Assessment of the natural air ventilation of buildings in urban area with the CFD tool UrbaWind

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About the thermal indoor comfort

- The indoor temperature depends on the air change rate and the thermal characteristics of the envelope (conduction, radiation, storage).

- The thermal comfort depends on the indoor temperature, air speed on occupants (>1 m/s, T=>-4°C), Air humidity, activity, clothing.
About the thermal indoor comfort

- A building is well designed according to the thermal comfort criteria if:
  - The Indoor operative temperature is close to the mean outdoor temperature => Standard ASHRAE 55-2010 Criteria
  - The Indoor operative temperature and the air humidity are into the Givoni comfort polygone curves
About the thermal indoor comfort

Example in warm tropical climate: \( T(\text{outdoor}) = 30^\circ \text{C} \); \( T(\text{indoor}) < 32^\circ \text{C} \)

\[ \Delta T = T(\text{indoor}) - T(\text{outdoor}) < 2^\circ \text{C} \]

Questions:
How to reduce the overheating of indoor air?
Who ‘s responsible?
Insulation and ventilation as well
Cross ventilation principles

- Flows go from the highest pressure areas to the lowest pressure areas
- Velocity depends on the root square of the pressure gradient

From CSTB guidelines book (Natural ventilation in tropical warm climate)
The pressure coefficient is a parameter without dimension that depends on the complex interactions between the wind and the building.

\[ C_P = \frac{P - P_{\text{ref}}}{\frac{1}{2} \rho U_{\text{ref}}^2} \]

Upstream face: \( C_P \) from 0.5 to 0.8

Downstream face: \( C_P \) from -0.5 to -0.3

Side faces: \( C_P \) from -1 to -0.3

Pressure = engine of the cross ventilation
How to assess the air change rate?

Air change rate and indoor velocity fundamentally depend on the external wind pressure at the openings.

\[ Q = \sqrt{\frac{C_{p1} - C_{p2}}{1} \frac{1}{A_1^2 C_1^2 + A_2^2 C_2^2}} U_{WIND} = A_{eq} \sqrt{C_{p1} - C_{p2}} U_{WIND} \]

Basic formula for crosswind ventilation (one volume, 2 openings)

- \( A_{eq} \) = Aerodynamic area of the openings
- \( U_{wind} \) = wind speed
- \( C_{p1} \) et \( C_{p2} \): pressure coefficients

We need \( U_{WIND} \) and \( C_p \) to calculate the mass flow rate.

Tables (Liddament, Eurocode) and parametric models can be used for standard cases, that means for simple, detached and isolated buildings.
How to assess the air change rate?

In urban configurations, wind velocity and pressure on buildings may not be easily evaluated. **Tables and analytic models can not be used.**

- Experimental approach (Wind tunnel)
- Numerical approach (CFD)

Mass flow rate could be evaluated with a network model. The inputs are:
- External pressure field
- Characteristics of openings (A,C)
- Indoor volume dimensions
Find a tool for modeling the flow over complex terrains, in urban area, into buildings... Lots of applications

The effects created by the buildings make the modeling of urban flows more difficult.

Some typical effects:

- Vortex at the base of the towers
- High wind speed near the edges of the upwind face
- Wake effects behind a building
- Speed up in pedestrian ways under a building and between buildings

Meteodyn developed UrbaWind, an automatic CFD software for computing the wind between buildings... as well as possible
UrbaWind solves the averaged equations of mass and momentum conservations (Navier-Stokes equations) for steady flow and the incompressible fluids.

The CFD calculation computes the outside flow and the pressure field for every wind direction.

**Velocity field**

**Pressure field**
The CFD Tool: Air Change Rate

The Network calculation computes ACH based on CFD pressure field

The indoor pressure $P_i$ is unknown and the flow rates through the openings are solved by a Newton-Raphson iterative process.

$$P_i^{n+1} = P_i^n - \omega F(P_i^n) / F'(P_i^n)$$

where $F(P_i)$ is the first derivative of $F(P_i)$ with respect to $P_i$, and $\omega$ is an under-relaxation coefficient.

In the case of a multi-volume configuration, the $k$ openings’ aerodynamic area $A_k$ is replaced by an equivalent aerodynamic surface taken into account the door aerodynamic surface $A_{door}$.
The CFD Tool: Air Change Rate

The Network part computes ACH based on CFD pressure field. UrbaWind provides wind roses, distribution, and time series of the air change rate.

**WIND**

**VENTILATION**
Example n°1

Round robin test

CFD vs experiments (scaledown model)
Round robin test case

Experimental measurements in Wind tunnel

*French Working Group for Natural Ventilation Standardization*

- Detached simple house
- Sub-urban wind
- Pressure and mass flow rate comparisons
Pressure correlation CFD/Experience

Pressure coefficient correlation Exp vs UrbaWind

\[ y = 1.0235x + 0.0035 \]

\[ R^2 = 0.9438 \]
Mass flow rate correlation CFD/Experience

Cross configuration – 2 Windows

\[ <\text{ACH}> \text{ (UW)} = 9 \text{ vol/h} \]
\[ <\text{ACH}> \text{ (Exp)} = 10 \text{ vol/h} \]
Mass flow rate correlation CFD/Experience

Full cross configuration – 4 Windows

<ACH> (UW) = 18 vol/h
<ACH> (Exp) = 21 vol/h
Example n°2

Natural ventilation of a urban block
La Réunion Island
Renovation of urban districts
Natural ventilation potential

First step: Numerical simulations of the wind flow into the urban area

Time of computations: 30’/wind direction
500000 cells
Renovation of urban districts
Natural ventilation potential

Second step: ACH computations (time step: every hour of a year)
**Renovation of urban districts**

**Natural ventilation potential**

<table>
<thead>
<tr>
<th>CASES</th>
<th>&lt;ACH&gt;</th>
<th>ACH (P&lt;0.05)</th>
</tr>
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<tbody>
<tr>
<td>North: 3 windows</td>
<td>65 Vol/h</td>
<td>9 Vol/h</td>
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<td></td>
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<tr>
<td>Doors: enlarged</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North: 3 windows</td>
<td>105 Vol/h</td>
<td>15 Vol/h</td>
</tr>
<tr>
<td>South: 2 windows</td>
<td></td>
<td></td>
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<tr>
<td>(1.4 m² + 1 m²)</td>
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Third step: ACH statistics

Parameters:
- Position of the openings
- Wall porosity
- Area of the windows
- Internal porosity
- Area of the doors
- Area of the internal openings

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Example n° 3

Summer night cooling for an industrial building (wind and stack effects mixed)
Natural air ventilation (wind and stack effects)
Natural air ventilation (wind effects)

- NE wind, NE view
- SW wind, NE view
- NE wind, SO view
- NE wind, SW view

Pressure coefficient

Simulation with software "UrbaWind"
### Natural air ventilation (wind effects)

#### Summer Free Cooling

<table>
<thead>
<tr>
<th></th>
<th>SUMMER</th>
<th>FREE COOLING</th>
</tr>
</thead>
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<tr>
<td>Average ACH</td>
<td>9600 m$^3$/h – ACH = 2.0 vol/h</td>
<td>7600 m$^3$/h ACH = 1.6 vol/h</td>
</tr>
<tr>
<td><strong>INDUSTRIAL AREA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input door</td>
<td>4830 m$^3$/h</td>
<td>4300 m$^3$/h</td>
</tr>
<tr>
<td>Output door</td>
<td>4290 m$^3$/h</td>
<td>2910 m$^3$/h</td>
</tr>
<tr>
<td>Average ACH</td>
<td>3860 m$^3$/h ACH = 6.7 vol/h</td>
<td>2900 m$^3$/h ACH = 5.1 vol/h</td>
</tr>
<tr>
<td><strong>OFFICE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input door</td>
<td>2000 m$^3$/h</td>
<td>1600 m$^3$/h</td>
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Natural air ventilation (wind and stack effects)
Add thermal pressure gradient due to stack effects

Tall volume (ACH +15%)
2 storeys building (ACH +40%)
Example n° 4

Natural ventilation of a secondary school
Kourou – French Guiana
Whole geometry of the secondary school

Optimisation of the cooling of the class rooms

• depends on the configuration (line, V or grid)
• depends on the windows positions and aerodynamic behaviors
Pressure potential depends on configuration configuration

$\Delta CP = 0.8 \quad \Delta CP = 0.9 \quad \Delta CP = 1.1$

(href=10 m)
Mean speed up factor

Mean pressure coefficient
Two louvers with sizes 1x2 m² and 2x2 m² (downstream)

\[ \Rightarrow ACH \text{ average } = 71 \text{ Vol/h} \]

\[ \Rightarrow 18\% \text{ of time with } ACH < 30 \text{ Vol/h} \]
Decreasing of the air change rate compared to the detached configuration without the main buildings:

-18%  
-22%  
-6%   
-9%
Further data for thermic tools

- ACH Statistics for average models
  Distribution, frequency, mean, RMS
  Day and night data, monthly…
- Indoor air velocity statistics

- Time series for the dynamic thermic models
  Mass flow rate for each opening
Others examples
Architectural design competition assistance

Validation of the project designed by the architect according to the local climatology

Assistance to define the ventilation strategy

Wind pressure on buildings
Choice of the openings
Ventilation strategy
Diagnostic of the preliminary project design

Validation of the project proposed by the Project designer to the Project owner

Diagnostic of the building ventilation scenario and mass flow assessment

Visualization of the natural ventilation potential
From the preliminary to the detailed project design

Validation of the project

Visualization of the natural ventilation potential and diagnostic

Interior architectures and openings validation

Data extraction for thermal software
Design of “green” district

Planners’ project

Time of computations:
- 120’/wind direction
- 3 Millions cells

Natural ventilation potential of the buildings

Diagnostic of the ventilated buildings => Proposal of a new improved version
Keep in touch

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