

# **SIMULATING NATURAL VENTILATION: COUPLING THERMAL AND VENTILATION MODEL**

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## **ABSTRACT**

Ventilation determines the indoor air quality and has a profound effect on the energy consumption and thermal (summer) comfort of buildings. Simulation of natural ventilation leads to the prediction and evaluation of these performances.

Coupling ventilation network and thermal simulation models is necessary to simulate natural ventilation as the mass and energy balance are physically linked in a naturally ventilated building. Several ways of coupling exist, each having its own possibilities and difficulties. An example of sequentially coupling the thermal model Capsol and the ventilation network simulation software AIOLOS is discussed.

## **KEYWORDS**

Natural ventilation, building simulation, coupling thermal and ventilation simulation model.

## **IMPORTANCE OF SIMULATION OF NATURAL VENTILATION**

Ventilation affects building performances in three ways.

Firstly, indoor air quality problems are caused by the existence of gases and particles in the air like tobacco smoke, CO<sub>2</sub>, moisture, radon, micro-organisms, allergens, fibres, VOC's (Grieve 1991). Adequate ventilation decreases these indoor pollution levels.

Secondly, ventilation is a dominant factor in the building energy balance in well insulated buildings. The contributors to the global energy consumption in a recently built office building in Brussels for instance are lighting (34%), transmission (33%), ventilation (21%), fans (8%), pumps (2%) and hot water (2%) (Vandaele et al 2001).

Thirdly, ventilation is a primordial mechanism to condition thermal comfort in buildings. Intensive night ventilation in particular, may be used to prevent overheating problems during summer. This ventilation technique cools down the exposed building structure at night and reduces and postpones consequently the temperature peaks by day.

Natural ventilation is used in most Western European residential buildings and can be a good alternative for mechanical ventilation in office buildings. To apply natural ventilation well, simulation is necessary to predict and evaluate thermal comfort, indoor air quality and energy consumption in a naturally ventilated building.

The first part of this paper discusses two questions about the simulation of natural ventilation. Why is a coupled thermal and ventilation model necessary to simulate natural ventilation? Which coupling methods exist and what are their possibilities and difficulties? The second part focuses on an example of sequential coupling.

## COUPLING THERMAL AND VENTILATION MODEL

### Necessity of coupling thermal and ventilation model

In a naturally ventilated building the total pressure difference  $\Delta p$  across an opening at height  $z$  is written as the sum of the wind and thermal stack pressure difference minus the unknown pressure difference at reference height  $\Delta p_0$  (ASHRAE 1993), eqn. 1:

$$\Delta p(z) = \frac{1}{2} \rho_e C_p v^2 - (\rho_e - \rho_i) g (z - z_0) - \Delta p_0 \quad [1]$$

The air flow through the opening varies with the square root of the pressure difference across the opening. Interpreting the zonal mass balance determines the unknown pressure  $\Delta p_0$  in equation 1. As a result, the air flow through the openings of each zone depend on the unknown zonal air densities (or temperatures, following the ideal gas law). These densities are determined by the zonal dynamic energy balance (see equation 2). The ventilation, transmission and radiant heat losses and the heat storage in the building structure are summed and equal to the sum of the internal and solar heat gains, equation 2:

$$\sum \rho c \dot{V}_{aj} (\theta_i - \theta_j) + \sum AU (\theta_i - \theta_j) + C \frac{d\theta_i}{dt} = \Phi_I + \Phi_s \quad [2]$$

The unknown internal air temperatures  $\theta_i$  in eqn. 2 depend in their turn on the interzonal air flow  $\dot{V}_{aj}$ . Consequently, the processes of heat and air flow by natural ventilation are physically linked by the energy and mass balance.

However, most existing nodal network ventilation simulation models use the mass balance in combination with estimated values of internal temperatures to simulate natural ventilation. Furthermore, given the ventilation air flows, existing thermal simulation models calculate the indoor temperature based on the energy balance per zone.

Therefore a coupled thermal and ventilation simulation model, which iterates the mass and energy balance per zone till convergence, is necessary to simulate natural ventilation.

### Coupling methods

Hensen (1995) describes several methods for coupling ventilation and thermal models.

Firstly, in 'sequential coupling', the two models run separately. The mass flow rates are calculated in the ventilation model for the whole simulation period and fed into the thermal model. The calculated internal temperatures, on their turn, form the input of the ventilation model. This method can be easily implemented when data exchange is possible. It is often the only possibility when existing codes are coupled. A disadvantage of sequential coupling is limited control on the calculation process and results as the same time step is used for the whole calculation period. Moreover, controlling ventilation paths is difficult as the same day time schedule is used for the whole calculation period.

Secondly, the 'ping-pong method' runs the thermal and ventilation model sequentially. The models use the results of each other in the next time step. This time step must be chosen adequately to prevent substantial errors.

Thirdly, the iteration between the thermal and ventilation model within each time step until convergence is called the 'onions method'. This method calculates more accurate results but requires more calculation time.

## EXAMPLE OF SEQUENTIAL COUPLING

This section discusses the sequentially coupled simulation of the dynamic thermal model Capsol (Physibel 2000), and the steady state ventilation model AIOLOS (Allard 1998). Capsol calculates multi-zone transient heat transfer. A building and its environment are considered as a set of zones, between which heat flows occur due to conduction, convection, (solar) radiation and ventilation. Interzonal air flow data per time step can be imported (Standaert 1996), which is necessary to link this model to the ventilation model.

AIOLOS calculates the air flow rate in natural ventilation configurations, based on the principles of network modelling. This ventilation model is chosen since the zonal temperatures can vary and be read from a file, which is necessary to exchange data with the thermal simulation model.

### Input

Air flow and temperature are calculated in a naturally ventilated row house on a normal Belgian summer day. All the ventilation paths, windows and doors, are open all the time and simulated as double flow openings. Weather and building data are given in table 1 and figures 1 and 2.

TABLE 1  
Building data

Ventilation building data					
b <sub>x</sub> h (window)	2x1 m	b <sub>x</sub> h (door)	1x2 m	C <sub>D</sub>	0.7
Thermal building data					
Φ <sub>l</sub>	0 W	U (roof)	0.39 W/m <sub>2</sub> K	U (ground floor)	0.32 W/m <sub>2</sub> K
τ <sub>s</sub> (window, door)	1	U (ext wall)	0.57 W/m <sub>2</sub> K	U (first floor)	1.69 W/m <sub>2</sub> K
U (door)	5.89 W/m <sub>2</sub> K	U (int wall)	3.32 W/m <sub>2</sub> K	U (window)	3.05 W/m <sub>2</sub> K
Wall composition					
External wall	brick cavity wall	Flat roof	hollow core concrete slabs	Ground floor	concrete slab
Internal wall	sand-lime bricks	First floor			

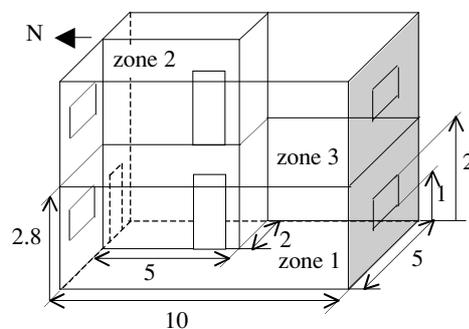
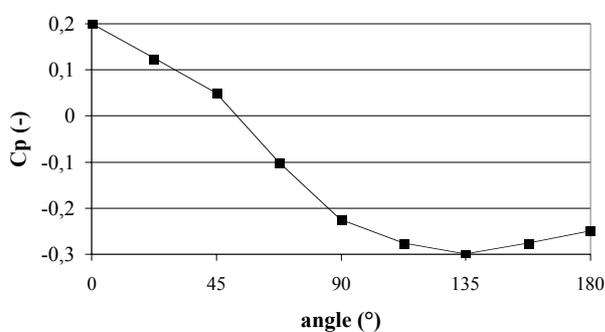


Figure 1: Wind surface pressure coefficient  $C_p$  varies with the angle between the wind direction and the normal on the surface, calculated with Cpcalc<sup>+</sup> (Grosso 1995) (left). Geometrical data (right)

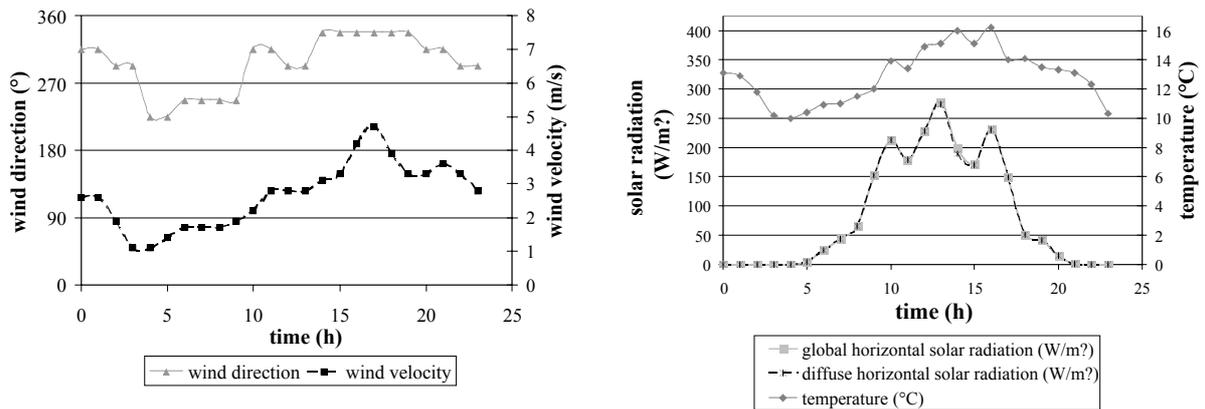


Figure 2: Weather data (Test Reference Year Uccle, July 1): wind direction and velocity (left) and temperature and solar radiation (right)

## Calculations

In sequential coupling, the mass flow rates are calculated in the ventilation model for the whole simulation period and fed into the thermal model. The calculated internal temperatures, on their turn, form the input of the ventilation model. In this section this iteration process is studied during three iteration steps.

In the preceding calculation, the air flows are calculated assuming an internal temperature of 20°C in zone 1 and 3 and 18°C in zone 2. As no pre-calculation was performed in Capsol, the initial zonal temperatures are equal to the external temperature (see figure 3, 0 h).

Figure 3 shows the exchanged air flow between outside and zone 3 and its zonal temperature during the iteration process.

It proves the statement that a coupled thermal and ventilation simulation model is necessary to predict the size and the direction of the natural ventilation flow.

In the iteration process numerical errors in the temperature result from sudden changes in the air flow. A reduction of the time step in the thermal simulation model solves this problem (see figure 4). As a result the time step in Capsol varies from 10 minutes in the first iteration step to 1 minute in the following calculations. The time step in AIOLOS is fixed to 1 h.

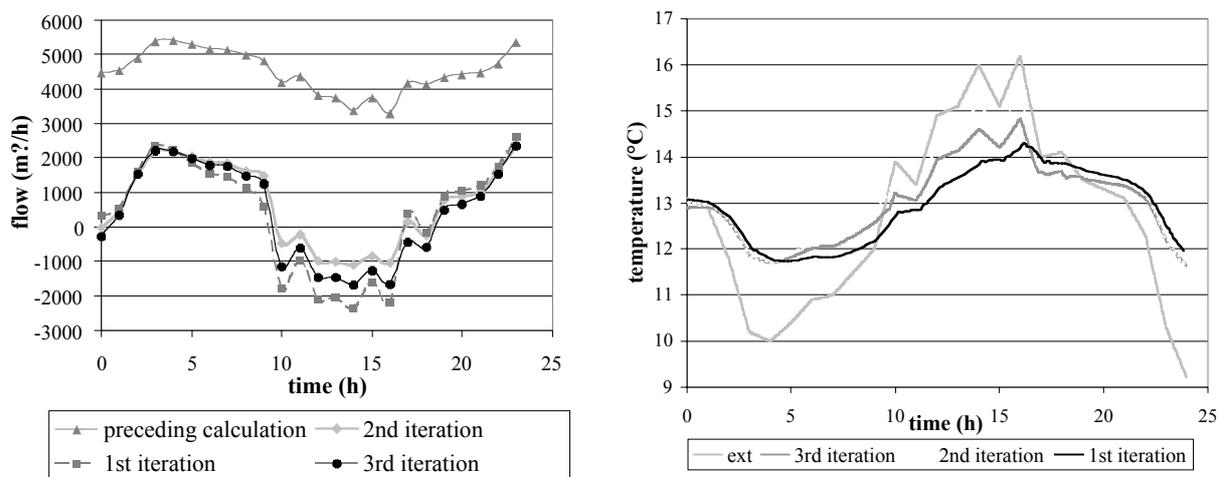


Figure 3: Air flow from zone 3 to outside (positive) and from outside to zone 3 (negative) (left) and temperature in zone 3 (right) during iteration process.

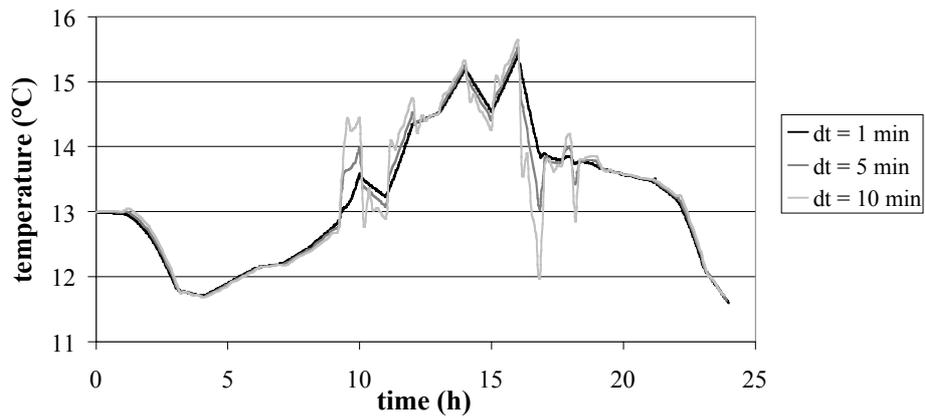


Figure 4: Reduction of the time step in the calculation of the temperature of zone 3 in the second iteration step to prevent substantial numerical errors.

## Results

Figure 5 shows the calculated air flow and temperature in the naturally ventilated row house after three iteration steps. The results fulfil in essence the expectations, except from approximately 16.8 till 17.2 h and from 18.2 till 19 h (see arrows). The temperature in zone 2 exceeds suddenly the temperature in zone 3.

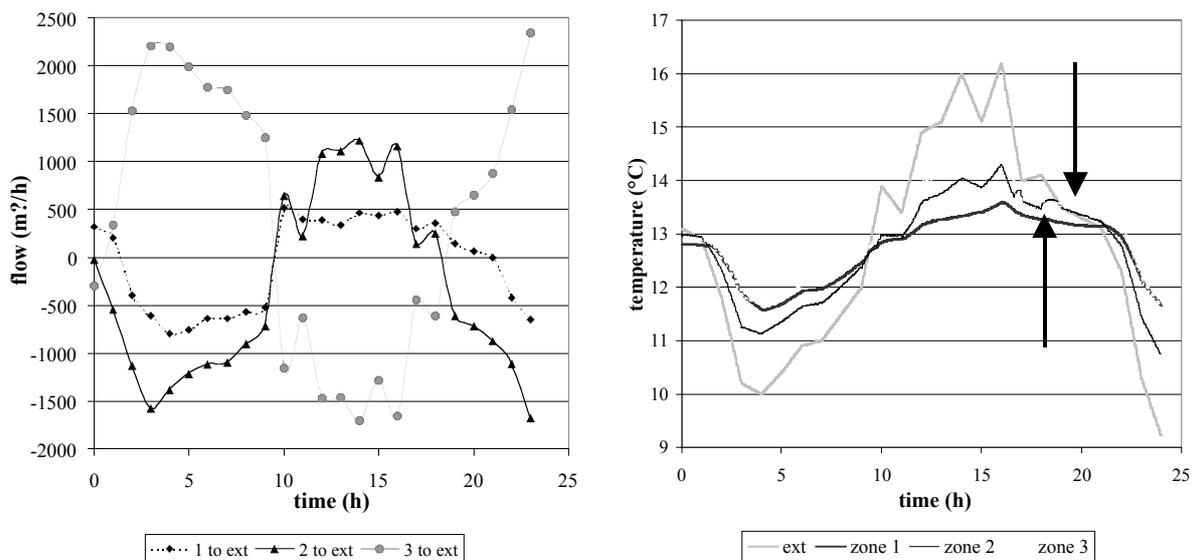


Figure 5: Calculated zonal air flow (in  $m^2/h$ ) (left) and temperature (in  $^{\circ}C$ ) (right) after three iteration steps

Three dominating air flow patterns can be distinguished.

Firstly, the internal temperature exceeds the external and the thermal stack effect dominates the wind effect (weak southwestern or moderate northwestern wind) between 1.5-9.5 h and 21-23 h. As a consequence, the external air enters the house on the ground floor in zone 2 and on the northern or southern side of zone 1, depending on the wind direction. It mainly leaves the building on both sides of the first floor (zone 3).

The second pattern occurs from 9.5 h till 18.5 h when the external temperature exceeds the internal, while the thermal stack effect dominates the wind effect. The external air principally enters the house on the north side of zone 3 (first floor) and mainly leaves on the ground floor in zone 2 and on the south side of zone 1.

The third pattern is found between 0.5-1.5 h and 18.5-21 h when the internal and external temperatures differ little and the wind, blowing strong from north-northwest, dominates the thermal stack effect. The external air enters on the north side of both levels and leaves on the south side of zone 1 and 3. The external air entered in zone 2, splits up into two flows to zone 1 and 3 respectively.

## CONCLUSIONS

Simulation of natural ventilation leads to the prediction and evaluation of thermal summer comfort, indoor air quality and energy consumption.

A coupled ventilation and thermal model is necessary to calculate air flow and temperatures in a naturally ventilated building as the energy and mass balance are physically linked. Sequential coupled simulation of thermal model Capsol and ventilation model AIOLOS is tested. Air flow and temperature in a naturally ventilated row house on a normal Belgian summer day are calculated. This example shows that the time step must be chosen adequate preventing substantial numerical errors. Furthermore, the iteration process seems to converge and the results fulfil in essence the expectations.

## NOMENCLATURE

TABLE 2  
Nomenclature

symbols			
A	area (m <sub>2</sub> )	p	pressure (Pa)
C	effective heat capacity of a zone (J/K)	$\dot{V}_{aj}$	air flow (m <sub>3</sub> /s)
$c_a$	specific air heat capacity (J/(kg.K))	U	thermal transmittance (W/(m <sub>2</sub> .K))
$C_D$	discharge coefficient, determines the flow resistance of the opening (-)	v	wind velocity at site (m/s)
		$z_0$	neutral pressure level (m)
$C_p$	surface pressure coefficient, positive at the windward and negative at the leeward side (-)	$\theta$	temperature (°C)
		$\rho$	air density (kg/m <sub>3</sub> )
g	gravity acceleration (m/s <sub>2</sub> )	$\Phi$	heat flow (W)
subscripts			
e	external	i	internal

## REFERENCES

- Allard, F. (ed) (1998). *Natural ventilation in buildings: a design handbook*, James & James, London, UK
- ASHRAE (1993). *Fundamentals Handbook 1993, chapter 23*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, USA
- Grieve, P. W. (1991). *Measuring ventilation using tracer-gases*, Brüel & Kjaer
- Grosso, M. (1995). *Cpcalc<sup>+</sup>: calculation of wind pressure coefficients on buildings: user's manual*, Pascool, Commission of the European Communities Directorate General for Science, Research & Development
- Hensen, J., L., M. (1995). Modeling coupled heat and air flow: ping-pong vs onions, *16th AIVC conference: Implementing the results of ventilation research*, Palm Springs, USA
- Physibel (2000). *Capsol: computer program to simulate multi-zonal dynamic heat transport: users's manual*, Physibel, Maldegem, Belgium
- Standaert, P. (1996). *Coupling Capsol and Comis*, Physibel report 9608A, Physibel, Maldegem, Belgium.
- Vandaele, L. (ed), Vandermarcke, B., Flipts, G., Dousselaere, D., Wouters, P., Schietecat, J. and Schouwenaars, S. (2001). *Modern offices: less energy for more comfort (in Dutch)*, BBRI and Ministry of the Flemish Government, Brussels, Belgium