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Two-zones Model for Predicting Passive Stack Ventilation in Multi-storey Dwellings

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SYNOPSIS

Proper dimensioning of natural ventilation system for multi-storey buildings is a critical matter, because the air flow rate depends on many parameters as outdoor temperature, wind, distribution of air inlets and envelope air leakage, characteristics of outlets and cowls.

The computer code GAINE BIZONE predicts the ventilation rates in multi-storey dwellings equipped with passive stack ventilation system. Each level is treated as a two-zones configuration, but each zone is linked to the collective ventilation shaft of the building. The model calculates the pressures in every zone of the building and the ducts, using iterative method to balance the mass flows in and out of each zone. One of the both zones represents the kitchen, the other one the rest of the dwelling including the bathroom and the toilets. The kitchen door that links the both zones is represented by an internal transfer opening.

The model takes into account the common cowls used to avoid reverse flow, but also the cowls with motorised device. The latter are very useful, especially to achieve the peak flow rate when cooking or when the stack effect is insufficient because of moderate wind and outdoor temperature. In addition, the model makes it possible to treat a gas appliance linked to the exhaust duct of the kitchen.

The basic modelling method used is known as the 'ping-pong' method because the two-zones model combines two models which are called in turn. In the first step, the ventilation rates are calculated in a stack of storeys representing a part of dwellings, then for the other part. The both models are called in turn until that, for each dwelling, the exchanged flow rate between the two zones are balanced.

Examples of applications conducted with the two-zones model are presented in this paper.

LIST OF SYMBOL

ach	air changes per hour(h^{-1})
C	suction coefficient of the cowl
ΔP	difference of pressure (pascal)
D	diameter of duct (m)
index $_0$	air characteristics at 20 °C
ks	absolute duct material roughness (m)
L	length of duct (m)
Λ	friction factor
m	mass air flow (kg/s)
Q	volume air flow (m^3/s)
ρ	air density (kg/m^3)
Re	Reynolds number
S	duct area (m^2)
V	velocity (m/s)
ζ	local loss factor
ζ_c	pressure drop coefficient of the cowl

1- INTRODUCTION

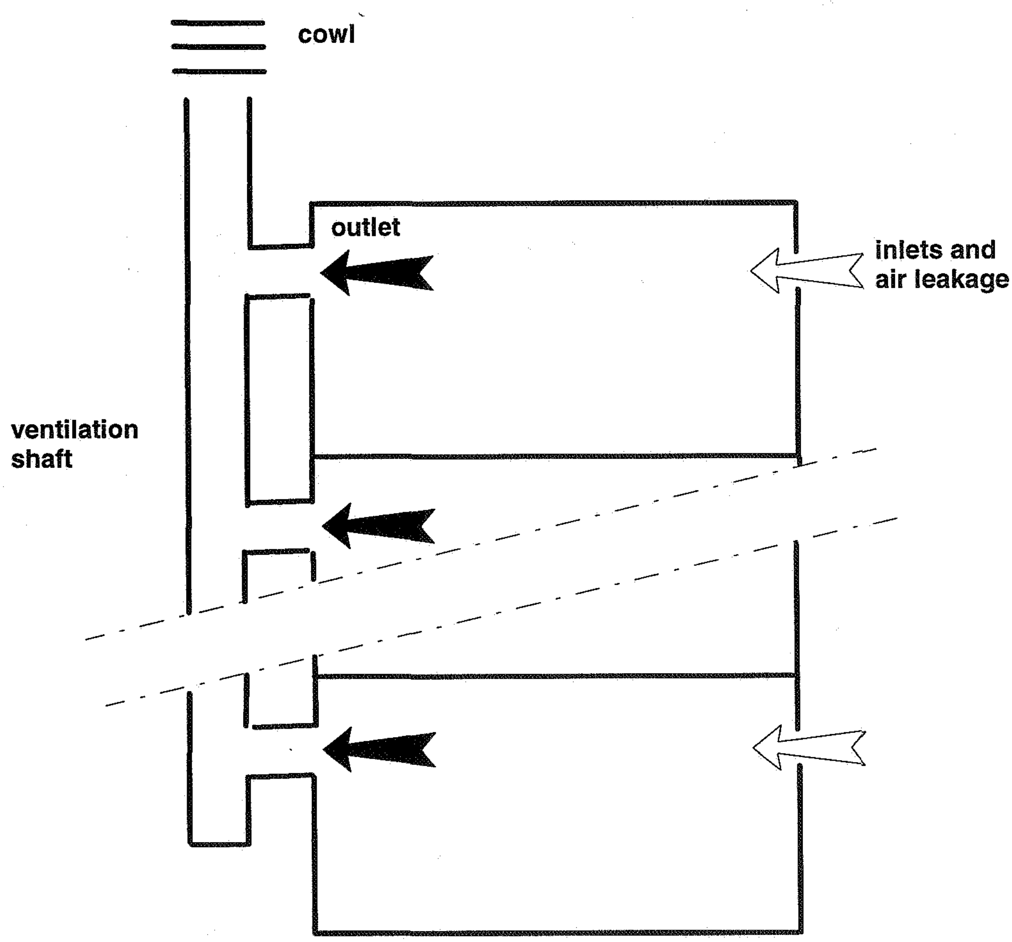
In France, the regulation on residential building ventilation is based, since 1969, on a general and continuous air renewal ; the fresh air comes into habitable rooms by air inlets and the stale air is drawn out to exhaust vents in the service rooms. [1]

Although the mechanical exhaust systems are now the most commonly used systems, the passive stack ventilation systems called in French 'ventilation naturelle' (different from natural ventilation by opening windows called in French 'aération'), were common in use in the buildings built in the sixties. An important part of the existing building stock have today to be refurbished.

When renovating existing building, air leakage of the envelope is often reduced ; this can lead to an insufficient ventilation if ventilation system is inadequate. A new system is then to be designed, reusing the existing ducts ; the proper dimensioning of system is a critical matter which can be solve using computer models.

2- THE COMPUTER CODE 'GAINE'

GAINE is a model of ventilation in multi-storey dwellings [2]. Each level is treated as a separate zone, but each is linked to a common ventilation shaft. The model calculate the pressure in every level of the building and the duct, using iterative methods to balance the mass flows in and out of each level.



It takes into account the combined effects of driving forces such as wind-induced pressures, thermal buoyancy and mechanical forces due to motorised cowls.

It is a 'mass balance' model, which assume the following :

- an homogeneous air temperature in each room, perfect mixing,
- that air is incompressible,
- steady state conditions,
- the air inlets and extract opening are at the same level,
- infiltration can be represented by a single opening.

The model is described by the following equations :

permeability : $$m = \varepsilon \times m_0 \times \left(\frac{T_0}{T} \times |\Delta P|\right)^{2/3}$$ (ε=+1 if $\Delta P \geq 0$ and -1 if $\Delta P < 0$)

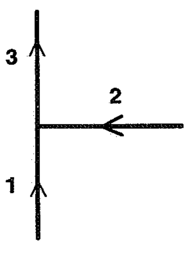
inlets : $$m = \varepsilon \times m_0 \times \sqrt{\frac{T_0}{T} \times \frac{|\Delta P|}{\Delta P_0}}$$ (ε=+1 if $\Delta P \geq 0$ and -1 if $\Delta P < 0$)

outlets : $$m = \varepsilon \times m_0 \times \sqrt{\frac{T_0}{T} \times \frac{|\Delta P|}{\Delta P_0}}$$ (ε=+1 if $\Delta P \geq 0$ and -1 if $\Delta P < 0$)

friction losses in ducts : $$\Delta P = \Lambda \times \frac{L}{D} \times 0.5 \times \rho \times V^2$$

with : $$\frac{1}{\sqrt{\Lambda}} = -2 \times \log_{10} \times \left(\frac{ks / D}{3.71} \times \frac{2.51}{\mathrm{Re} \times \sqrt{\Lambda}}\right)$$ (Colebrook)

pressure losses in duct branches [3] **:**



$$\Delta P_{3,1} = \zeta_{3,1} \times 0.5 \times \rho \times V_3^2 \qquad \zeta_{3,1} = 1 + \left(\frac{Q_2}{Q_3} \times \frac{S_3}{S_2}\right)^2 - 2 \times \left(1 - \frac{Q_3}{Q_2}\right)^2 - \frac{S_3}{S_2} \times \left(\frac{Q_2}{Q_3}\right)^2$$

$$\Delta P_{3,2} = \zeta_{3,2} \times 0.5 \times \rho \times V_3^2 \qquad \zeta_{3,2} = 1 - \left(1 - \frac{Q_2}{Q_3}\right)^2 - 1.41 \times \frac{S_3}{S_2} \times \left(\frac{Q_2}{Q_3}\right)^2$$

cowls : $$\Delta P = \frac{T}{T_0} \times \left(-\Delta P_X + \Delta P_0 \times \left(\frac{m}{m_0}\right)^2\right)$$

where : ΔPx is the available pressure for motorised cowls ($\Delta Px=0$ for static cowls)

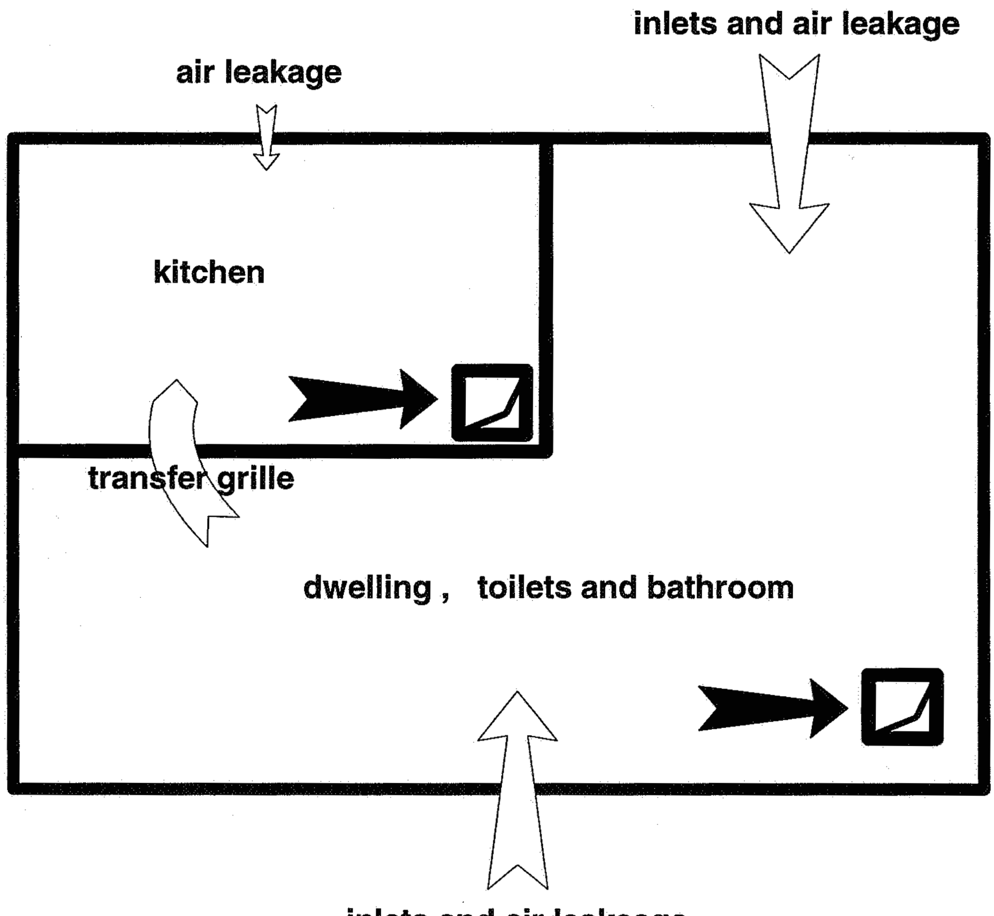
The air pressure on the exterior of the envelope due to wind are expressed by the dynamic pressure in a free-flowing wind stream multiplied by an dimensionless pressure coefficients. Wind velocity and direction are assumed constant (stationary conditions). The dimensionless pressure coefficients used in the model were derived from pressure distribution measurements performed in a boundary layer wind tunnel on a scale model [4].

GAINE has been used to improve the knowledge of the operating of ventilation systems, and in particular for dimensioning passive stack ventilation systems [5], for assessing the performance of mechanical ventilation systems [6], and for studying the passive stack ventilation in summer [7]

3- THE COMPUTER CODE 'GAINE BIZONE'

In GAINE only one ventilation shaft is modelled : it is not possible to study the reciprocal action between ducts and particularly the problem of siphoning. So we developed the code GAINE BIZONE.

Each level is treated as a two-zones configuration, but each zone is linked to the collective ventilation shaft of the building. The model calculates the pressures in every zone of the building and the ducts, using iterative method to balance mass flows in and out of each zone. One of the both zones represents the kitchen, the other one the rest of the dwelling including the bathroom and the toilets. The kitchen door that links the both zones is represented by an internal transfer opening.



The model takes into account the common cowls used to avoid reverse flow, but also the cowls with motorised device. The latter are very useful, especially to achieve the peak flow rate when cooking or when the stack effect is insufficient because of moderate wind and outdoor temperature. In addition, the model makes it possible to treat a gas appliance linked to the exhaust duct of the kitchen.

The basic modelling method used is known as the 'ping-pong' method because the two-zones model combines two models which are called in turn. In the first step, the ventilation rates are calculated in a stack of storeys representing a part of dwellings, then for the other part. The both models are called in turn until that, for each dwelling, the exchanged flow rate between the both zones are balanced.

The code GAINE BIZONE is linked with EXCEL® which manages the inputs and outputs : running under WINDOWS® the code makes it possible to study one case on about 10 seconds (PC 486DX33).

4 - EXAMPLES OF RESULTS

Retrofitting makes the building envelope more airtight and can lead to an insufficient air change rate in passive stack ventilated buildings : the existing ventilation system has therefore to be redesigned in order to insure an adequate indoor air quality.

4.1 - Before retrofitting

The building is five floor high. Each dwelling has four habitable rooms.

The dwellings are not airtight ; the air leakage rate is 4 ach under 50 pascal.

Inlets are installed in each habitable rooms (30 m^3/h under 20 pascal for each inlet).

Outlets (grilles of 100 cm^2) are installed in the service rooms.

Two shunt ducts (20 × 20 cm) serve the kitchen and the toilets/bathroom (ventilation system using one collective shaft and two individual ducts for toilets and bathroom are very common in France).

The ducts are covered by a concrete cowl ($\zeta_c = 2.5$ $C = -0.3$)

The table hereafter presents the results of calculation (in m^3/h) for the dwelling underprivileged (1) and the dwelling favoured (2) with regard to air renewal.

	outdoor temperature 0 °C				outdoor temperature 10 °C			
	wind 0 m/s		wind 5 m/s		wind 0 m/s		wind 5 m/s	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
extract flow in the kitchen	14	66	29	63	10	45	29	45
extract flow in toilets and bathroom	12	69	19	64	9	47	21	45
total flow (extract + cross ventilation) in the dwelling	26	135	194	245	19	92	190	216

The underprivileged dwelling is under ventilated in windless outdoor conditions.
When the wind is blowing all the dwellings are over ventilated by cross ventilation

4.2 - After retrofitting

Single glazing windows have been replaced by double glazing ; the dwellings are airtight ; the air leakage represent only 0.4 ach under 50 pascal.

When the ventilation system is not modified the table hereafter presents the results of calculation (in m^3/h) for the dwelling underprivileged (1) and the dwelling favoured(2).

	outdoor temperature 0 °C				outdoor temperature 10 °C			
	wind 0 m/s		wind 5 m/s		wind 0 m/s		wind 5 m/s	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
extract flow in the kitchen	16	43	14	42	11	29	12	24
extract flow in toilets and bathroom	15	50	11	48	10	34	11	26
total flow (extract + cross ventilation) in the dwelling	31	93	65	90	21	63	65	74

With regard to the previous situation the cross ventilation has sharply decreased and the underprivileged dwelling continued to be under ventilated. The ventilation system has to be redesigned.

We give here an example

Inlets are installed in each habitable rooms (30 m^3/h under 20 pascal for each inlet).

Self regulated outlets are installed in the service rooms (45 m^3/h between 5 and 30 pascal in the kitchen, 30 m^3/h between 5 and 30 pascal in the toilet and the bathroom).

Two shunt ducts (20 × 20 cm) serve the kitchen and the toilets/bathroom.

The ducts are covered by cowls ($\zeta = 1.5$ $C = -0.65$) ; these cowls are motorised and can give an additional pressure (15 pascal) when necessary.

The table hereafter presents the results of calculation (in m^3/h) for each dwelling.

	outdoor temperature 0 °C		outdoor temperature 10 °C	
	wind 0 m/s	wind 5 m/s	wind 0 m/s	wind 5 m/s
extract flow in the kitchen	45	45	45	45
extract flow in toilets and bathroom	60	60	60	60
total flow (extract + cross ventilation) in the dwelling	105	105	105	105

This system makes it possible to ensure a satisfactory indoor air quality and to save energy and the same flowrate in dwelling whatever the floor.

5- CONCLUSION

The computer code GAINE BIZONE makes it possible to design and to dimension the passive stack ventilation systems in particular for the renovation of buildings with existing shafts.

The examples above mentioned show that it is possible :

- to ventilate correctly the dwellings when external conditions (temperature and wind) are insufficient,
- to save energy when the outdoor temperature is low or when the wind is blowing.

Actual studies are carried out to improve the code in order to take better into account the individual duct which link the dwelling to the collective shaft and to validate the results by laboratory and field measurements.

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