoor. The airflows are separated into three parts :

- air exhausted by the ventilation system,
- air exfiltred through the envelope,
- airing by opening windows.

The average air flow and air change per hour is the direct averages during the heating season of the overall air dwelling airflow. It is not of direct interest because it is neither related to indoor air quality nor to heating needs. For example with the same average airflow, the heat needs will be increased if the ventilation in winter is higher (passive stack systems) and decreased if the ventilation is lower (humidity controlled systems).

We calculate **heat needs equivalent air flow rate** and air change rate which are the constant airflow (or air change rate) which would lead to the same heat needs as the ones calculated. It is simply calculated by :

$$Qave = \frac{\int 0.34 \times Q(t) \times (Ti - Te(t)) \times dt}{\int 0.34 \times (Ti - Te(t)) \times dt}$$

The electrical needs will be calculated on the whole year if this corresponds to the system running : the power is considered 40 W for a dwelling : the annual consumption is 350 kWh.

THE COMPUTER CODE *COMIS*

COMIS is a multi-zone flow model developed within Annex 23. The FORTRAN code was originally developed at the Lawrence Berkeley Laboratory in the framework of the COMIS one-year workshop. Significant further development of the model has taken place since that workshop. COMIS is programmed in FORTRAN 77.

User interfaces for input and output processing are available for PC (for both DOS and MS-WINDOWS).

This program allows for sophisticated multi-zone airflow and contaminant transport simulations. Air flow component for natural as well as mechanical ventilation systems can be modelled : it includes cracks, duct systems, fans, volumes, layers, vertical large opening, sources and sinks of pollutants, and pressure coefficients of façades.

Various schedules can be defined for the outdoor climate, indoor rooms temperatures, pollutants sources and sinks, and airflow component operation schedule.

The time evolution of flows and concentrations as well as integrated and mean values for the whole-simulated time period can be determined.

THE COMPUTER CODE *SIREN95*

The computer code SIREN95 is an evolution SIREN ("SImulation du RENouvellement d'air") developed in C.S.T.B [2]. It is used to calculate the airflow throughout the entire heating season (about seven months) in a dwelling (with a maximum of 15 rooms).

The code uses hourly meteorological data (temperature, relative humidity, wind speed and orientation) ; occupancy and pollutants production (CO_2 H_2O ...) are defined with a half an hour step ; actually four pollutant, plus water vapour can be taken into account ; for water vapour hygroscopic inertia an be adjusted.

Pollutants and humidity concentrations are assumed uniform in each room.

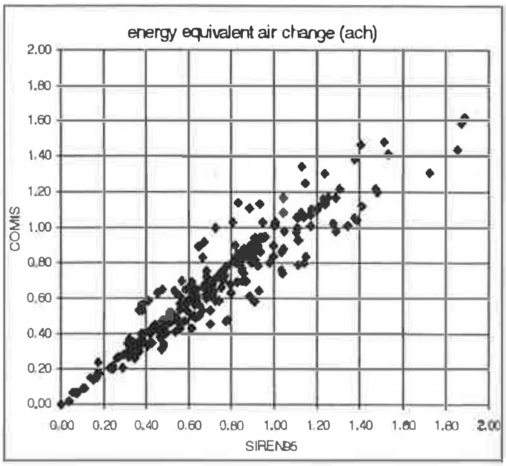
In SIREN95 internal pressures are assumed a hydrostatic field ; the inside temperature is considered constant in a horizontal plane (only vertical gradient : stack effect is taken into account).

Each component (air inlets, outlets, cracks, fans, windows, ...) is characterised by its flow rate curve as a function of the pressure difference and also when relevant, of the temperature, pollutant concentration or relative humidity. The curves of components can be given by functions (not necessary smooth) or tables : a possible hysteresis can be taken into account.

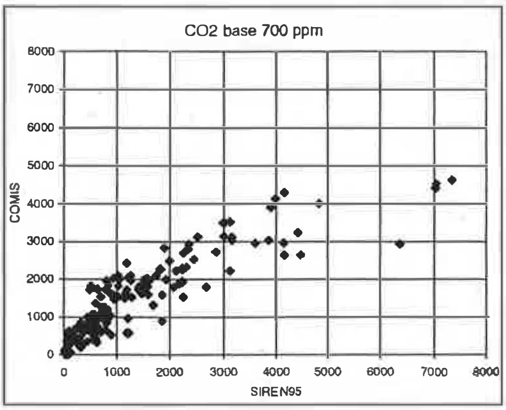
SIREN95 is written in FORTRAN 77 ; it runs an entire heating season in roughly four minutes (PC Pentium 150 MHz or more)

COMPARISON : COMIS & SIREN95

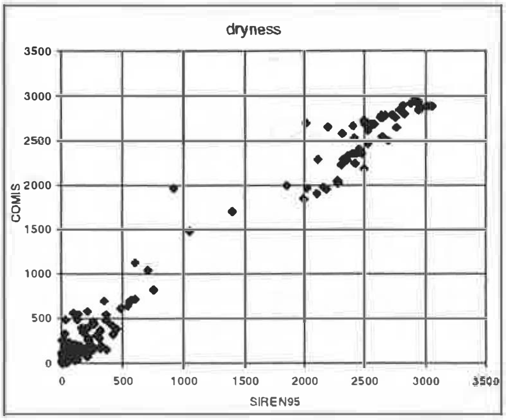
We compare COMIS and SIREN95 on the results of 174 simulations with changes in dwellings, ventilation system, climates, occupancy, ...



Results of equivalent air change are in good accordance : for natural airing, SIREN95 (which don't take into account pressure losses due to internal doors) gives a higher level than COMIS



Four cases corresponding to natural windows airing and passive stack ventilation systems are quite different (values calculated with SIREN95 above 6000 ppm.h)
For mechanical ventilation systems (exhaust only and balanced results are in good accordance.



Although COMIS use a post-processor to calculate indoor humidity the results are closely related.

PERFORMANCES OF VENTILATION SYSTEMS

With SIREN95 we have run 990 simulations with changes in dwellings, ventilation system and climates.

For the most important parameters (IAQ, condensation, energy) the results are given in five classes (++ - - approach). The class limits are not directly reproducing the 20% values, as the curves are not linear (which means that doing so would not make it possible to appreciate well the - - class).

We give hereafter the classes limit for three pollutants and equivalent air change rate :

	IAQ			
	CO2 700ppm	cooking	passive smoking	energy
unit	kppm.h	U3.h	U4.h	ach
++ to +	500	600	400	0.4
+ to 0	1000	1000	600	0.6
0 to -	2000	1500	1000	0.8
- to --	4000	4000	1600	1.0

Results are given in tables as follow :

- indoor air quality : we calculated for each case the - - to ++ classes for CO2, cooking products, and passive smoking ; the final result is the worst value.
- condensation : we calculated for each case the - - to ++ classes for the habitable rooms and the wet rooms ; the final result is the worst value.
- energy (equivalent air change rate).

In addition to the ++ -- approach related to principal parameters of IAQ and energy ,additional parameters are qualified with warning flag as follows

- Dryness feeling : Warning flag if the number of hours of dryness feeling (R.H. < 30 %) is more than 800 hours
- Pressure difference : Warning flag if the pressure difference indoor – outdoor is more than 20 Pa for 200 hours a year
- Indoor humidity (house dust mite) : warning flag if no period of 4 weeks with A.H. > 7 g/kg can be found during the heating season

Indoor air quality

		nat. wind. airing								p. stack				mechanical exhaust												balanced					
	airing ->	no				yes				no																					
	supply ->	0		410		0		410		0		400		0						100											
	flow rate ->													15		30		45		15		30		45		15		30		45	
	add fan ->	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
dwelling	n 50																														
D4a	1	--	--	-	o	--	--	-	o	--	--	o	o	-	--	o	-	+	o	-	-	o	o	+	+	-	-	o	+	+	++
	2.5	--	-	-	o	--	-	-	o	-	-	o	+	-	-	o	-	+	o	-	-	o	o	+	+	o	o	o	+	+	++
top	5	-	-	-	+	-	-	-	+	o	o	o	++	o	o	o	o	+	+	o	o	o	+	+	+	o	+	o	++	+	++
D4a	1	--	--	-	o	--	--	-	o	--	--	o	+	-	--	o	-	+	o	-	-	o	o	+	+	-	-	o	+	+	++
	2.5	--	-	-	o	--	-	-	o	-	-	+	++	-	-	o	-	+	o	-	-	o	o	+	+	o	o	o	+	+	++
ground	5	-	-	-	+	-	-	-	+	+	+	+	++	o	o	o	o	+	+	o	o	o	+	+	+	o	+	o	++	+	++
D4c	1	--	--	o	o	--	--	o	o	--	--	+	+	-	--	o	--	+	-	-	-	o	-	+	o	-	-	o	+	+	++
	2.5	--	--	o	+	--	--	o	+	-	-	+	++	-	-	o	-	+	o	-	-	o	-	+	o	o	o	o	+	+	++
	5	-	-	o	+	-	-	o	+	-	-	+	++	-	-	o	-	+	o	o	o	o	o	+	o	o	o	+	++	+	++
	10 case a	o	+	+	++	o	+	+	++	+	+	+	++	o	+	+	+	+	+	+	++	+	++	+	+	+	++	+	++	+	++
	10 case b	-	-	+	+	-	-	+	+	-	-	+	++	-	-	-	-	-	-	o	o	o	o	o	o	o	o	+	++	+	++

Heat needs

		nat. wind. airing								p. stack				mechanical exhaust												balanced					
	airing ->	no				yes				no																					
	supply ->	0		410		0		410		0		400		0						100											
	flow rate ->													15		30		45		15		30		45		15		30		45	
	add fan ->	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
dwelling	n 50																														
D4a	1	++	++	+	o	++	++	+	o	++	+	-	--	++	+	+	o	-	-	++	+	+	o	-	-	++	++	++	+	++	+
	2.5	++	++	+	o	++	++	+	o	+	o	-	--	++	+	+	o	-	-	++	+	+	o	-	-	++	+	++	+	+	o
top	5	++	+	o	-	++	+	o	-	o	-	--	--	+	o	o	o	-	--	+	o	o	-	-	--	++	+	+	o	o	o
D4a	1	++	++	+	o	++	++	+	o	+	-	--	--	++	+	+	o	-	-	++	+	+	o	-	-	++	++	++	+	++	+
	2.5	++	++	+	o	++	++	+	o	o	--	--	--	++	+	+	o	-	-	++	+	+	o	-	-	++	+	++	+	+	o
ground	5	++	+	o	-	++	+	o	-	--	--	--	--	+	+	o	o	-	-	+	o	o	-	-	--	++	+	+	o	+	o
D4c	1	++	++	+	o	++	++	+	o	+	o	-	--	++	++	+	o	o	-	++	+	+	o	o	-	++	++	++	+	++	+
	2.5	++	++	o	o	++	++	o	-	+	o	--	--	++	+	+	o	o	-	+	+	+	o	-	-	++	+	++	+	+	o
	5	++	+	o	-	++	+	-	-	-	-	--	--	+	o	o	-	-	-	+	o	o	-	-	--	+	+	+	o	o	o
	10 case a	-	-	--	--	-	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	-	--	--	--	--	--
	10 case b	o	-	--	--	o	-	--	--	--	--	--	--	o	-	-	--	--	--	-	--	--	--	--	--	o	-	-	--	-	--

evaluation of indoor air quality and heats needs vs ventilation system and dwelling characteristics for Ottawa climate

These above tables give examples of results for Ottawa for air quality and heat needs only;

The input parameters of the table are as follows :

- Dwellings (D4A top, D4A ground, D4C) are described in the studied parameters
- n 50 value (1; 2.5 ; 5; 10) is described in the studied parameters. For leakage 10 the additional cracks are located at the floor and at the ceiling for the case a, and are concentrated in the hall for the case b.
- The ventilation systems are identified by four base systems. Those systems can then be combined with local fans in bathroom/toilet and/or kitchen and

window opening patterns (closed, or climate depending). Complete mixing is assumed in each room.

1. Natural ventilation by means of cracks/window airing ,

2. Natural ventilation, passive stack (passive stack ventilation),

3. Mechanical central exhaust, natural supply,

4. Mechanical central supply and exhaust (balanced).

1. windows opening (airing)

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

Two cases of purpose provided openings are taken into account:

- : 0 cm2
- : 410 cm2 (80 cm2 in each habitable room. 30 cm2 in each of the toilet, bath, kitchen)

2. passive stack

Two cases of purpose provided openings are taken into account:

- : 0 cm2
- : 400 cm2 (80 cm2 in each bedroom and 160 cm2 in the living-room)

The passive stack exhaust system is as follows :

Length of the ducts: Multifamily building. Building height to the top floor ceiling +1.5m; Single family houses +2.5 m.

Ducts are circular sheet metal with the sizes: Ø150 mm bath and toilet, Ø200 mm kitchen. The friction factor of the ducts is *=0.05.

The equivalent area of the exhaust device ("grilles"), (Cd=0.6), is 70 % of the cross area of the duct

Kitchen: 200 cm2

Bathroom and toilet: 125 cm2

3. mechanical exhaust

Two cases of purpose provided openings are considered:

- : 0 cm2
- : 100 cm2 (20 cm2 in each bedroom and 40 cm2 in the living-room)

The mechanical exhaust flow rate is given for three levels.

1. 15 l/s (7.5 l/s in the kitchen 5 l/s in the bath and 2.5 l/s in the toilet)
2. 30 l/s (15 l/s in the kitchen 10 l/s in the bath and 5 l/s in the toilet)
3. 45 l/s (22.5 l/s in the kitchen 15 l/s in the bath and 7.5 l/s in the toilet)

4. balanced

Three cases of supply flow rates are considered :

- 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)
- 4 5 l/s (9 l/s in each bedroom and 18 l/s in the living-room)

The exhaust flow rates are the same as for the mechanical system, with a heat exchanger efficiency of 50 %

Local additional fans

For all systems additional fans can be used or not :

a) Kitchen hood: Running time 1 h/day, at 17.00 - 18.00 o'clock. Flow rate is 100 l/s

b) Bathroom fan: Running time is 2 h/day. Weekdays 6.00 - 8.00 o'clock and weekends at 9.00 - 11.00 o'clock. Flow rate is 25 l/s.

The output parameters are the classes as described in the performances paragraph.

An IAQ + + result indicate that the result is + + for the CO2, cooking and passive smoking pollutants. A - - value indicates that at least one of this pollutant leads to a - - value.

A - - value for energy indicates that the equivalent air change rate is higher than 1.0 a.c./h ; a + + that it is less than 0.4 a.c./h

These tables makes it possible to evaluate the efficiency of a given ventilation system depending on the use of airing and additional fan in relationship with the dwelling characteristics (type of dwelling, situation, airtightness).

Some comments can be made regarding the produced values for Ottawa climate :

- it appears that a ventilation system can't be ++ both in air quality and energy needs. That is particularly true with natural windows airing and passive stack,
- For mechanical systems and providing that the dwelling is airtight enough, systems can be good (+) for IAQ and very good (++), especially for balanced system with heat recovery,
- For mechanical exhaust system with no air inlets, the presence of an additional fan decrease the IAQ index if the dwelling is airtight : this is due to the fact that air enter through the fan hole when the fan is not running, which reduce the amount of air entering the habitable rooms,
- The location of unknown air leakages can have a strong impact on air quality for all systems but the balanced ones : this can be seen for the house D4c case a (equally split air leakages) and case b (half of air leakages in the hall). In this case, air is poorly entering through the habitable rooms, which leads to both high heat needs and low air quality.

ACKNOWLEDGEMENTS

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REFERENCES

[1] IEA Annex 27 "Assumptions for the simulations"

[2] Villenave JG, Millet JR, Ribéron J "Theoretical basis for assessment of air quality and heat losses for domestic ventilation systems in France". 14th AIVC conference on Energy Impact of Ventilation and Air Infiltration, Copenhagen, September 1993.

[3] Ribéron J, Millet JR, Villenave JG. "Assessment of energy impact of ventilation and infiltration in the French regulations for residential buildings". 14th AIVC conference on Energy Impact of Ventilation and Air Infiltration, Copenhagen, September 1993.

[4] Villenave JG, Ribéron J, Millet JR, "French Ventilation in dwellings", Air Infiltration Review, vol. 14, n°4, pp 12-15, September 1993.