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Theoretical Basis for Assessment of Air Quality and Heat Losses for Domestic Ventilation Systems in France

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ABSTRACT.

Ventilation of buildings is necessary, both to insure adequate indoor air quality and to protect the building itself against condensation and mould growth. On the other hand, ventilation rates must not lead to excessive energy consumption.

French regulation doesn't appreciate directly the indoor air quality but fixes requirements for the value of exhaust stale air in service rooms ; furthermore heat losses related to cross ventilation due to wind effects are also taken into account. For assessment of Demand Control Ventilation systems both air quality and heat losses have to be compared to a mechanical exhaust only system.

In this paper, we describe the methodology and the CSTB computer models, and how they have been used to design the French rules related to the energy demand of ventilation systems and the air quality level obtained with DCV systems by reference to a conventional mechanical ventilation system.

1 - INTRODUCTION.

Ventilation of buildings is necessary, both to insure adequate indoor air quality and to protect the building itself against condensation and mould growth. On the other hand, ventilation rates must not lead to excessive energy loads. Mechanical ventilation systems, which have been in common use in France since the sixties, comply this requirement.

Mechanical systems have been improved for ten years : new systems with variable flow rate according to the prevailing indoor climatic conditions, enable energy conservation and indoor air quality to be further improved.

Evidence from a variety of investigations and systematic studies (in France but also in other countries) suggests that the use of these systems can improve indoor air quality while the energy consumption be reduced [1, 2 and 3].

2 - BASIS OF FRENCH REGULATION.

2.1 - Historical.

For more than 20 years French Regulations for dwelling have been the mover of the building insulation and ventilation technological progress.

In 1969 ventilation had to supply fresh air to the habitable rooms and to exhaust stale air from the service rooms (this point of the French regulation has been continuously used since then) with an air change rate about 1 volume/hour. The French authorities decided to include the energy loss due to the ventilation in the total energy loss of the buildings. This point of the French regulation, which has been continuously used since then is very specific and important : it makes it possible to compare the design alternative and parametrics studies.

After the energy crisis (1974) research on occupied dwellings came to the conclusion that almost 50 % of dwellings were over ventilated; with the 1982/83 regulation the flow rate depends on the number of habitable rooms with a possibility of reducing the ventilation rate during under occupancy. One of the technological consequence is the development of humidity controlled ventilation systems. Air leakage's through a building envelope can disrupt the intended operation of heating and ventilation. In view of high stakes, research works were conducted at the C.S.T.B. into air infiltration in buildings [4]. They involved improvement in heat losses calculation due to cross ventilation and development of air leakage measurement methods.

$Q_V = 45 * 15 \times n$

DCV $Q_V = 5 * n$

2.2 - Heat losses due to ventilation systems.

Using the computer code GAINE which includes climatic data, a new way of calculating cross ventilation flow rate was developed [5 and 6]. Cross ventilation heat losses do not only depend on flow rate through the building envelope, but also on flow rate due to the ventilation system operation. They are decreased when the negative pressure inside the building, caused by the operation of the ventilation system is increased.
The 1991 regulation describes how to calculate the thermal losses due to ventilation : [7]

$$Ev = 0.34 \times (Qv + Qs) \qquad (1)$$

where :

Ev	heat losses due to ventilation in W/°C
0.34	specific heat of air (Wh/m^3.°C)
Qv	air flow due to the ventilation system (m^3/h)
Qs	air flow due to wind effects (m^3/h)

2.2.1 - Air flow due to the ventilation system.

The air flow due to the ventilation system is the total air flow through the outlets

$$Qv = (1 - a) \times Qm + a \times QM \qquad (2)$$

where :

a=1	fixed area outlet
a=1/12	outlet with manual additional flow rate
a=1/24	outlet with time controlled (30 minutes) additional flow rate
Qm and QM	are given in table 1

Table 1 : values of air flow due to ventilation system

	number of habitable rooms						
	1	2	3	4	5	6	7
Qm (m^3/h)	35	60	75	90	105	120	135
QM (m^3/h)	105	120	150	165	210	210	210

2.2.2 - Air flow due to wind effects.

The expression of the air flow due to wind effects (cross ventilation) is :

$$Qs = P \times \frac{e}{1 + \frac{d}{e} \times \left(\frac{Qv}{P}\right)^2} \qquad (3)$$

where :

P	air leakage rate of the dwelling (m^3/h for 1 Pa)
e	wind shield factor (from 0.15 to 1.35): depends on : location in France, altitude of façade, single or multiple front dwelling.
d	d=1.55 (single front dwellings) or d =1.15 (multiple front dwellings)

2.3 - Demand Control Ventilation systems.

Equations 1, 2 and 3 are used for design of standard mechanical or passive stack ventilation systems. For particular DCV systems as humidity controlled ones, the SIREN code is directly used to calculate the equivalent thermal air flow rate to be taken into account in thermal calculations. The air quality is defined by comparison of some indexes (CO_2 concentration, condensation risks) with the results of a standard mechanical system.

3 - THE COMPUTER CODE "SIREN".

3.1 - Generalities.

The computer code SIREN ("SImulation du RENouvellement d'air") was developed in C.S.T.B. It is used to calculate the air flow throughout the entire heating season (about seven months) in a dwelling (figure 1) equipped with a mechanical ventilation system. The code uses hourly meteorological data (temperature, relative humidity, wind speed and orientation) ; occupancy and pollutants production (CO_2 and H_2O) are defined with an half an hour step.

Each component (air inlets and air outlets) is characterised by its flow rate curve as a function of the pressure difference and also when relevant, of the temperature or relative humidity.

Some assumptions have bee, made in the development of the model : it assume complete mixing for pressure and temperature in dwelling, the inside temperature is considered to be constant to 19 °C when external temperature is below 17 °C and equal to external temperature plus 2 °C in the other cases, stack effect is neglected, humidity concentration and CO_2 concentration are assumed to be uniform in each room.

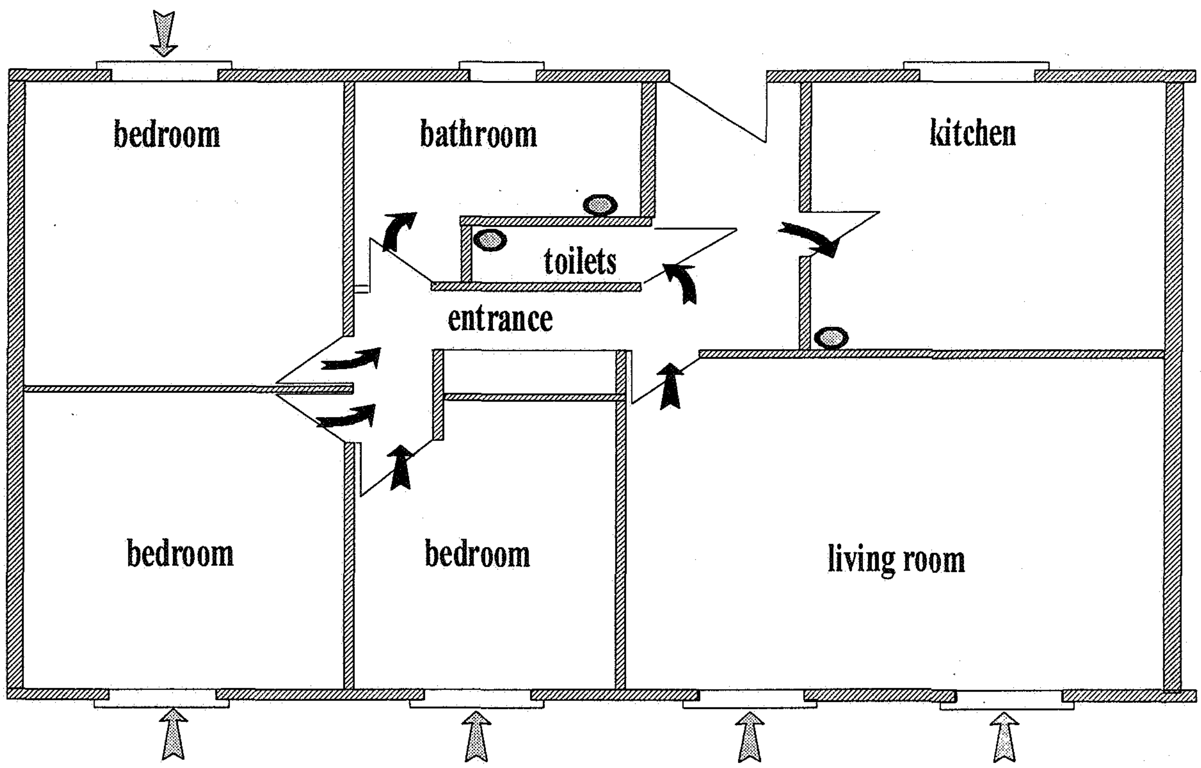


Figure 1 : airflows in a dwelling with mechanical ventilation.

inlets are located in living room and bedrooms,
exhaust vents are located in kitchen, bathroom and toilets.

3.2 - Modelling.

3.2.1 - Occupation and pollutants production.

Figure 2 presents the occupation schedule of the dwelling.

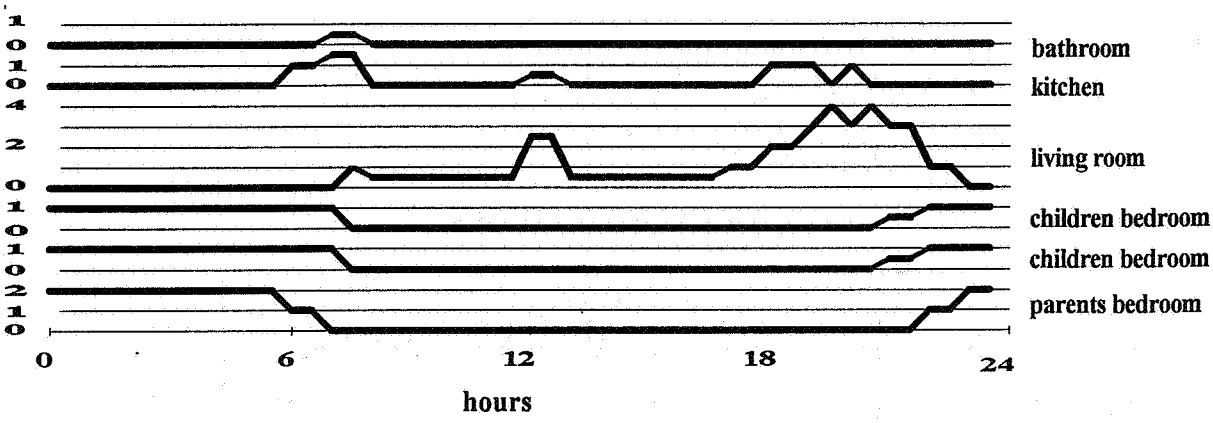


Figure 2 : occupation schedule of the dwelling (number of person)

The CO2 concentration inside rooms is calculated taking into account pollutants production due to occupation, air renewal due to ventilation system operation and CO2 outside concentration. The CO2 outside concentration is assumed as 350 ppm.

The production of pollutants by occupants is
- moisture dissipation 40 g/(h.person)
- CO2 : waking 16 l/(h.person) , sleeping 10 l/(h.person)

Figure 3 shows the water vapour production in the kitchen and in the bathroom of the dwelling.

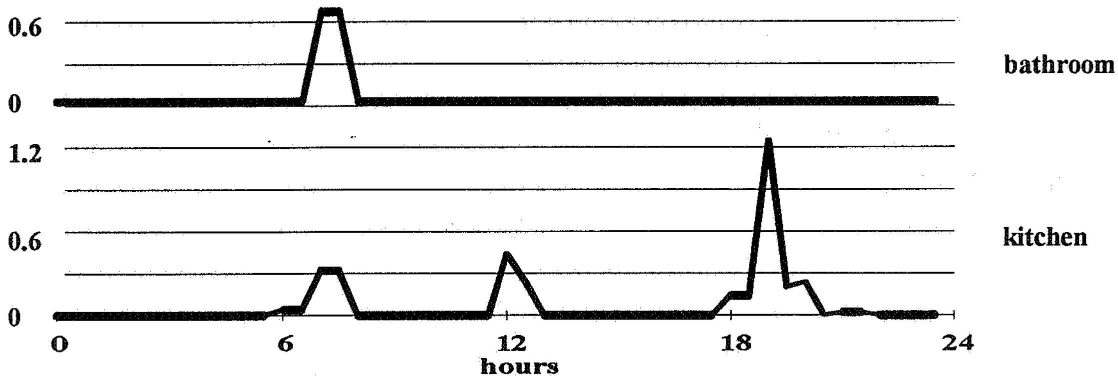


Figure 3 : water vapour (kg) schedule in the dwelling

The humidity transfer between the air and the furniture is given by the simplified formula :

$$\frac{dM}{dt} = 0.035 \times S \times RH - 0.018 \times M \qquad (4)$$

where :

where :	t	time (hours)
	M	mass of water in furniture (kg)
	S	equivalent area of the furniture (m^2)
	RH	relative humidity in the room

3.2.2 - Wind effects.

The pressure (Pascal) in the front of the dwelling is :

$$P = Cp \times \frac{1}{2} \times \rho \times V^2 \qquad (5)$$

where : Cp wind pressure coefficient (table 2)
ρ volumic mass of air (kg/m^3)
V wind speed (m/s)

Table 2 : Cp versus wind direction

	α (degrees) 0 30	30 60	60 120	120 150	150 180
Cp	0.60	0.20	-0.30	-0.60	-0.35

3.2.3 Heat losses due to ventilation system.

The DCV and the standard mechanical ventilation systems are compared with an averaged flowrate which give the same heat losses on the heating season (seven month) :

$$Qave = \frac{\int 0.34 \times Q(t) \times (Ti - Te) \times dt}{\int 0.34 \times (Ti - Te) \times dt} \qquad (6)$$

where : Q(t) instantaneous ventilation flow rate (m^3/h)
Ti internal temperature (°C)
Te external temperature (°C)
0.34 specific heat of air (Wh/m^3.°C)

3.3 - Description of the studied systems.

3.3.1 - Reference system [8].

The curve of the components of the reference system are shown in figure 5 :

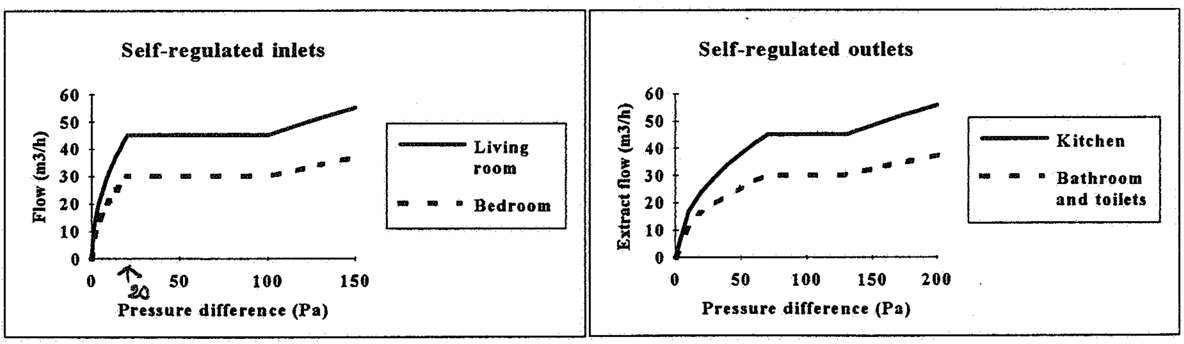


Figure 5 : simulated curves of components (flow versus pressure)

- one self regulated inlet in each habitable room,
- one self regulated outlet in each service room ;
  in the kitchen an additional flow rate of 135 m3/h is available

3.3.2 - Humidity controlled system 1.

The curve of the components of the system 1 are given in figure 6 :

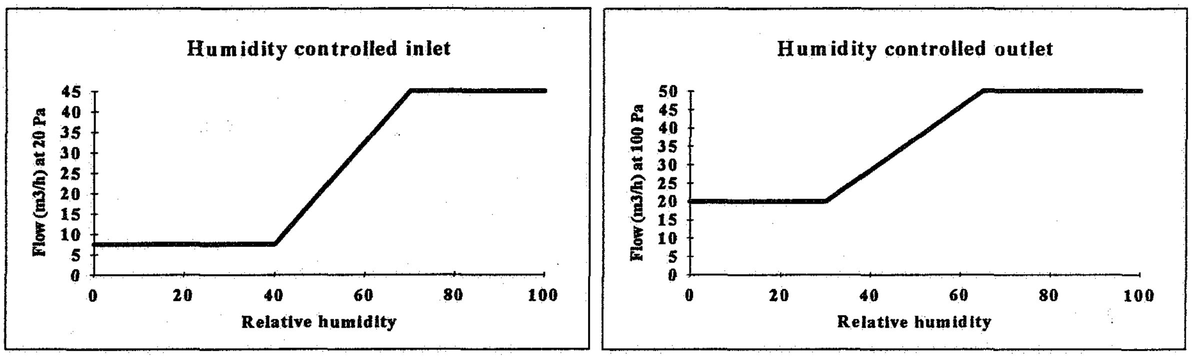


Figure 6 : simulated curves of humidity controlled components (flow versus humidity)

- one humidity controlled inlet in each habitable room
- one humidity controlled outlet in the kitchen and the bathroom; in the kitchen an additional flow rate of 150 m3/h is available
- one two flows outlet (5 m3/h with additional flow of 30 m3/h) in the toilets.

3.3.3 - Humidity controlled system 2.

Humidity controlled system 2 as the same inlets than reference system and the same outlets than humidity controlled system 1.

4 - RESULTS

We present results of the two humidity control ventilation systems compared with the reference system.

4.2 - Air renewal.

The averaged air renewals calculated with formula 6, and the heat losses due to air renewal (in the Parisian area) are given here after :

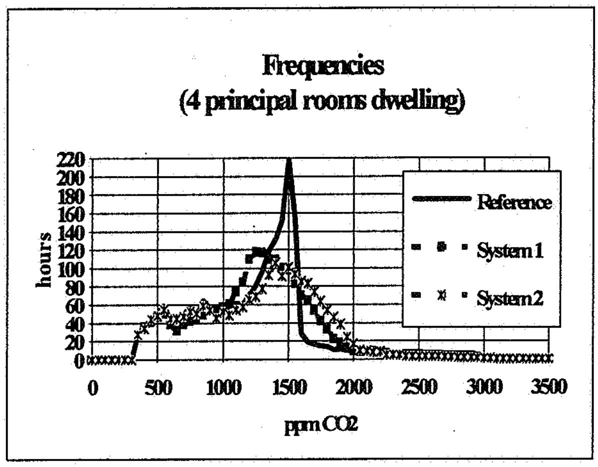
	Reference	System 1	System 2
Air renewal (m3/h)	**105**	**86**	**91**
Heat losses (kWh/year)	**6300**	**5160**	**5460**

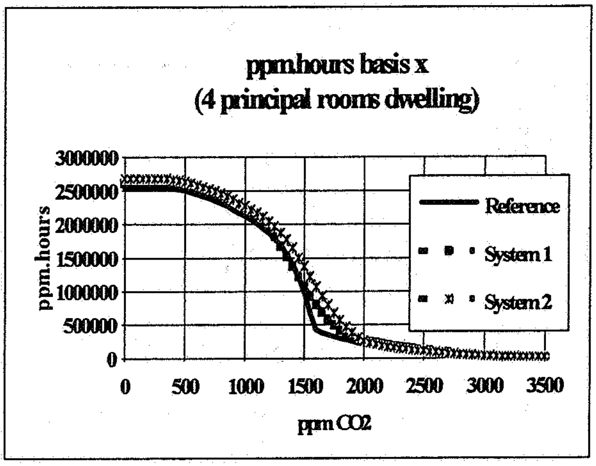
Heat losses due to air renewal depend on location in France : humidity control system 1 can save between 700 (Mediterranean area) and 1400 (east of France) kWh per year

4.3 - Air quality

It is necessary to distinguish the pollution due to human activities and the pollution sources due to materials in the building. Even when these second pollution sources are as low as possible, the ventilation system has to exhaust human bioeffluents. CO_2 concentration reflects the human bioeffluents concentration [9 and 10].

To compare the systems we calculate the CO_2 ppm.hours cumulated basis X in the parents' bedroom which permit a better comparison between the systems than the simple frequencies. To meet requirements the ppm.hours cumulated basis 2000 have to be lower than 500000.





5 - CONCLUSION

A computer model is used to assess the performances of different mechanical ventilation systems, including DCV systems, in dwellings.

Heat losses by air renewal are calculated with reference to a standard ventilation system. The flow rates of DCV systems should be dimensioned in order to achieve a similar air quality level for each system. On this basis the load reduction, using advanced systems, which have been released since ten years on the French market, is found to be appreciable.

The two humidity controlled system described in this paper save energy. Although the air quality of the two DCV systems is slightly lower than the air quality of reference system, the energy savings are more important with the system 1 which has a better air quality level than the system 2.

The calculated values of this reduction are somewhat depending on the air quality indicator chosen, which therefore should be carefully selected.

Further work with a model taking in account phenomena which, so far, have been neglected (windows opening, stack effect, ...) is needed in order to confirm the results presented in this paper.

ACKNOWLEDGEMENTS

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