Methods and methodological tools for the elaboration of natural ventilation strategy

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ABSTRACT

The efficacy of a natural ventilation strategy is essentially conditioned by the sizing of components on which the airflow control depends. The indoor environment conditioning is submitted to strict regulation. The implementation of the natural ventilation strategy is related to the building layout; therefore, the devices' sizing is important for the architect. On the basis of the 'loop equation' proposed by James Axley, we developed a simple 'sizing tool'. This tool relies on macroscopic airflow models through flow resistances of the natural ventilation components written in the object-oriented solver Spark. The multizone dynamic program Comis Trnsys permits achieving a coupled thermal airflow analysis of a sized ventilation system.

INDEX TERMS

Natural ventilation; Loop equation; Sizing tool; Component

INTRODUCTION

The new European directive in favour of energy saving and environmental protection must find an echo close to the architects on whom rests the responsibility to convey these new concepts. Unlike mechanical ventilation, the implementation of natural ventilation systems involves the building envelope design, thus the building designer. The design process of naturally ventilated building is conditioned by both ventilation strategy conditions and building layout. Accordingly, the elaboration of a natural ventilation strategy is based on:

The choice of the system components that permits to taking advantage from prevailing natural phenomena, i.e. wind and stack effect on the one hand, and on the other hand the strategy building-up that is adequate with the building spatial composition.

The components' sizing that is adequate with the indoor environment quality requirements. The airflow control depends on the successive components that compose the natural ventilation system: orifice, duct, duct fitting, self-regulating vent, etc.

METHOD

The architects have to inform the users about the future performance of the ventilation strategy, i.e. indoor level temperature, air change, wind speed, indoor humidity, etc. In fact, the 'sizing tool' must be accessible to a non-specialized user. At the same time, it allows to give a general idea of the components' sizing in reference to the required ventilation rates imposed by the indoor conditioning standards. It is composed of three elements:

The general physical model is based on the 'Loop equation'. The natural ventilation system is idealized in the 'loop equation' as a succession of volumes (e.g. rooms, zones) linked by airflow control components (e.g. windows, doors, cracks or ducts, etc.). The mathematical analysis of a ventilation strategy implies both buoyancy-driven and wind airflow paths. The

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algebraic sum of the pressure changes around a loop must necessarily be zero. A number of mathematical models for modelling airflow-driven forces and the more common components are presented. Before that, the mathematical models that express natural phenomena solicitations at the origin of the airflow drive are enumerated:

Wind-driven pressures at the component level ΔP (Pa)

$$\Delta P = (Cp_{\text{Inlet}} - Cp_{\text{Exhaust}})\rho U_{\text{ref}}{}^2/2 \tag{1}$$

where Cp_{Inlet} and Cp_{Exhaust} are the pressure coefficients at the inlet and outlet positions, respectively, at the building faces, ρ (kg/m^3) is the density of the air and U_{ref} (m/s) is the reference wind speed.

Pressure changes due to elevation changes, within a component or zone ΔP (Pa)

$$\Delta P = \Delta\rho g Z \tag{2}$$

where ΔZ (m) is the elevation change, g (m/s^2) is the acceleration of gravity and ρ (kg/m^3) the density of the air. The density of dry air is estimated from its temperature T (K) using ideal gas law

$$\rho = \frac{352.6\,\text{kg} \quad -\text{K/m}^3}{T\ (\text{K})} \tag{3}$$

Mathematical models are needed to rationally size components of natural ventilation systems. James Axley proposes the library of flow component relations used in the pressure 'loop equation'(Axley, 1999). In general, these mathematical models express the pressure drop ΔP (Pa) in a component as a function of the volumetric flow rate and the design characteristics that define the component (e.g. size).

Orifice component:

$$\Delta P = \frac{\dot{m}^2}{2Cd^2\rho A^2} \tag{4}$$

where $\dot{m}$ (kg/s) is the mass airflow, A (m^2) is the cross-sectional area and Cd (–), discharge coefficient, is an empirical dimensionless parameter applied to openings. Concerning the indoor orifice the discharge coefficient can be calculated by

$$Cd = (0.4 + 0.0075\Delta T) \tag{5}$$

where ΔT (°C) is the interzonal temperature change (Allard, 1998).

Duct component:

$$\Delta P = \frac{fL\dot{m}^2}{\rho Dh A^2} \tag{6}$$

where f is a dimensionless friction factor and L (m), A (m^2) and Dh (m) are, respectively, the length, the cross-sectional area and the hydraulic diameter of the duct equal to the area of the cross-section divided by its perimeter.

Duct fitting component:

$$\Delta P = \frac{C\dot{m}^2}{\rho A^2} \tag{7}$$

where C is a dimensionless fitting loss coefficient.

Self-regulating vent component:

$$\Delta P = \Delta P_0 \ln\left(1 - \frac{\dot{m}}{\dot{m}_0}\right) \tag{8}$$

where ΔP_0 (Pa) and $\dot{m}_0$ (kg/s) are, respectively, the pressure difference at which control effectively begins and the nominal self-regulated volumetric flow rate. This model was fitted to measured data for Dutch and French self-regulating vent data (Axley, 1999).

Equation systems were written in the object-oriented environment Spark, which contains an equation solver that allows solving the calculation problem.

The Simulation Problem Analysis and Research Kernel Spark is an object-oriented software system that performs such resolution of equation systems. The object-oriented means that components and subsystems are modelled as classes that can be interconnected to specify the model of the entire system. Spark offers symbolic algebra tools for automatic creation of atomic classes, macro-classes and Spark problem files. This program has permitted the development of the general problem structure of the 'sizing tool' presented in Figure 1. The 'sizing tool' permits the tackling of the natural ventilation problems with different targets:

- Calculate the ventilation rates related to one component, which belongs to the ventilation system.
- Calculate a component size, for example, the duct length or diameter.

From the mathematical point of view, the components are defined under Spark by their physical behaviour equation. The program considers this as a class, i.e. objects, that can be used for an unlimited number of times. The problem structure called 'system' defines the relations between different selected objects. We have chosen to define each component nine times under different forms. In other words, for each type of component 10 different versions with different characteristics can be used in the definition of a ventilation strategy. At the same time, concerning the buoyancy stack driven flows, nine different heights are possible in the same system. Thus, both the same height differences and the same components can be introduced an unlimited number of times.

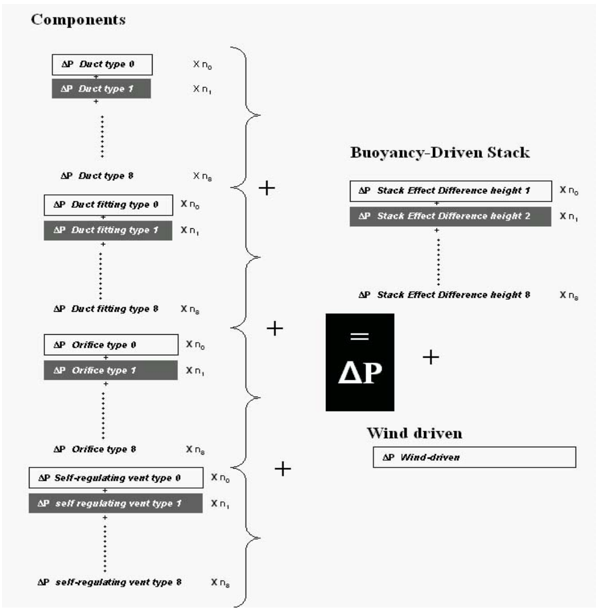
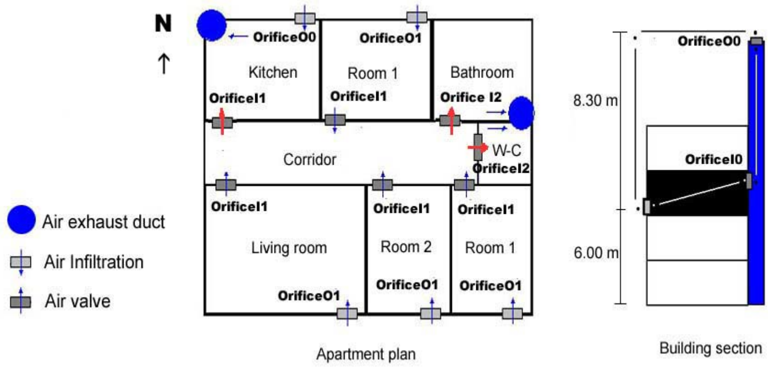


Figure 1 The 'sizing tool' mathematical models structure.

The third very significant element is the interface definition, which permits both to key in the system parameters and to provide guidance for the users. The interface is developed under Microsoft Access and aims at providing to the users sufficient guidance to implement the calculation.

APPLICATION

Based on the previous approach, we propose to size a natural ventilation system. The purpose of the following study is to ventilate an apartment located in the third floor of a building. Seven zones constitute the apartment. The ventilation system is composed of air inlet situated on the building faces. Ducts lead the air exhaust above the building roof. The specified ventilation rates in Figure 2 for each space follow the French regulation. The study aimed to size a ventilation system under winter conditions. Indeed, the inquiry is to meet the indoor air quality requirements and the energy saving purpose. The considered outdoor temperature is 13°C and wind speed 3.5 m/s. The indoor environment is normally heated, so the indoor temperature was assumed to be around 20°C. The positive windward coefficient pressure and the negative leeward coefficient pressure are, respectively, 0.6 and –0.3.



Design conditions ventilation rates (kg/h)	
Kitchen	144
Living room	24
Room	24
Bathroom	36
W-C	36

Figure 2 Ventilation system description and required ventilation rates defined for each space.

In Figure 2 are described the air inlets and air exhausts position in the apartment. The outdoor air comes in through the orifices positioned on the building faces. The air exhaust, collected in the corridor, is rejected through the ducts situated in the bathroom and the w-c. The second duct, situated in the kitchen, permits to ventilate this space regardless of the rest of the apartment because of bad smells. The ventilation strategy is based on two configurations. The Spark computed simulation allows sizing of each component. Following the imposed conditions, several solutions are possible. For both configurations, the solutions with negative pressure drop in the duct are eliminated because the leakage is reversed. In Figure 2, the selected solutions are highlighted. The architectural impact of the considered solution is also taken into account.

Surface orifice (m)					ΔP Duct (Pa)	Duct Diameter (m)
O1 (m²)	O0 (m²)	I2 (m²)	I1 (m²)	I0 (m²)		
Configuration N°1						
0.03	0.02	0.03	0.03	0.04	1.12	0.199
0.03	**0.025**	**0.03**	**0.03**	**0.04**	**2.79**	**0.166**
0.03	0.02	0.03	0.03	0.01	-26.87	0.105
Configuration N°2						
	0.01			0.03	-31.40	0.102
	0.025			**0.035**	**0.58**	**0.226**
	0.04			0.025	1.86	0.180

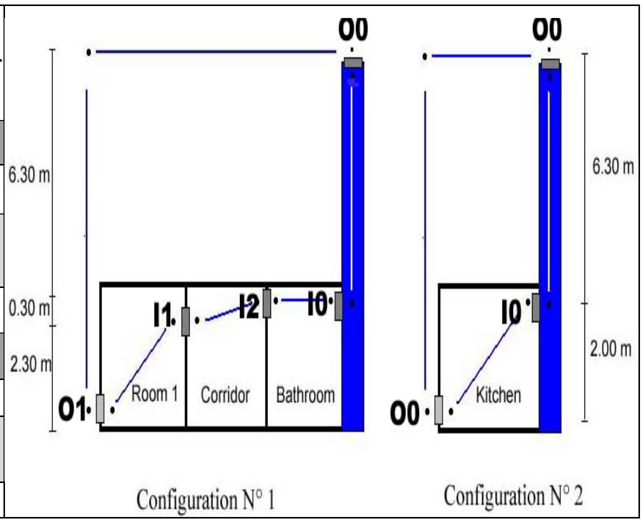


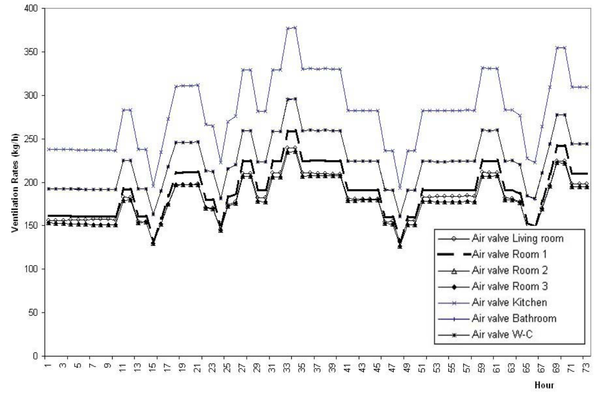
Figure 3 The component sizing for both configurations.

EVALUATION

The following step in this study concerns the evaluation of the proposed ventilation system performance following the defined criteria. The last part of this paper is devoted to the analysis of the natural ventilation system behaviour. The multizone dynamic analysis program

Comis-Trnsys supports modelling of coupled thermal airflow interactions and building ventilation system. This section presents and discusses the building behaviour for both proposed configurations. The Comis program allows implementing, based on the 'Numerical data for air infiltration and natural ventilation' (Orme *et al.*, 1998), the pressure coefficient on both the opposed faces of the building. The chosen buildings are surrounded by obstructions equivalent to half the height of the building. The building is submitted to outdoor conditions based on the weather data of La Rochelle in France. The project set out to evaluate the component performances in real conditions of outdoor climate. The modelling studies are used to evaluate: the indoor air temperature during natural ventilation system operation; and air changes in terms of times histories.

The results presented in the graphs below concern the resulted ventilation rates and temperatures for the period 11–13 June. To investigate the flow behaviour, the ventilation rates exhausted by each space are plotted in Figure 4.



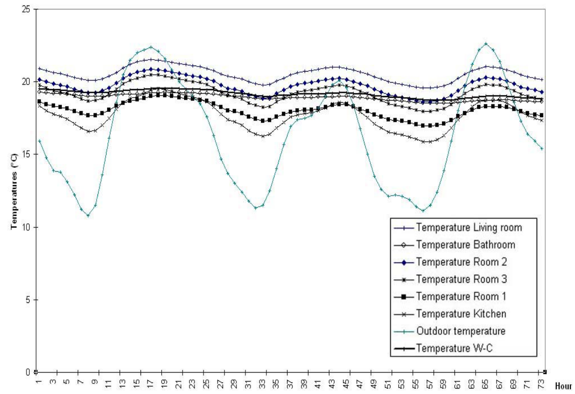


Figure 4 Resulting ventilation rates and indoor temperatures in the apartment.

The results reveal that the ventilation rates specified by the regulation are reached. However, the ventilation rates are excessive. Indeed, the ventilation leads to important heat loss, essentially in winter. The building orientation influences largely the indoor temperatures. In another part, the temperature in the bathroom is also more important in comparison to the kitchen temperature while the orientation is similar. The important ventilation rates observed in the kitchen results in important heat losses. Actually, over the year the ventilation requirements are not satisfied for only 0.3% of the time. Consequently, the ventilation requirements determined for the component sizing are largely satisfied. Thus, the proposed tool meets the architect's expectations. However, the important variation of ventilation rates, essentially in the kitchen, highlighted the difficulty of the airflow control in the natural ventilation system. To investigate this problem of increasing airflow rates further, we analyse the computed results over the year. The standard deviation given in Table 1 reveals important ventilation rate variations. Moreover, natural ventilation involves acceptance of a certain degree of fluctuation of the indoor conditions. Also, the implementation of a natural ventilation strategy necessitates implementation of management systems.

Table 1 Evaluation of system performance and ventilation rates over the year

	Kitchen	W-C	Living room	Room 1	Room 2	Room 3	Bathroom
Percentage of the year of dissatisfaction of ventilation requirements	0.32%	0.24%	0.62%	0%	0.39%	0.39%	0.16%
Standard deviation over the year (kg/h)	230.54	81.41	57.22	76.74	66.31	66.30	81.17

The methodology used for the components' sizing satisfied the ventilation requirements.

However, the thermal aeraulic analysis reveals important ventilation rate variations. Indeed, the proposed tool gives indications about the components' sizing according to the specified climatic conditions. It is clear that to perform the ventilation strategy further simulations are needed. Unlike the ventilation system sizing, the duct diameter, for example, with a margin of error of 0.1 m is insignificant, at the project outline stage. The components sizing determined allow the designer essentially to evaluate the architectural impact of the sketched strategy on the building envelope design.

CONCLUSION

The proposed tool faces up to the request of architects as regards design tools to fulfil the users' demand for quality; it is significant to envisage adapted tools for the designers who are confronted with problems in the building trade. The proposed tool permits to traduce knowledge information: temperatures, required ventilation rates, elevation changes and climatic conditions in terms of component size. This tool assists the designer in the conception process. Following the building situation on the one hand and the ventilation requirements on the other hand, the 'sizing tool' gives information about the architectural impact of the ventilation strategy. At the outline designing process the scale of the component sizing given by this tool is sufficient. However, more calculations are necessary to confirm accuracy. Indeed, the 'sizing tool' contributes to a decisive stage in the implementation of a natural ventilation system. It gives to the designer the means to master the architectural impact of a natural ventilation strategy at the project outline. According to the ventilation requirements, the 'sizing tool' permits optimizing or changing the ventilation strategy.

ACKNOWLEDGEMENTS

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