COMPARATIVE ANALYSIS OF THE ENERGY IMPACT OF AIR INFILTRATION FOR DIFFERENT VENTILATION SYSTEMS

A. Voeltzel and F.R. Carrié

Centre d'Etudes Techniques de l'Equipement de Lyon
46 rue Saint Théobald
F – 38081 L'Isle d'Abeau Cedex, France

ABSTRACT

This work presents simulations results exploring the influence of the building air-tightness on the energy consumption of buildings for different hypothesis on the type of ventilation system. It shows that the energy impact is different depending on the ventilation system, and that buildings ventilated with a supply-extract ventilation system, even those without heat exchanger, are much more sensitive to air infiltrations than buildings ventilated with an extract ventilation system.

KEYWORDS

air infiltrations, leakage, energy consumption, supply-extract ventilation system, heat recovery

INTRODUCTION AND OBJECTIVES

Airborne energy losses represent from 30 % to 50 % of heating needs of dwellings equipped with an extract ventilation system. This proportion can be even higher for buildings built with high standards of thermal insulation like the Passiv Houses in Germany for instance.

Airborne energy losses depend on the air flow rates procured by the mechanical ventilation system and the air infiltrations. Poor building air-tightness can be responsible for cross air flows increasing significantly the total air change rate and consequently the energy consumption of a building.

The building air-tightness has a different impact on the energy consumption depending on the ventilation system. In buildings with an extract ventilation system, the ventilation system maintains the building at a depression of a few Pascals (Figure 1(a)). In buildings equipped with a supply-extract ventilation system, the pressure difference across the buildings envelope is much lower (Figure 1(b)). This makes the buildings equipped with a supply-extract ventilation system more sensitive to cross ventilation due to wind and poor air-tight building envelope.

A way to reduce the energy consumption of buildings consists in installing energy efficient ventilation systems like supply-extract ventilation system with heat recovery. Nevertheless, the global efficiency of the system can be affected if the air leaving the building doesn't flow through the heat exchanger. This happens when part of the air flow leaves the building through exfiltrations (Figure 1 (b)).

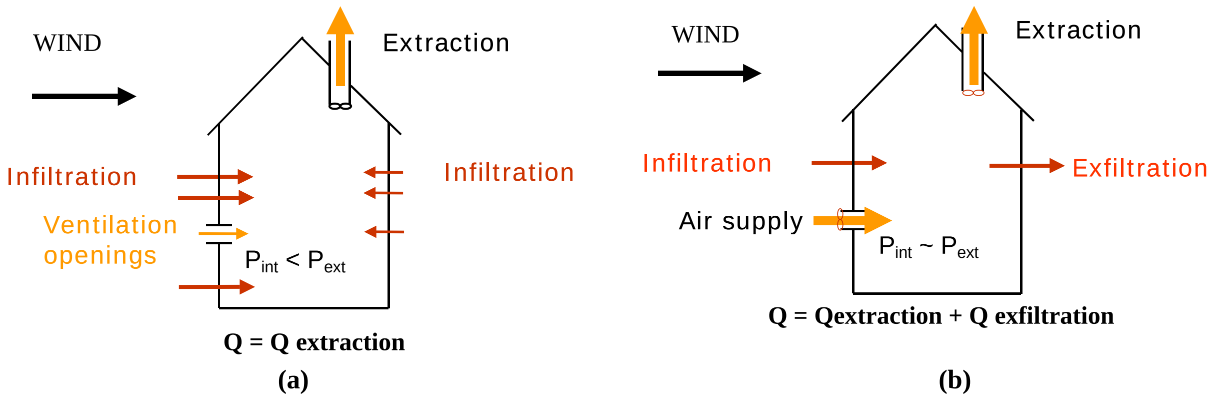


Figure 1 : Influence of the ventilation system on the total air change rate of a building. Case of a good air-tightness : (a) building ventilated with an extract ventilation system, (b) : building ventilated with a supply-extract ventilation system.

Thus, as shown in Figure 1, the presence of air infiltrations does not systematically increase the total ventilation rate of a building. It depends on the capability of the ventilation system to maintain a sufficient pressure difference across the building envelope to fight the wind forces on the building facades.

The work presented in this paper aims at comparing and quantifying the energy impact of the building air-tightness on the energy consumption of a building for different ventilation systems.

The approach was based on the use of the simulation tool developed for the French thermal regulation RT2000 (Réglementation Thermique 2000) **[1]**. This simulation code computes the total energy consumption of a building, taking into account the energy needed to heat the building, to produce hot water, and for non residential buildings also for lighting. Results are given in primary energy, defined as the total energy needed including the generation-, transmission- and emission energy losses.

PHYSICAL MODELLING OF AIR FLOW RATES

Air infiltration modelling in the French thermal regulation RT2000

The model used in RT2000 is based on EN 13465 **[2]** for the computation of the ventilation and infiltration flow rates in the building, and on the ISO 13790 **[3]** for the computation of the heating needs. The model described in EN 13465 is based on a mono zone pressure code that compute the pressure inside the building according to the exterior pressures on the building facades, the characteristics of the ventilation system, and the airflow laws of openings in the building envelope. Each element of the building envelope (ventilation openings and air infiltration cracks) is described by an airflow law of the form (Eq. 1). The pressure inside the building is obtained by solving the mass conservation equation, and the airflows through the different openings are then given by applying Eq. 1.

$$Q = K(\Delta P)^n$$ **Eq. 1**

Q	airflow through the opening	[m3.h^{-1}]
K	opening coefficient	[m3.h^{-1}.Pa^{-n}]
ΔP	pressure difference across the opening	[Pa]
n	flow exponent	[-]

The coefficient K is related with the effective leakage area, and the value of n gives some information on the shape of the openings: values next to 0.5 correspond to large openings, whereas values next to 1 means that the openings are very small and diffuse.

The parameter used in the French regulation RT2000 to characterize the air-tightness of the building envelope (I_4) is the leakage airflow under a pressure difference of 4 Pa across the building envelope, divided by the area of the "cold surface" which is defined as the building envelope area separating the heated volume from the outside or from a non heated room, excluding the bottom floor from this definition (Eq. 2).

$$I_4 = \frac{Q_{4Pa}}{A_c}$$ **Eq. 2**

A_c	Area of the "cold surface"[1] of the building envelope	[m^2]
Q_{4Pa}	Leakage airflow through the building envelope at a pressure difference of 4 Pa	[m^3.h^{-1}]
I_4	Leakage airflow per m^2 of "cold surface" at a pressure difference of 4 Pa	[m^3.h^{-1}.m^{-2}]

Reference values for building air-tightness in the French thermal regulation RT2000

The RT2000 introduces reference and default values. The reference value is the value that lead to the reference consumption if all others characteristics of the building are also at the reference value. The default value is the value that a designer can use if he doesn't have an idea of or doesn't know the real value at the stage he makes the computation. This value increases the energy consumption and has to be compensated by a performance higher than the reference on an other part of the building.
The reference- and default values in the regulation depend on the building use. They are summarized in Table 1. For a typical French single family dwelling[2], the reference value of the leakage airflow under a pressure difference of 4 Pa (0.8 m^3.h^{-1} .m^{-2}) is equivalent to the airflow through a hole of about 200 cm^2 at the same pressure difference.

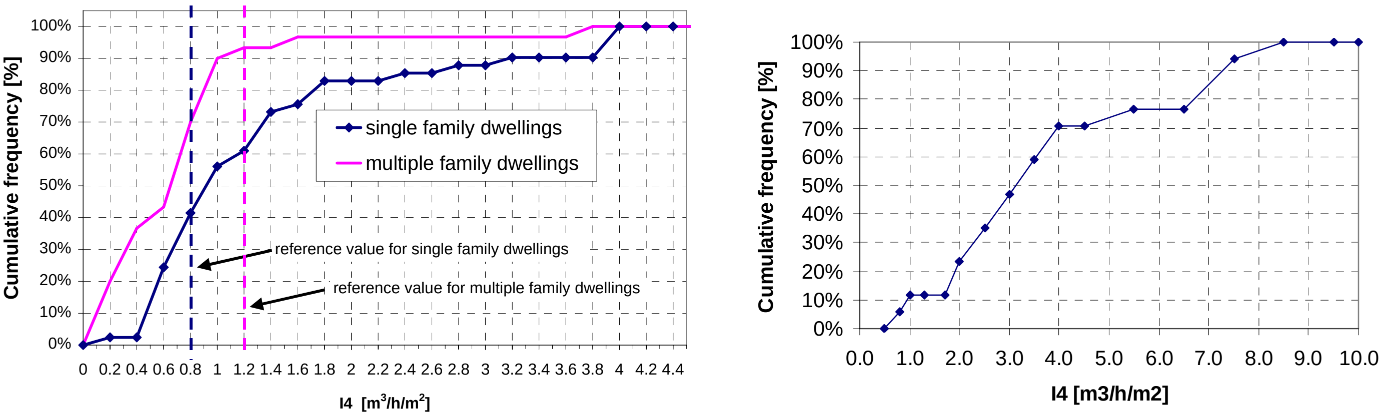
Table 1 : Reference and default values for the building air-tightness defined in the French regulation RT2000

	Leakage airflow Q at ΔP = 4 Pa [m^3.h^{-1} .m^{-2}]	
	Reference value	Default value
Single family dwellings	0.8	1.3
Multiple family dwellings	1.2	1.7
Tertiary sector buildings	1.2	1.7
Others buildings	2.5	3.0

[1] defined as the building envelope area separating the heated volume from the outside or from a non heated room, excluding the bottom floor from this definition.
[2] One level house, 110 m^2 of floor area, a heated volume of 280 m^3, and 230 m^2 of "cold surface".

Fields measurement results of the air-tightness of French buildings

Figure 2 shows the air-tightness performances measured on French buildings, resulting from a test sample of 71 dwellings and 17 non residential buildings. One can see that dwellings are much more airtight than others buildings. Only one third of the non residential buildings that have been tested in this sample have an I_4 value better than the reference value defined by the French thermal regulation (1.2 or 2.5 $m^3.h^{-1}.m^{-2}$ depending on the type of ventilation, see Table 1). On the other hand, about 40 % of the single family dwellings and 90 % of the multiple family dwellings have an I_4 value better than the RT2000 reference value (Figure 2(a)).



(a) **(b)**

Figure 2 : Cumulative frequency of indicator I4 measured on French buildings. (a): dwellings (sample : 41 single family dwellings, 30 multi family dwellings), (b): non residential buildings (office buildings, industrial buildings, village halls, gymnasiums) (measurement sample : 17 buildings). Source : [4]

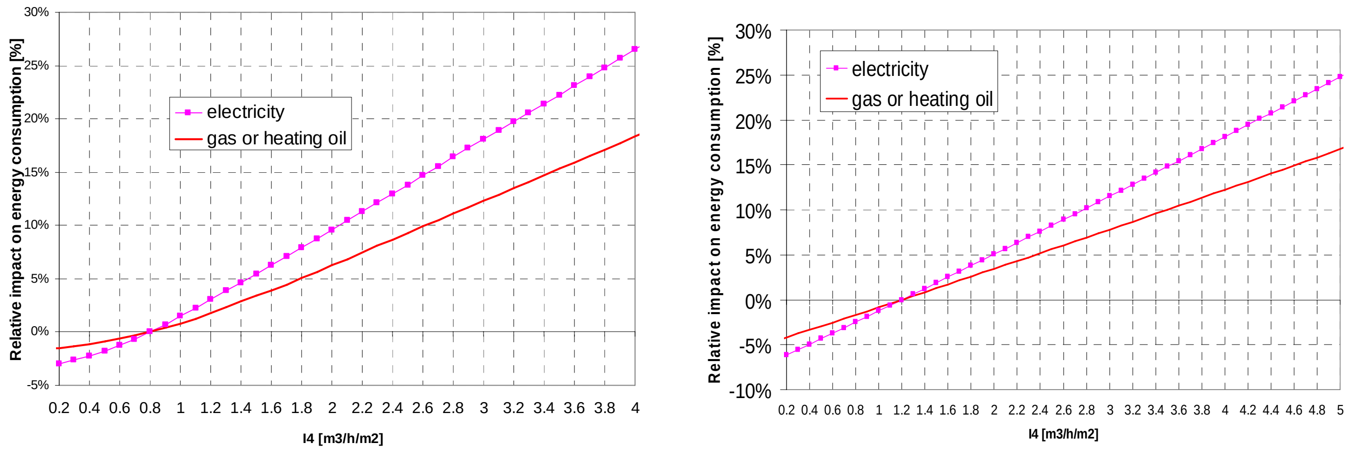
SIMULATION RESULTS AND DISCUSSION

Simulations have been made with the simulation code THCmotor (release 2.1.1) specially developed for the French thermal regulation RT2000. The total energy consumption has been computed for a single family dwelling and an office building for different assumptions concerning the ventilation system installed (extract ventilation system, supply-extract ventilation systems with or without heat recovery).

Influence of building air-tightness on total energy consumption

Figure 3 (a) and (b) presents the influence of the building air-tightness on the global energy consumption for respectively a single family dwelling ventilated with a mechanical extract ventilation system, and an office building ventilated with a supply-extract ventilation system without heat recovery. These figures show that the energy consumption grows for increasing values of the air leakages airflow, which is logical as the total ventilation rate is increased by the air infiltrations. Nevertheless, Figure 3 (a) also shows that for values of I_4 lower than 0.8 $m^3.h^{-1}.m^{-2}$, the amelioration of the building air-tightness does not decrease any more the energy consumption of the building ventilated with an extract ventilation system. This can be explained by the fact that for air-tight buildings ventilated with an extract ventilation system, the depression induced by the ventilation system is sufficient to drive the air flow through the mechanical extraction and fight exfiltrations.

On the other hand, for the simulated office building ventilated with a supply-extract ventilation system, the improvement of the building air-tightness is always beneficial for the energy consumption, even for low value of I_4 (Figure 3(b)). This illustrates the fact that buildings ventilated with a supply-extract ventilation system are much more sensitive to air infiltrations than those ventilated with an extraction ventilation system, because of the lower value of the pressure difference caused by the ventilation system across the building envelope (Figure 1(b)).



(a) (b)

Figure 3 : Influence of the building envelope air-tightness on the total energy consumption. (a): single family dwelling ventilated with an extract ventilation system, simulation file : CSTB file MI4 THC-APP-04 ref.thc, (b): office building ventilated with a supply-extract ventilation system without heat exchanger, simulation file : CSTB file bureaux2 THC-APP-14 ref.thc.

Figure 4 compares the energy consumptions for the same office building supposing in one case that the building is ventilated with an extract ventilation system, and in the other case with a supply-extract ventilation system without heat recovery. For I_4 greater than 1.1 $m^3.h^{-1}.m^{-2}$, the energy consumption is higher when the building is ventilated with a supply-extract ventilation system without heat exchanger. This is due on one side to the increased electricity consumption because of the presence of two fans, and on the other side to the air infiltrations.

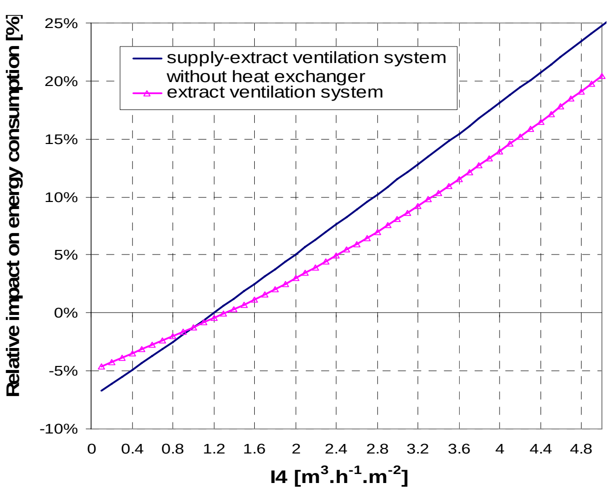


Figure 4 : Influence of the building air-tightness for an office building ventilated respectively with an extract – and a supply extract system. Sim. file : CSTB file bureaux2 THC-APP-14 ref.thc.

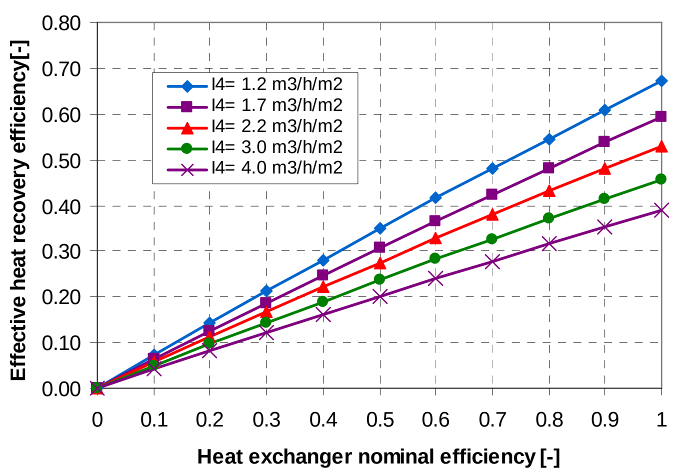


Figure 5 : Influence of the building air-tightness on the effective heat recovery for an office building ventilated with a supply-extract ventilation system. Sim. file : CSTB file bureaux2 THC-APP-14 ref.thc.

Influence of building air-tightness on the heat recovery efficiency

Figure 5 presents the evolution of the effective heat recovery efficiency, defined as the part of the enthalpy flux leaving the heated volume that is recovered to pre heat the entering air, as a function of the nominal heat exchanger efficiency, for different hypothesis of the building air-tightness. This simulation has been made for an office building ventilated with a supply-extract ventilation system. For poor air-tight building envelopes, the effective heat recovery efficiency can drop to very low values. For instance, for a building envelope with an I_4 value of 4.0 $m^3.h^{-1}.m^{-2}$, the effective heat recovery efficiency is three times lower than the nominal efficiency of the heat exchanger.

Taking into account that one third of the French non residential buildings that have been tested have an I4 value greater than 4.0 $m^3.h^{-1}.m^{-2}$ (see Figure 2(b)), this shows potential energy savings that lay in bettering the building air-tightness.

CONCLUSION

Air-tightness is becoming a growing concern for energy efficient buildings. Simulations of the impact of air infiltrations on energy consumptions depending on the type of ventilation system installed have been made with the simulation tool specially developed for the French thermal regulation RT2000.

The simulations showed that the energy consumptions of buildings equipped with a supply-extract ventilation system can be significantly increased by leaky building envelopes, and that these buildings are much more sensitive to air infiltrations than buildings equipped with an extract ventilation system. Moreover, when the supply-extract ventilation includes a heat exchanger, the effective heat recovery of the system can be deeply limited by air infiltrations, even for very efficient heat exchangers.

Theses results indicate that particular attention should be paid to the verification of the building air-tightness performance of buildings equipped with supply-extract ventilation systems, especially with low-energy buildings.

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[2] EN 13465 : Ventilation for buildings - calculation methods for the determination of air flow rates in dwellings.

[3] ISO 13790 : thermal performance of buildings - calculation of energy use for space heating.

[4] Guillot K. and Litvak A. (2000). Field measurement campaign of 70 French dwellings, ADEME, France.