Energy Impact of Ventilation and Air Infiltration
14th AIVC Conference, Copenhagen, Denmark
21-23 September 1993

Assessment of Energy Impact of Ventilation and Infiltration of the French Regulations for Residential Buildings

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SYNOPSIS

Ventilation is necessary to insure acceptable indoor air quality as well as to protect the building itself against damage due to condensation. Ventilation rates however, must not lead to excessive energy consumption.

In order to comply with these requirements of hygiene, comfort and energy savings, French regulations stipulate that the ventilation of dwellings has to be general and continuous and achieved by specific systems by which fresh air is provided to the dwellings. The ventilation requirements are expressed by exhaust air flow rates required in each service room as a function of the number of the habitable rooms in the dwelling.

Moreover, according to the thermal regulations, the heat loss due to ventilation has to be include in the overall energy loss of the dwelling. For this purpose, calculation rules based on results of numerical simulations has been developed. These rules make it possible to calculate the overall ventilation heat loss : the heat loss due to ventilation system operation and the heat loss due to cross-ventilation. The heat loss due to cross-ventilation depends on air tightness level of the building, ventilation system and meteorological data.

This paper reviews the common ventilation systems used in France, the various aspects of the French regulations for ventilation of dwellings and calculation rules of ventilation heat loss. This paper does not cover DCV systems, since they will be dealt in another paper [1].

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 consumption. Energy conservation concern and new requirements for thermal acoustic and olfactory comfort led to the spreading out of specific ventilation systems such as natural ventilation systems using vertical shafts, mechanical systems or new techniques such as humidity-controlled ventilation systems. This paper reviews the common ventilation systems used in residential buildings and outlines their advantages and drawbacks. It also addresses methods for energy efficiency assessment of these systems.

2. VENTILATION SYSTEMS

Since 1969, the French regulation on residential building ventilation is based on general and continuous air renewal. The air circulation in the dwelling must be provided in such a way that fresh air enters into the habitable rooms (living room, bedrooms) via air inlets and contaminated air leaves the service rooms (kitchen, bathroom, toilets) via exhaust vents. In this way, air is transferred from the rooms with a higher air quality to the rooms with a lower one.

2.1. Mechanical exhaust systems

The mechanical exhaust systems are composed of self-regulated air inlets, exhaust vents, duct networks and an exhaust fan. The principle of a self-regulated air inlet is based on progressive modification of the air passage section of the inlet according to the pressure difference across the inlet. The change in section keeps the air flow constant over a wide range of pressure differences (see figure 1). These inlets, which have been in widespread use for more than fifteen years, help prevent uncomfortable draught when the wind pressure is too high [2]. Also, they help reduce heat losses due to cross-ventilation.

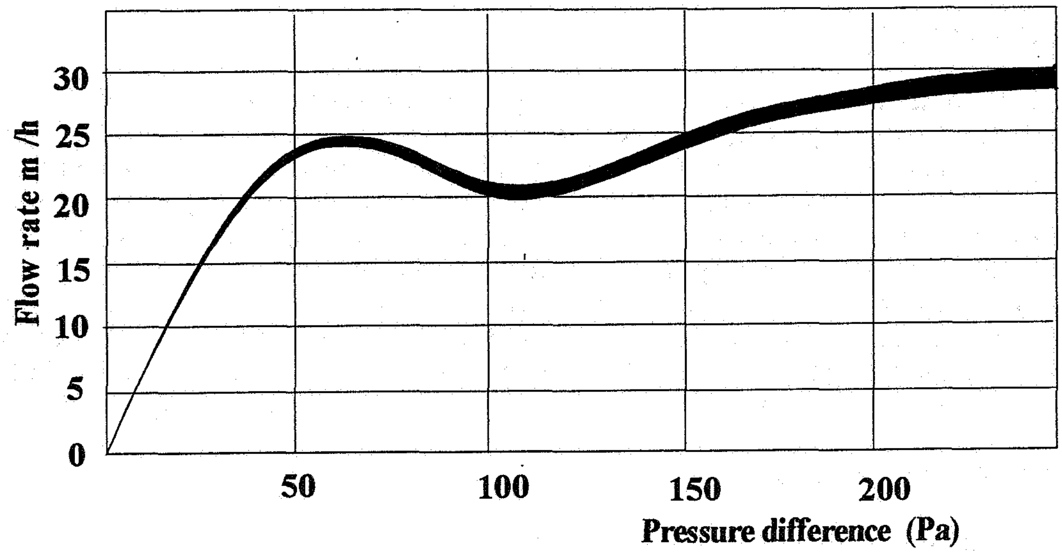

Figure 1 : A characteristic self-regulated air inlet curve.

About 60% of newly-built dwellings are equipped with a mechanical exhaust ventilation system. Ventilation plants depend on the type of dwellings. In the single-family dwellings, the exhaust fan is located in the attic and each exhaust vent is linked to the extract fan unit by an individual flexible plastic duct. In the multi-storey buildings, the network is generally composed of several vertical ducts. These ducts then connected to an exhaust fan via a horizontal duct. Vertical ducts act as collector to gather individual air flows from several dwellings.

The French regulations have allowed the use of variable exhaust air flow systems, controlled by an indoor relative humidity sensor, in order to limit heat loss due to ventilation, in dwellings. These humidity-controlled ventilation systems, which reduce the ventilation rates during lower occupancy, must be certified by an "Avis Technique" (technical approval) with regard to heat loss and indoor air quality. The air passage section of air inlets and exhaust vents is a function of the room air relative humidity, in order to increase air change when relative humidity is too high (see figure 2). About 20% of flats and 5% of houses (newly built) are equipped with such demand controlled ventilation (DCV) systems.

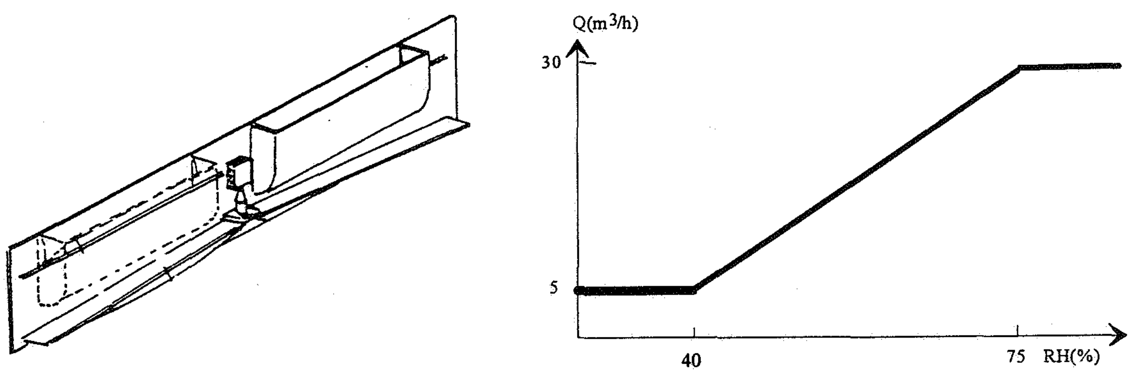

Figure 2 : Example of humidity-controlled air inlet. The curve depicts the flow rate as a function of the room air relative humidity when the pressure difference is 10 Pa.

2.2. Balanced systems

In France, the balanced system is less common than the mechanical exhaust system; only 6% of the new single-family dwellings is equipped with it. Nevertheless, the balanced system has numerous advantages. In comparison with the exhaust only systems, the balanced systems control air flow rate in each room of the dwelling and therefore provide a better ventilation efficiency, prevent discomfort due to cold draught, acoustic annoyance due to noise, and prevent pollutants migration (e.g. dust, radon,...) from outside. Additionally, the balanced ventilation systems make it possible to adjust ventilation rate according to needs, by transferring air flow from a room to another one, and to save energy using heat recovery system. However, the dwelling equipped with such a ventilation system must be sufficiently airtight in order to limit the heat losses due to cross-ventilation. Particular attention must be paid to the installation and maintenance to insure the energy saving potential.

2.3. Natural exhaust systems

In natural exhaust systems, the air flow rate is generated by buoyancy and wind effects. Therefore, flow rates are varying continuously. In single-family dwellings, every service room is provided with an exhaust vent linked to an air duct operating by passive stack effect (see figure 3). At the top of the duct, a cowl is installed in order to transform wind velocity to pressure head. In multi-family dwellings, the vent ducts are either individual ones or shunt ducts : a shunt duct is a double duct composed of a small duct used for individual air exhaust of each flat and a larger one used to collect individual air flows up to the top. The air inlets, located in every habitable rooms, are like the ones of mechanical exhaust systems (i.e. self-regulated air inlet), except that the dimensioning must be higher. In order to prevent acoustic annoyance due to larger aperture area of air inlets, especially in noisy environment, air inlets with acoustic insulation are frequently used. Figure 4 depicts the acoustic attenuation versus the frequency domain related to an air inlet equipped with or without different silencers; results show that the acoustic attenuation is increased from 10 dBA up to 20 dBA when using a silencer.

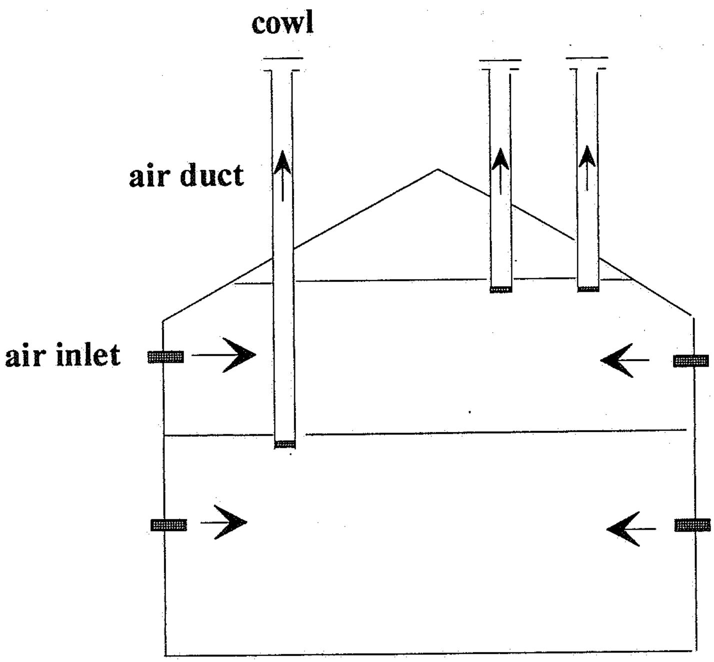

Figure 3 : Passive stack ventilation in a single-family dwelling

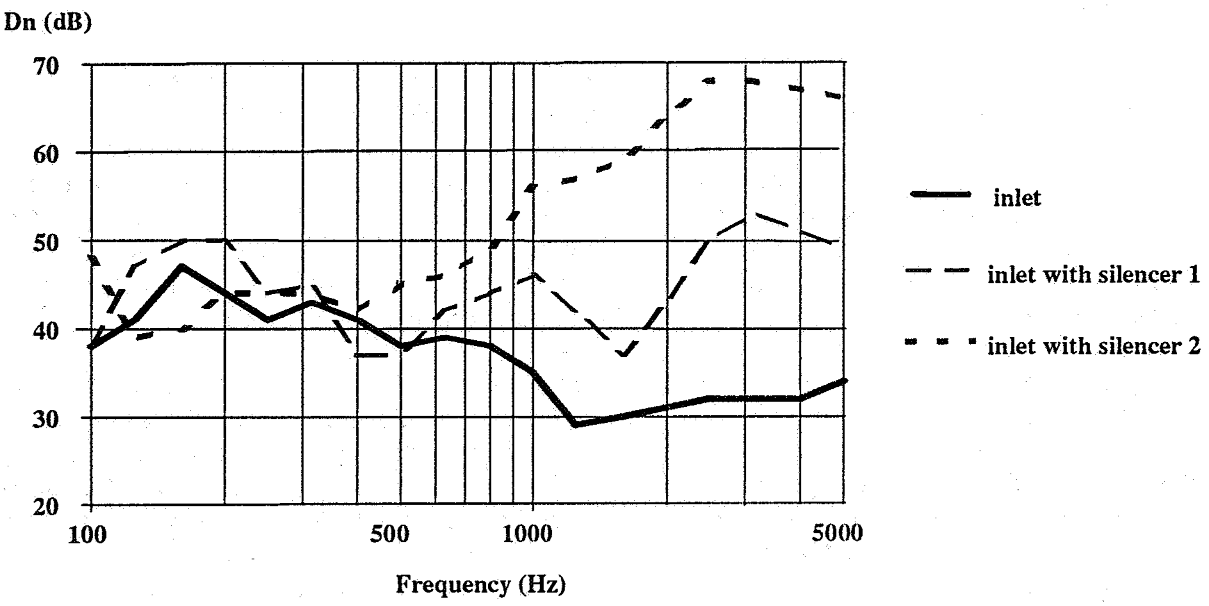

Figure 4: Acoustic attenuation of an air inlet with or without a silencer (the nominal flow rate of the inlet is 30 m3/h)

The natural ventilation systems were in common use in the sixties. About 20% of the newly-built houses are equipped with natural ventilation systems. In comparison with the mechanical systems, the natural ventilation installations can be easily cleaned; on the other hand, they do not provide a steady air flow rate, since it depends on the outdoor climatic conditions. Recently, new hybrid systems combining natural and mechanical effect have been developed. These systems work as common cowls when the fan is switched off. They are very useful, especially to achieve the peak flow rate when cooking or when the stack effect is insufficient because of moderate wind and outside temperature.

3. PERFORMANCE ASSESSMENT OF VENTILATION SYSTEMS

3.1. Regulation approach

In France, the key feature of the ventilation progress is the synergy between the evolution of techniques and regulations [3]. As an example, the 1969 regulation required to continuously provide one air change per hour in each habitable room; this led to the introduction of central mechanical ventilation. Conversely, the development of new products, such as DCV systems designed to optimise air renewal, led French authorities to amend some mandatory provisions relevant to minimal ventilation rate. By the early seventies, the French thermal regulation required to include the energy loss due to ventilation in the total energy loss of the building. In order to assess the performance of ventilation systems - and more particularly the amount of heat loss due to ventilation - methods based on computer models were derived. These models make it possible to compute the heat loss as well as the condensation hazards and the air quality level. A simplified method [4], derived from the numerical simulations, which is applied to usual ventilation systems, except DCV systems, is described hereafter. The performance of DCV systems are assessed by using a specific technical procedure described in ref. [1].

3.2. Modelling

In order to assess the performances of the traditional ventilation systems the single-zone air flow model, GAINE, is used. This model is developed at CSTB [5], takes into account the combined effects of driving forces such as wind-induced pressures, thermal buoyancy and ventilation systems. The air change due to cross-ventilation was calculated over the heating season using meteorological data and for a given ventilation system and building with characteristics. Dimensionless pressure coefficients used in this model were derived from pressure field measurements performed in a boundary layer wind tunnel on a scale model. An experimental validation of this model has been undertaken by measuring air change rate in the CSTB's full-scale rotating house [6].

Using this computer model, a new way of calculating cross-ventilation flow rate was derived. Cross-ventilation heat losses do not only depend on air leakage area but also on flow rate due to ventilation system operation [7]. They are decreasing when the negative pressure inside the building, caused by the operation of the ventilation system, is increasing. The case of a dwelling with four habitable rooms with two exposed façades was simulated. The cracks and the self-regulated air inlets were distributed in two equal parts on the façades and the exhaust flow rate was taken equal to 90 m^3/h. The model was run for several values of the leakage flow rate in the range of 20-100 m^3/h at 1 Pa and for four wind shielding class, using the meteorological data of Trappes, near Paris. Figure 5 shows the change in cross-ventilation rate as function of flow rate due to ventilation system operation for different wind shielding class. Coefficients d and e of the formula (3) were derived by fitting the cross ventilation rate with the simulation results.

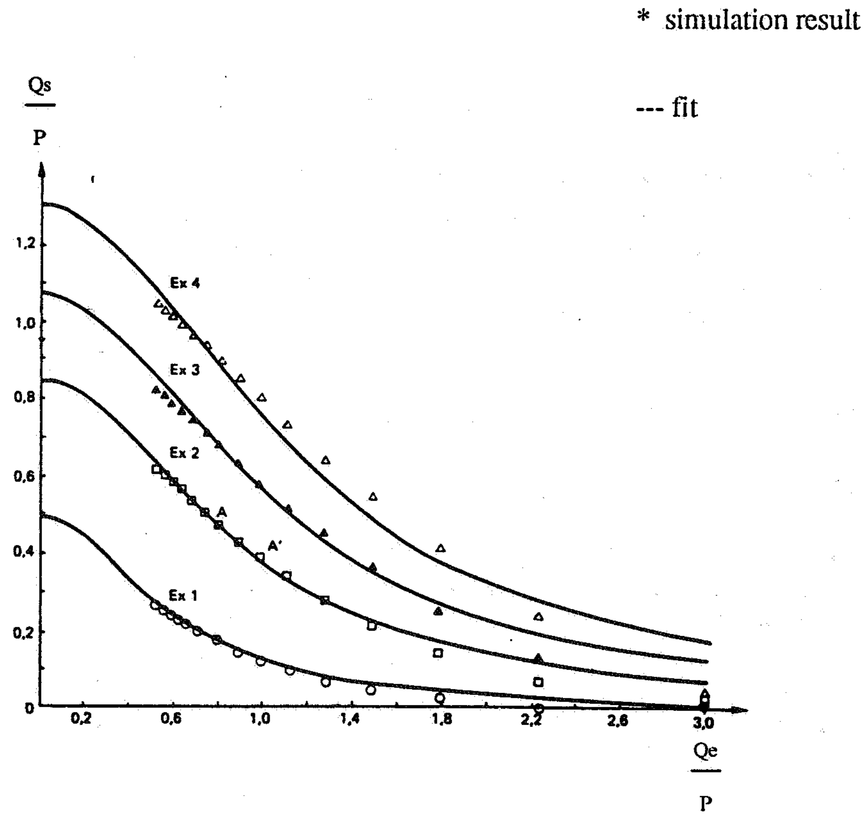

Figure 5 : Change in cross-ventilation rate versus flow rate due to ventilation system operation for different wind shielding class

case of two exposed façades dwelling with exhaust ventilation system (Qi=0)
Ex1 is the heaviest shielding class, Ex4 is the lightest one
(refer to formula 3 for meaning Qs, Qe, P)

3.3. Method

The calculation rules, so-called "Règles Th-G" [4], describe how to calculate heat loss due to ventilation. They apply to all traditional ventilation systems i.e. systems which are not innovative. Heat loss due to air renewal can be expressed by:

$$DR=0.34(Q_V+Q_S) \qquad (1)$$

Where : DR is the heat loss due to air renewal (W/°C),

0.34 is the value of the specific heat capacity of air ($Wh/m^3°C$),

Q_V is the air flow rate due to ventilation system operation (m^3/h),

Q_S is the air flow rate due to cross-ventilation (m^3/h).

For the dwellings having an exhaust ventilation system, the air flow rate Q_V is the sum of the flow rates of each exhaust vent. The flow rate exhausted by a vent q_V depends on its minimum and maximum values and variation during the vent operation :

$$q_V=(1-a)q_m+a*q_p \qquad (2)$$

Where: q_V is the specific flow rate of the exhaust vent (m^3/h),

q_m is the minimum flow rate (m^3/h),

q_p is the maximum flow rate (m^3/h),

a is the modulation factor.

a =1 when the aperture area of the vent is fixed

a =1/12 when the modification of the area is operated by manual control

a =1/24 when the vent is time controlled (peak time of 30 minutes).

The minimum and maximum flow rates have to be at least as great as the values allowed by the building regulation, these last ones being dependent on the number of habitable rooms.

In case of balanced ventilation systems, the supply and exhaust flow rates of the whole dwelling are calculated in the same way from formula (2); then, the specific air flow rate of the dwelling Q_V is the greatest value of both.

It is obvious that cross-ventilation induced by wind effect depends on numerous factors such as air tightness level of the building envelope, shielding of the surroundings and pressure inside the building due particularly to the operation of the ventilation system. Using computer model GAINE which uses meteorological data as input, a new way of calculating cross-ventilation flow rate was derived :

$$Q_S = \frac{P x e}{1 + \frac{d}{e}\left(\frac{Qi - Qe}{P}\right)^2} \qquad (3)$$

Where : Q_s is the flow rate due to cross-ventilation (m^3/h),

P is the flow rate through cracks and purpose provided openings in the building envelope when the pressure difference is 1 Pa (m^3/h at 1 Pa),

Qi is the total supply flow rate (m^3/h),

Qe is the total exhaust flow rate (m^3/h),

d =1.55 for dwellings with only one exposed façade and 1.15 for dwellings with more than one exposed façade,

e is the shielding coefficient which depends on shielding class and building exposure type.

In the case of exhaust only ventilation systems, the supply flow rate Qi is equal to zero and the exhaust flow rate Qe is equal to the specific rate Q_V.

This formulation of the cross-ventilation rate has been accepted as an informative annex in the European standard on the simplified method of calculation of building thermal performance [8].

4. CONCLUSIONS

In France, dwelling regulation has enabled the development of efficient ventilation systems. They have to be assessed with regard to heat loss. Performance assessment is an important issue as it may ease the development of new systems with a better efficiency. The energy loss due to ventilation depends on the ventilation system operation and the infiltration. The flow rate due to air leakage of the building envelope are calculated taking into account the cracks of doors, windows and other components of the envelope.

Applying this computer model which uses meteorological data as input, a new procedure of calculating cross-ventilation flow rate was derived. This procedure is more representative of the physical phenomena and describes efficiently the shield effect due to the negative pressure in the building.

ACKNOWLEDGEMENTS

The authors wish to thank Mr Redwan MOUNAJED for his assistance in the development of the computer model. The participation of ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) and ML (Ministère du Logement) is gratefully acknowledged for their financial support.

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