VENTILATION SYSTEM PERFORMANCE

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Paper 27

DESIGN OF VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS

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ABSTRACT

Building regulations prevailing in France made it compulsory to use specific ventilation systems in new residential buildings since 1969. Different kind of ventilation systems (mechanically powered, temperature driven, hybrid systems,...) have been developed. This paper reviews these systems and outlines their advantages and drawbacks in single-family or multi-family buildings, with respect to architectural flexibility and comfort or safety requirements. In a second part, the paper introduces and discusses the scientific grounds (for instance, wind effect) which govern the ventilation rates. Results of theoretical work are given and design methods in use in France, with their influence on architecture conception, are featured.

1 - INTRODUCTION

Ventilation systems in residential buildings are primarily intended to remove air pollutants (moisture, combustion products, odours,...) and prevent building damage due to condensations and mould growth. This was previously achieved by natural means : window opening and also air change when fireplaces are working. In the sixties, new architectural trends appeared : water-closets and bathrooms are often in a central position with no window, and fireplaces have almost disappeared in multi-family houses. On the other hand, greater concern has been paid to energy conservation and comfort matters (protection against outdoor noise and cold draught). This has led to the spread of specific ventilation systems such as : natural ventilation using vertical shafts, mechanical systems ; or new techniques such as : humidity controlled ventilation. The usual air flow pattern, using such systems, is shown in fig 1.

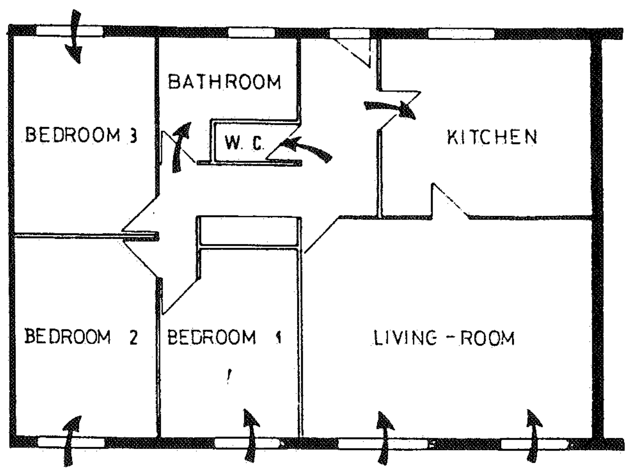


Fig. 1 : *Air flow pattern in dwellings :*
Since service rooms are ventilated by exhaust vents, there are no air inlets in these rooms.

These systems must comply with additional requirements :

. limit heat losses to a reasonable value, independent of climatic conditions (wind, outdoor temperature) ;

. prevent acoustic annoyance, due either to noise emission or noise transmission through ventilation components ;

. prevent reverse flow through a common ventilation network ;

. design and install the air inlets in order to avoid cold draughts ;

. avoid drift of components characteristics due to fouling or aging ;

. allow access for maintenance operations and provide safety in case of vented or unvented combustion appliances.

2 - VENTILATION SYSTEMS IN USE IN FRANCE

Mechanical exhaust systems which appeared in France in the sixties are now the most commonly used systems. As opposed to natural ventilation, they provide a much greater flow rate steadiness, whatever the outdoor climatic conditions. Mechanical systems have been improved in recent years. New systems, with flow rates depending on the prevailing indoor climatic conditions, enable energy conservation and indoor air quality to be further improved.

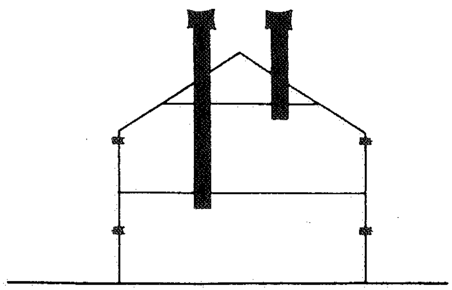


Fig. 2 : *Scheme of a natural ventilation system a single-family house.*

In natural exhaust systems (fig.2) the flow rate is generated by buoyancy and wind effects. Accordingly, flow rates vary a lot. Other systems (mechanical balanced systems,...) are also in use and many new systems (humidity controlled vents, hybrid systems combining natural and mechanical effect,...) have been recently developed.

3 – VENTILATION SYSTEMS DESIGN AND DIMENSIONING

3.1 – Dimensioning of air inlets

Air inlet sizing must lead to a good balance between air quality and energy conservation requirements. As a matter of fact, air inlets are intended to ensure as equal as possible fresh air distribution amidst the different rooms. Therefore, their sizing must be sufficient with regard to non-uniformity of flow due to building shell leakage : fig. 3 depicts the influence of air leakage increase on fresh air flow in a room.

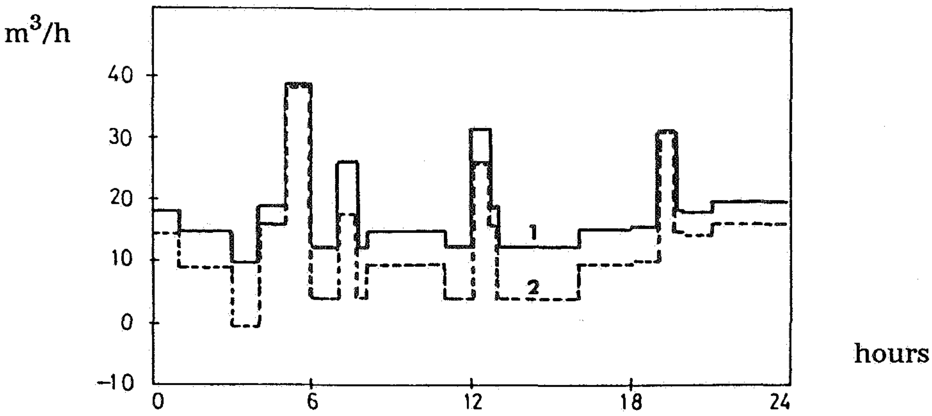


Fig. 3 : *Influence of building shell air leakage on air flow pattern*

The curves represent the calculated values of fresh air entering a bedroom (cf fig. 1) according two different assumptions :

Curve 1 : *external walls of the kitchen are assumed to be perfectly airtight.*

Curve 2 : *air leakage value of the kitchen external walls is assumed to be equal to 20 m^3/h under 1 Pa pressure difference.*

On the other hand, air inlets size must be as low as possible, in order to reduce heat losses due to cross ventilation in case of wind. Calculations [1] have shown that cross ventilation heat losses are a function of the negative pressure inside the dwelling, according to the following equation :

$$Q_S = P . \frac{e}{1 + d . \left(\frac{Q}{P}\right)^2}$$

where :

Q_S (m^3/h) flow rate corresponding to cross ventilation

Q (m^3/h) exhaust flow rate due to ventilation system operation

P (m^3/h) flow rate through the building shell air leakage and air inlets when the pressure difference is 1 Pa

e, d numerical coefficients, the values of which depend on building wind exposure.

Taking into account the mean air leakage values of the building shell in new buildings, the above considerations lead to a proposal that the area of air inlets should be equal to 30 cm^2 in each room, when exhaust flow rate is achieved by a mechanical systems. When a natural exhaust system is used, the air inlet area must be higher.

3.2 – Sizing of mechanical exhaust network

fig. 4 depicts an example of an air flow calculation in an exhaust network. Air flows are mainly depending on the pressure-flow rate curves of the fan, exhaust vents and network itself. However, the negative pressure in the network, (hence the flow rates at each exhaust vent), may vary considerably. As a matter of fact, thermal or wind effect may substantially increase the flow rates. Moreover, according to French regulation, it is allowed that exhaust vent aperture area may be set by the occupant either to a low value, or to a peak value. When most of the exhaust vents are at their peak value, pressure drop in the ducts increase and exhaust flow rates in other vents are lower.

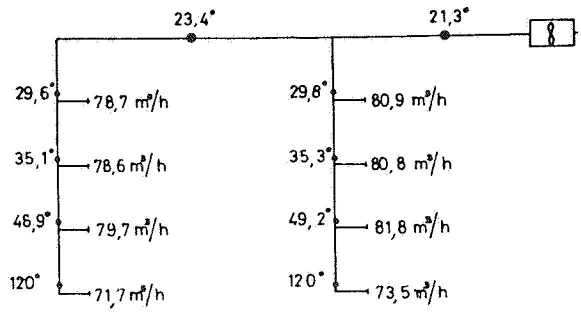
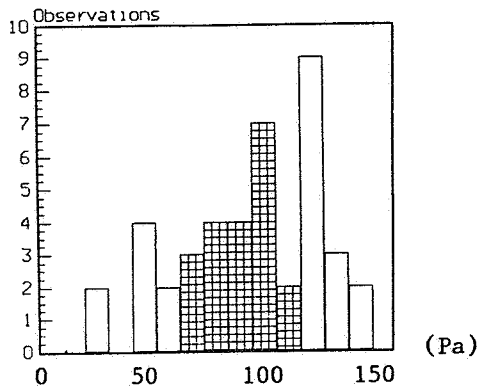


Fig. 4 : *Mechanical exhaust network* :

this figure depicts calculated flow rates and temperatures [6] in an exhaust network. The exhaust vents of the first floor are linked to vented gas appliances, the flue temperature of which is assumed to be equal to 120°C.

The pressure variation inside the network may be, as illustrated in fig. 5, quite important and cause either noise production, when the pressure is high, or unsufficient ventilation, when this pressure is low. The allowed values of noise production (acoustic pressure level) in the kitchen is 35 dB(A), which can be usually achieved, provided the negative pressure in the network does not exceed a value which usually is in the range of 120 to 140 Pa. On the other hand, the pressure must be high enough to limit flow rate variations due to wind or thermal effect. Moreover, the exhaust vent aperture area must not be too large in order to reduce noise transmission from one flat to another one.



<u>Fig. 5</u> : *Pressure variation in a mechanical exhaust network :*

this histogramme shows the distribution of negative pressure which were measured in an exhaust mechanical system. Crossed lines indicate the range of pressure for which air flow and acoustic requirements of the exhaust vent are met. A large number of measured values are not in the authorized range ; the sizing of this particular exhaust network must therefore be improved.

For all these reasons, a typical pressure range is 70 - 120 Pa. Most of the exhaust vents in use in France are designed to meet the flow rate steadiness and noise requirements in this range of pressure.

The design principle of mechanical exhaust systems in multi-family buildings is therefore to dimension the network in such a way that the pressure drop of exhaust vents remains in the authorized range of values, regardless of the climatic data and the occupant behaviour. This is generally achieved either by using purpose-designed fans or, preferably, in using ducts with sufficiently large diameters, which allow accommodation of the pressure drop variation due to human behaviour (i.e : variation of required exhaust flow rate). A design method [3], based on this principle, is under preparation and will hopefully help designers improve exhaust network sizing.

3.3 Dimensioning of natural ventilation systems

Proper dimensioning of natural ventilation system is a delicate matter, because the air flow is dependent, to a great extent, on the outdoor temperature and also on the wind effect, which still needs a lot of investigation. The need for more research can be illustrated by considering the example of shunt ducts which were in common use in multi-family buildings in the sixties : As it appears in fig. 6, the shunt duct is a double duct composed of a small duct used for individual air exhaust of each dwelling and a larger one used to collect individual air flows up to the top, where a cowl is installed to transform wind velocity into pressure head. From an architectural point of view, the shunt duct makes it possible, compared with individual ducts, to save space and decrease the building cost. On the other hand, it may lead to higher likelihood of reverse flow [4].

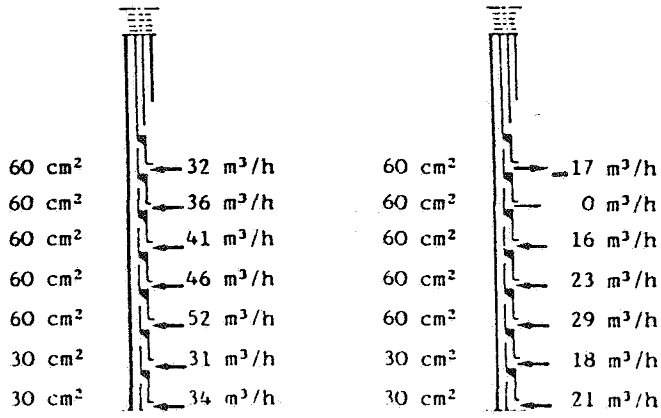


Fig. 6 : *Shunt ducts : influence of wind velocity and outdoor temperature on exhaust flow rates.*
first column : outdoor temperature : 0°C ; wind velocity : 0 m/s
second column : outdoor temperature : 10°C ; wind pressure : -3 Pa

It may be noticed that reverse flow rates occur under unfavourable climatic conditions. These reverse flow rates may be alleviated using high performance cowls. A practical difficulty is that, for a given cowl, the negative pressure caused by the wind is a complex function of wind velocity and air flow rate, thus making design calculation difficult to handle. Gonzalez [5] investigated that point, and showed that a relationship exist between two non-dimensional quantities :

$$X = \frac{DP}{1/2.\rho e.V^2} \qquad Y = \frac{1/2.\rho i.U^2}{1/2.\rho i.V^2}$$

Where :

DP (Pa)	:	difference between total pressure at the cowl inlet and outdoor static pressure
U (m/s)	:	air velocity in the duct
V (m/s)	:	wind velocity in the cowl neighbourhood
ρ i, ρe (kg/m^3)	:	volumic mass of indoor and outdoor air

The simplest way of formulating the relationship between X an Y is to assume that suction effect due to wind and pressure drop due to air flow are independent, which leads to :

$$X = \frac{Y}{A} + C \qquad (3)$$

It may be observed (fig.7) that the agreement between this formula and experimental points is far to be good. Thus a new relationship was derived :

$$X = \frac{Y}{A} + C + \sqrt{\frac{-\,C.Y}{2.A}} \qquad (2)$$

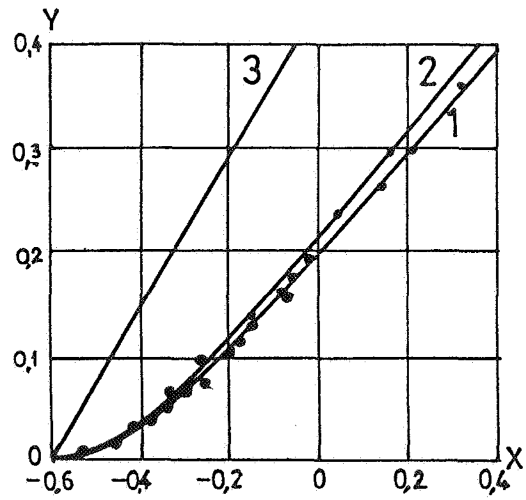


Fig. 7 : *Cowls : agreement between experimental data and different formulas*
1 best fit
2 fit using equation (2)
3 fit using linear equation (3)

This relation leads to a better agreement and is quite easy to handle because the coefficients, A and C may be readily measured, according standardized methods :

A is related to the cowl pressure drop when there is a no wind effect,

C is related to the suction effect due to wind velocity when there is no flow rate.

More work is still needed to correlate flow rates test results on commercially avaible cowls with theoretical analyses.

A last difficulty arises from wind turbulence. Computer simulations [6] [7] showed that taking into account wind turbulence makes it possible to explain reverse flow at the upper floor.

4 - CONCLUSION

Design methods based on computer codes makes it possible to improve the design of ventilation systems. More research work is still needed in order to ascertain results relevant to natural ventilation.

ACKNOWLEDGEMENTS

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Discussion
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Bas Knoll (TNO, Netherlands)

Did you do any research on flow rates and flow directions in leeward-side rooms? The high cross-ventilation you showed may cause under ventilation in these rooms.

D.Bienfait (CSTB, France)

We have not done this research yet, but I know it is important to reduce the airleakage to prevent these problems. Also in Canada tests are done on this item.

E.Arens (U.C. Berkeley, USA)

How are you proposing to solve the problem of residents closing the supply vents to control draughts? Is it a detail in the design of the supply vent itself?

C-A Roulet, (LESO, Switzerland)

In many countries it is shown that air inlets are often taped or closed by the occupants. Is it not time to take this fact into account and act in order to avoid this behaviour? (e.g. hide the inlets, avoid the draughts, inform inhabitants).

D.Bienfait (CSTB, France)

Use of closeable supply vents is not considered to be a good solution because the ventilation system would not work properly when closed. On the other hand, uncloseable supply vents should provide good comfort conditions, otherwise they are likely to be taped, which would be even worse. The design of supply vent should therefore be improved. This can be achieved by better qualification of the component with respect to draught problem. This is presently discussed inside CEN TC 156 Committee "Ventilation of residential buildings". On the other hand some unconventional components such as - pressure difference, or moisture, or outdoor temperature controlled devices; - dynamic walls or windows; - supply vents with heat exchanges or additional heater should be encouraged because they may help to solve the draught problem.

B.Fleury (ENTPE/LASH, France)

Industrial ventilation products are of very high quality but they are so poorly installed that the final building performance is terrible. What do you suggest to improve building quality and especially the leakage characteristics?

D.Bienfait (CSTB, France)

I would not give so definitive an appreciation as you on the quality of ventilation installations. However, some improvements may be necessary. Two complementary suggestions can be made: - better information for installers through guidelines or calculation methods; such documents are currently being issued in France and concern for instance building leakage or installation rules; - develop methods to check the performance of the installation, measurement of air leakage, airflows,... in France measurement of airflows at exhaust vents for checking purpose is an acknowledged practice. On the other hand it may be noticed that not all the ventilation systems have the same sensitivity to poor installation.