

## Context and Objectives

Natural ventilation of a building is driven by the combined forces of wind and thermal buoyancy. When opening areas are large enough, and except for high volumes, the natural ventilation is mainly driven by the wind forces. In tropical warm climates, the coupling between the thermal forces and the wind driven forces is generally assumed as negligible.

Air exchanges across buildings openings depend on:

- wind speeds in the urban area (regional wind climatology)
- buildings shapes (pressure coefficients on external walls)
- openings efficiency (geometric area and discharge coefficient)
- internal design (indoor pressure losses)

**Challenge for designers: choose the most appropriate openings strategy to improve the air change rate and optimize the thermal comfort according to the local climatology**

**Main purpose : Introduce a combined CFD-Network method in UrbaWind**

- To compute automatically the pressure fields on the building envelop and the air exchanges associated according to the urban climatology
- To include the indoor design with a simplified network model
- To deliver statistical data of the air change rate to assess the thermal comfort

## Methods

**The CFD part to compute the outside flow and the pressure field**

UrbaWind solves the averaged equations of mass and momentum conservations (Navier-Stokes equations) for steady flow and the incompressible fluids:

$$-\frac{\partial(\rho \bar{u}_j \bar{u}_i)}{\partial x_j} - \frac{\partial \bar{P}}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) - \rho \bar{u}'_i \bar{u}'_j \right] + F_i = 0$$

The turbulent fluxes are parameterized by using the turbulent viscosity considered as the product of a length scale by a speed scale which are both characteristic lengths of the turbulent fluctuations.

$$\frac{\partial}{\partial x_i} \left[ \rho \bar{u}_i k - \left( \frac{\mu_T}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right] = \mu_T \left( \frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) \frac{\partial \bar{u}_j}{\partial x_j} - C_\mu \frac{k^{3/2}}{L_T} \text{ and } \mu_t = \rho k^{1/2} L_T$$

The generation of the boundary conditions is automatic. The vertical profile of the mean wind speed at the computation domain inlet is given by the logarithmic law in the surface layer, and by the Ekman function ([1]). A 'Blasius'-type ground law is implemented to model frictions (velocity components and turbulent kinetic energy) at the surfaces (ground and buildings). The non-structured solver MIGAL-UNS is used in UrbaWind. It is a fast and robust coupled multi-grid algebraic solver which allows a complete resolution of 3D equations for fluid mechanics (RANS method).

The CFD code delivers mean velocity, mean pressure and turbulence intensity ([2]).

**The Network part to compute the air change rate based on CFD pressure field**

When using the Network approach, the indoor pressure  $P_i$  is unknown and the flow rates through the openings are solved by an Newton-Raphson iterative process ([3]). First step: at the iteration  $n$ , the flow rates  $Q_k$  for openings  $k$  are computed by:

$$|Q_k^n| = A_k \sqrt{2|P_k - P_i^n|/\rho}$$

Second step, the outflow rates are updated by solving the equation

$$F(P_i) = \sum_k Q_k^n = 0$$

with a Newton-Raphson iterative method, the internal pressure at step  $n+1$  being calculated as :

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

where  $F(P_i)$  is the first derivative of  $F(P_i)$  with respect to  $P_i$ , and  $\omega$  is an under-relaxation coefficient. The flow rates are adjusted and the iteration is stopped when convergence is achieved.

In the case of a multi-volumes configuration, we distinguish the main room with multiple openings and the secondary rooms with only one door to the main room. The aerodynamic surface  $A_k$  of the opening  $k$  is replaced by an equivalent aerodynamic surface taken into account the door aerodynamic surface  $A_{door}$  with :

$$A_k^{eq} = 1 / \sqrt{\frac{1}{A_k^2} + \frac{1}{A_{door}^2}}$$

## Results : simple example

Example of computation on a detached simple house located in countryside

**1. Computation of mean pressure field (UrbaWind)**

Mean  $C_p$  values close to the values for low rise buildings (AIVC, [4])

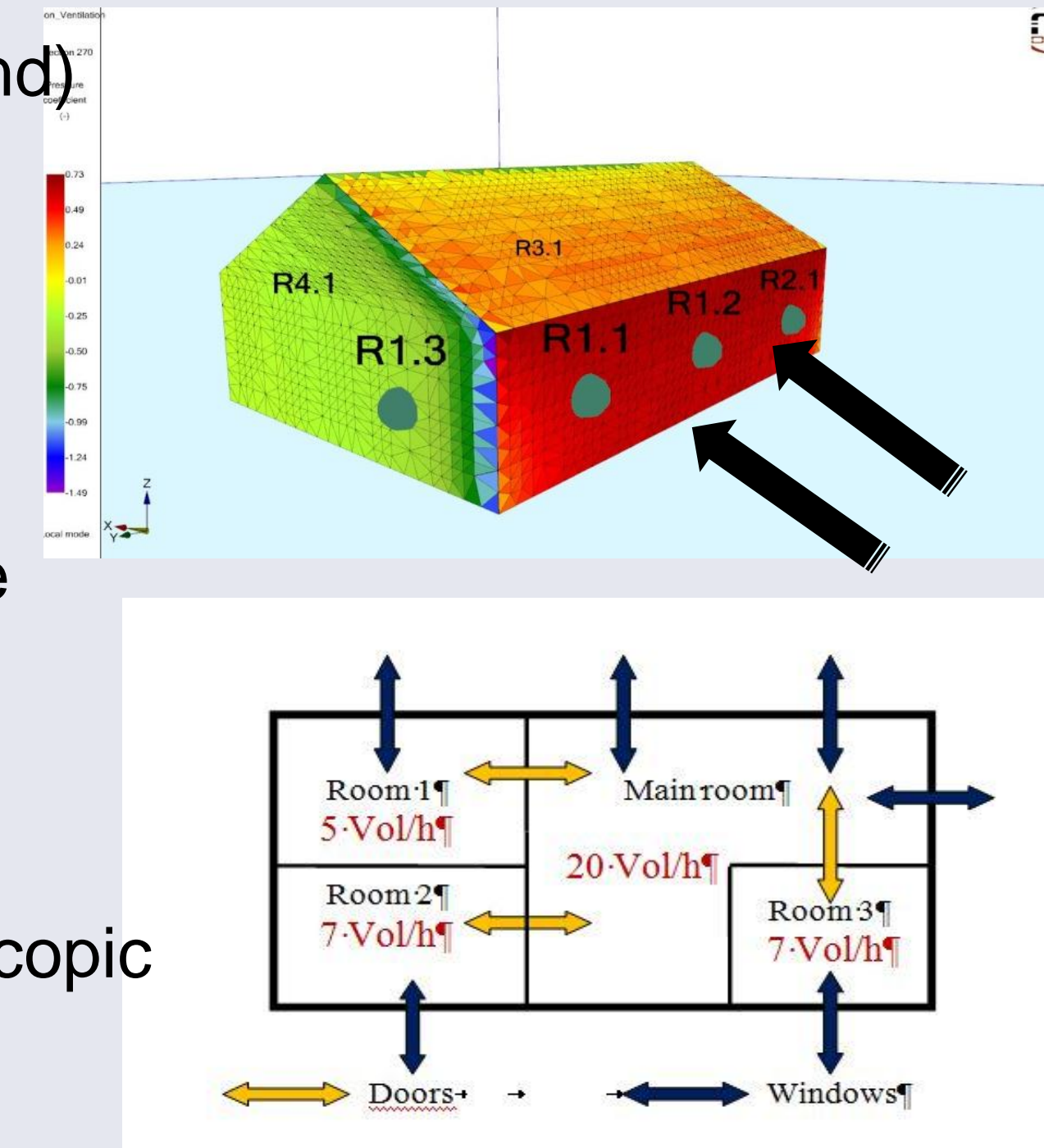
$$C_{puw}=0.7 \quad C_{pside}=-0.35 \quad C_{pdw}=-0.4;$$

**2. Computation of Air Change Rate ACH with the natural ventilation tool**

By including to the local climatology (Wind roses)

By including internal pressure losses in the macroscopic approach

Ex : doors area=windows area = 2 m<sup>2</sup> => Internal pressure losses reduce ACH by 20%

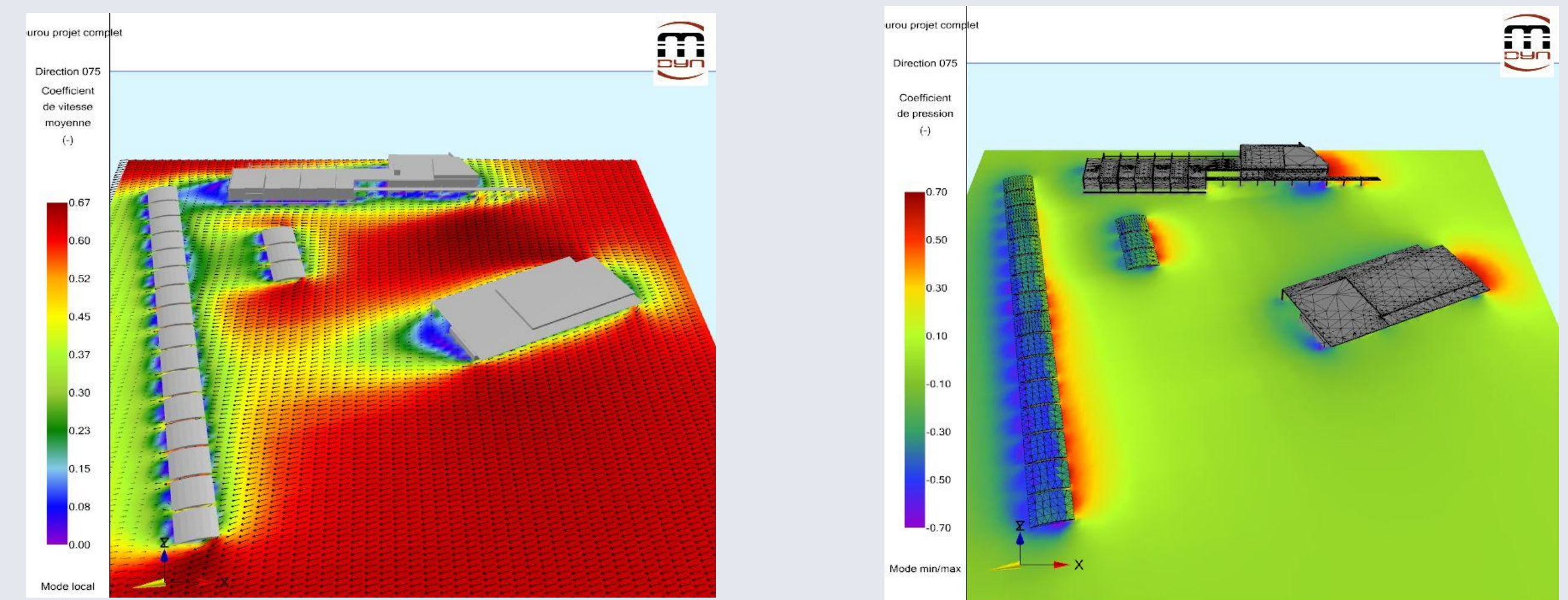


## Results : design application

**Assess the natural ventilation in new designed class rooms according to the local climatology (weak trade winds) and by including the neighbouring buildings**

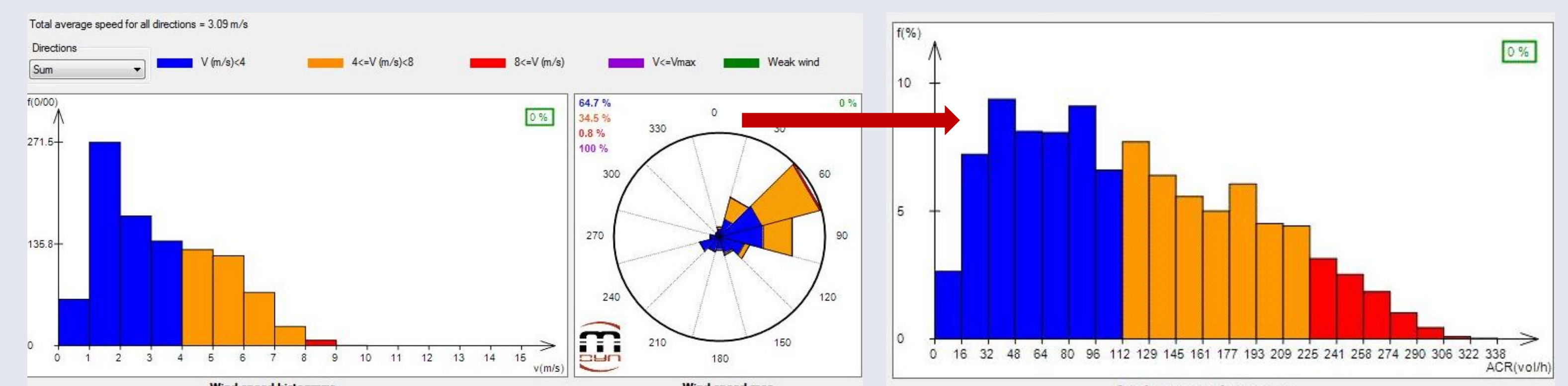
1. Uploading of the buildings geometries and computation of the flow

Velocity field and the mean pressure coefficient field for many wind directions

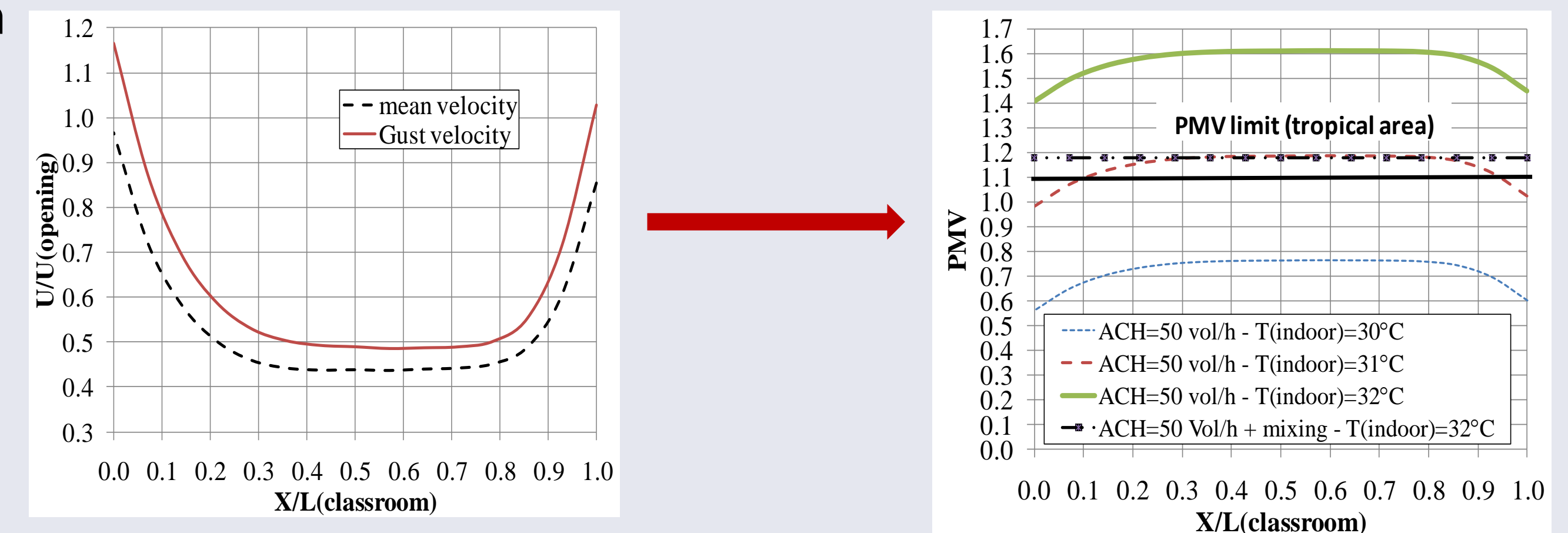


2. From the local climatology to the indoor thermal comfort (design tool for building)

Wind roses and distribution give distribution of Air Change Rate throw UrbaWind



Indoor velocity on occupants (CFD and [5]) and PMV comfort index ([6]) into the class room



## Conclusions

Urbawind was upgraded to introduce a cross ventilation tool based on a mixed CFD-Network approach. The software first computes the pressure fields on the building for every wind incidence with the wind reference velocity, then evaluates air exchanges for each climatology event and finally builds statistical data of the air exchanges as inputs for thermal tools for thermal comfort assessment.

## References

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3. Deru M., Burns P., 2003, Infiltration and natural ventilation model for whole-building energy simulation of residential buildings, March 2003, Conference Paper, NREL/CP 550-33698
4. Liddament, M. W., 1986, Air Infiltration Calculation Techniques, An Applications Guide, AIVC.
5. Karava P., Stathopoulos T., Athienitis A.K., 2010, Airflow assessment in cross-ventilated buildings with operable façade elements, Building and Environment, 1-14
6. Wang L., Wong N.H., 2006, The impacts of ventilation strategies and façade on indoor thermal environment for naturally ventilated residential buildings in Singapore, Buildings and Environment,