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

**Dr Stéphane SANQUER**

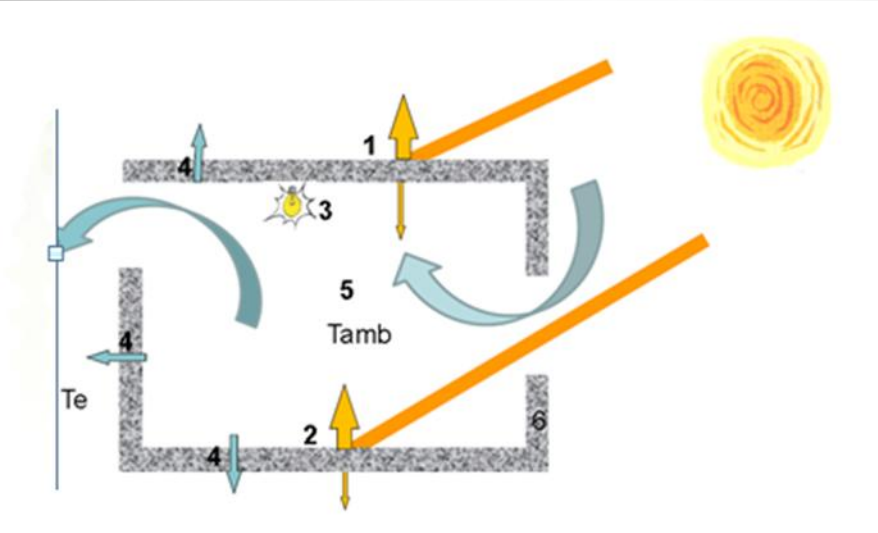
***Meteodyn***

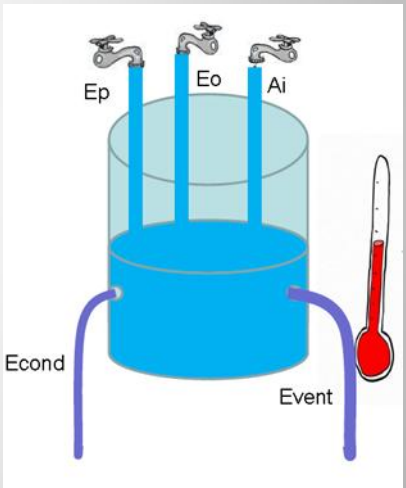
www.meteodyn.com

info@meteodyn.com

# 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

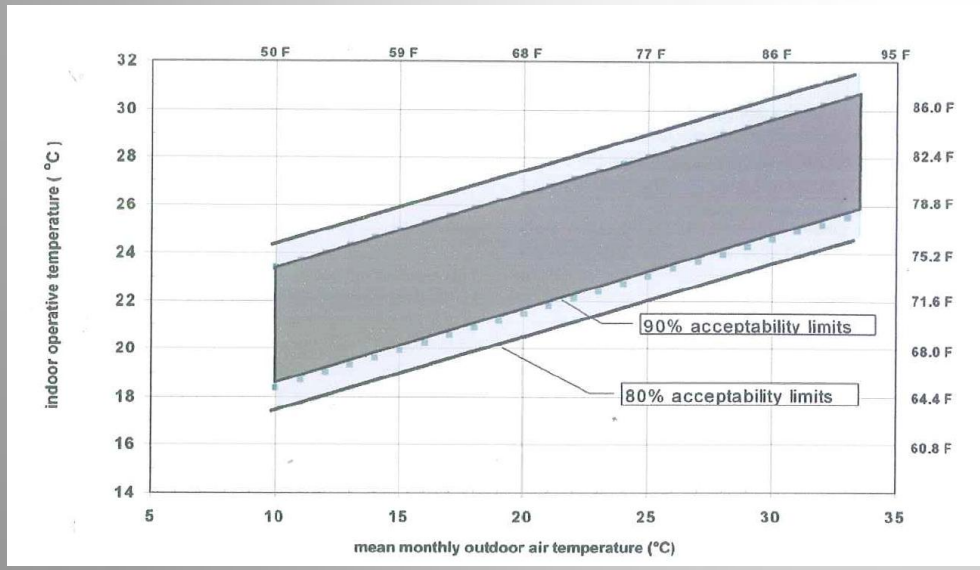
# About the thermal indoor comfort

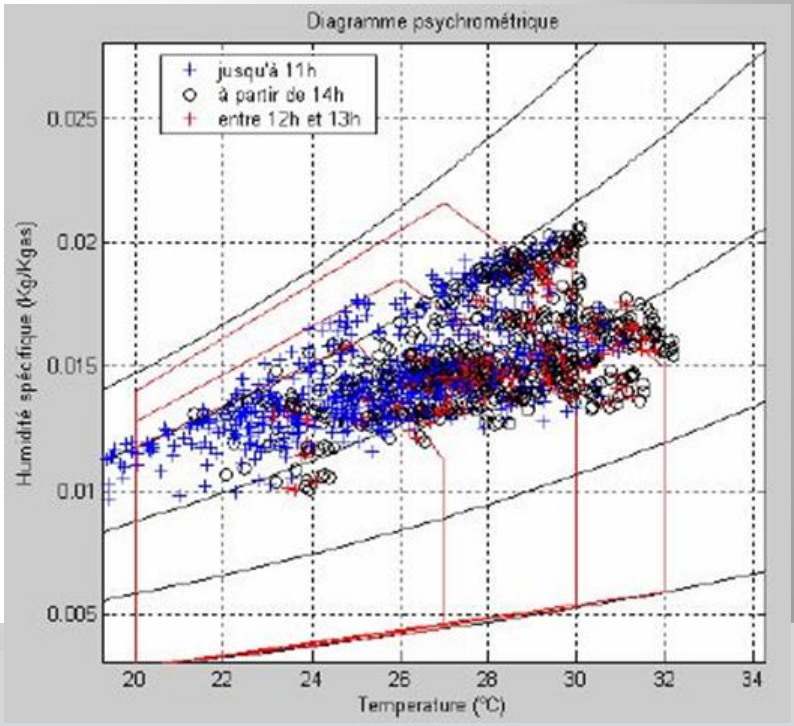
- A building is well designed according to the thermal comfort criteria if :

- 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



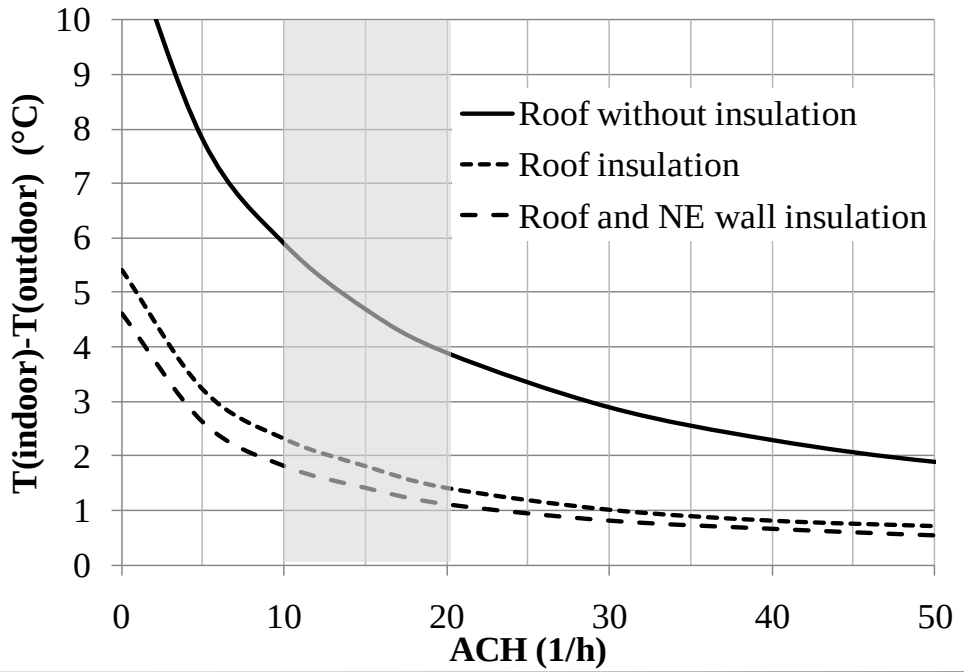
# About the thermal indoor comfort

Example in warm tropical climate : T(outdoor)=30°C ; T(indoor)<32°C
=> ΔT=T(indoor)-T(outdoor)<2°C

Questions : How to reduce the overheating of indoor air?

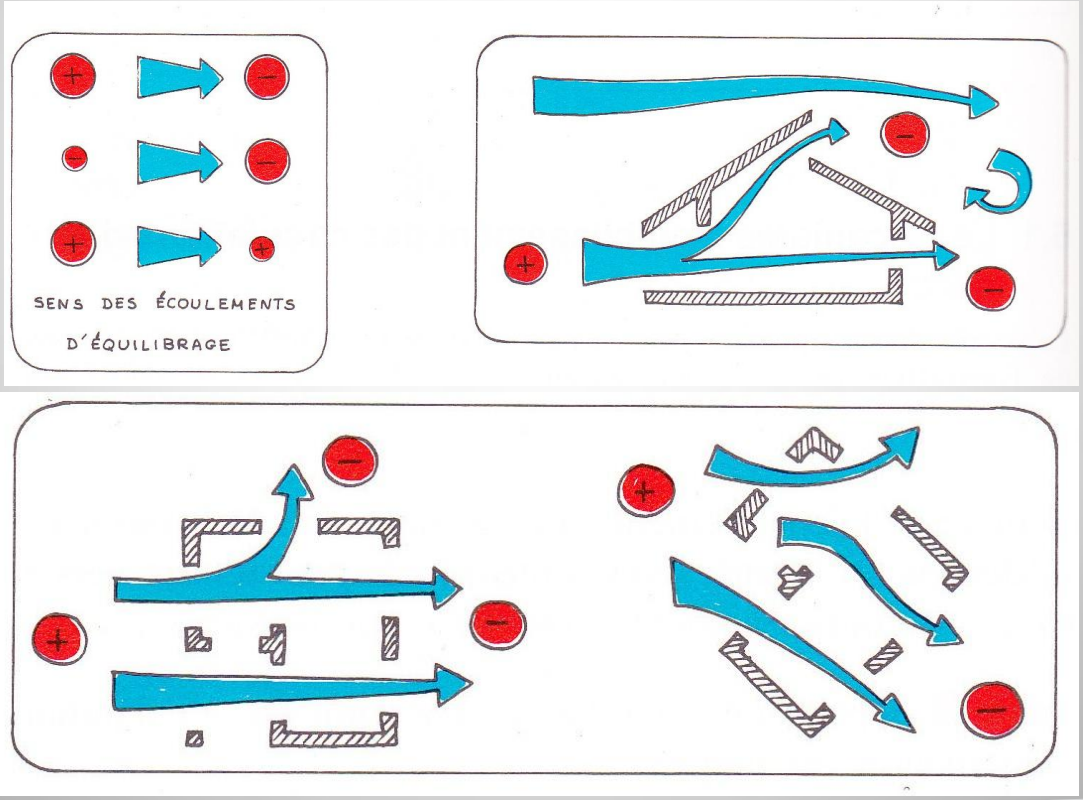
Who ‘s responsible?

Insulation and ventilation as well



# Cross ventilation principles

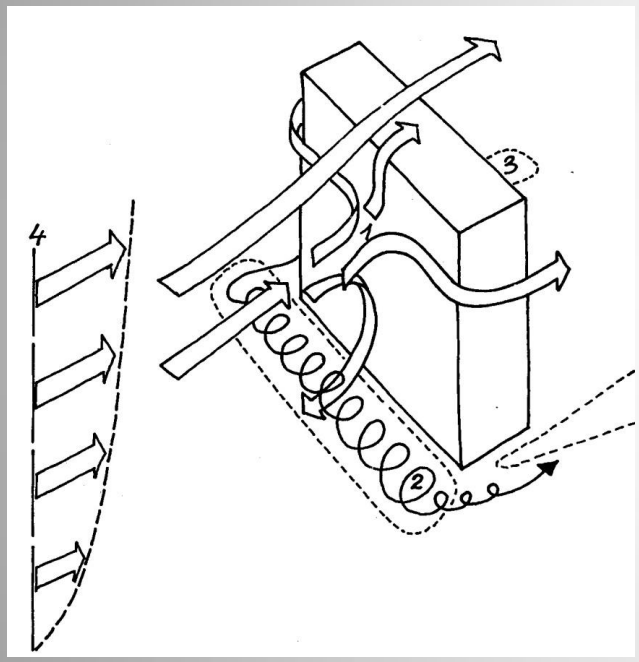
- Flows go from the highest pressure areas to the lowest pressure areas
- Velocity depends on the root square of the pressure gradient



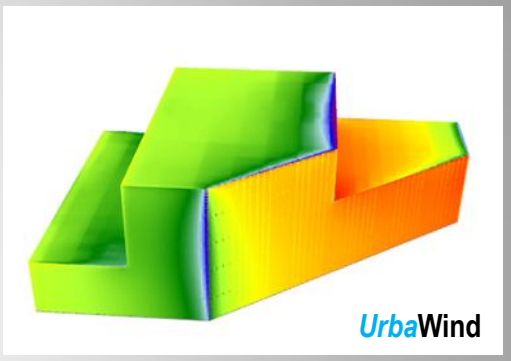

*From CSTB guidelines book (Natural ventilation in tropical warm climate)*

# Pressure = engine of the cross ventilation

The pressure coefficient is a parameter without dimension that depends on the complex interactions between the wind and the building




$$C_P = \frac{P - P_{ref}}{\frac{1}{2}\rho U_{ref}^{\ 2}}$$




Upstream face : Cp from 0.5 to 0.8

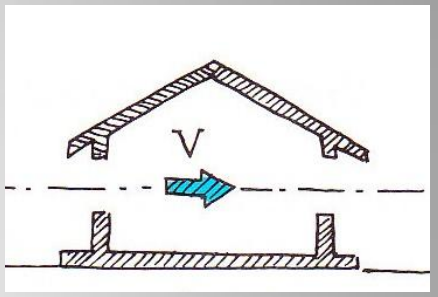
Downstream face: Cp from -0.5 to -0.3

Side faces: Cp from -1 to -0.3

# How to assess the air change rate ?

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

$$Q = \sqrt{\frac{Cp_1 - Cp_2}{\frac{1}{A_1^2 C_1^2} + \frac{1}{A_2^2 C_2^2}}}\, U_{WIND} = A_{eq}\sqrt{Cp_1 - Cp_2}\, U_{WIND}$$




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 $Cp$ 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)

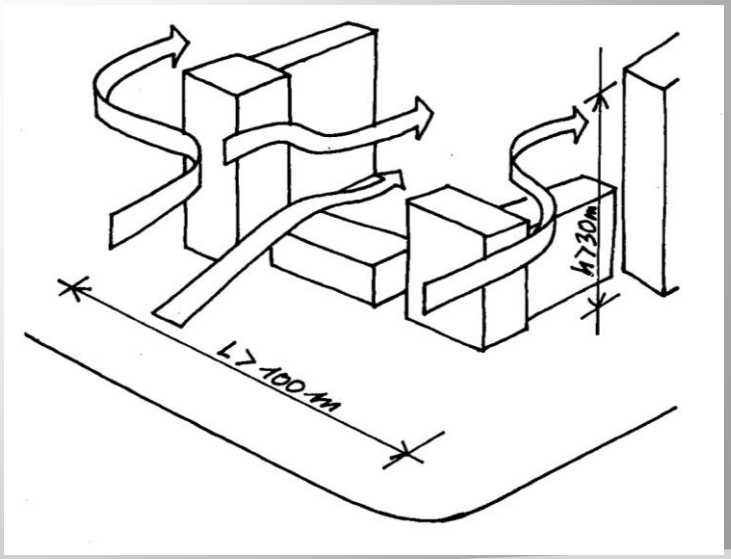
✓Numerical approach (CFD)

Mass flow rate could be evaluated with a network model. The inputs are :

-External pressure field

-Characteristics of openings (A,C)

-Indoor volume dimensions

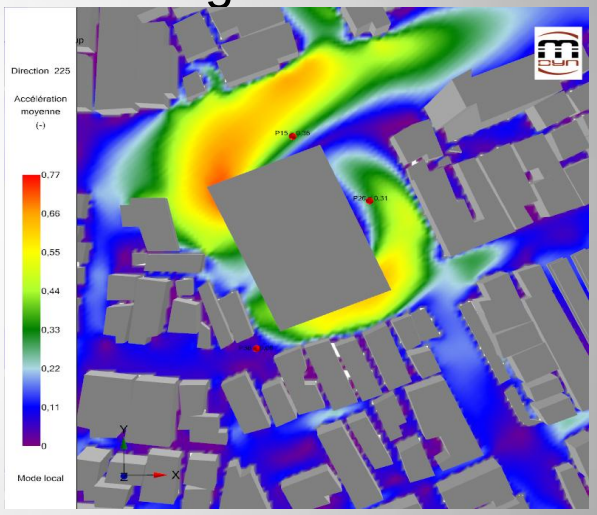


# Challenge in Wind Enginering

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.




UrbaWind

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

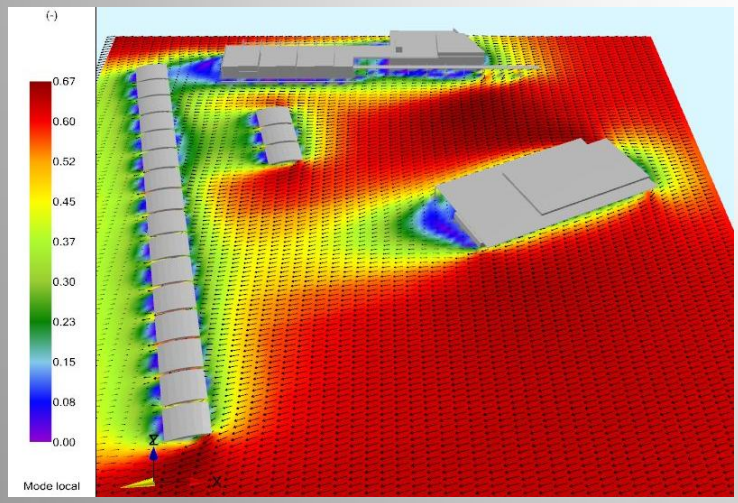
Meteodyn developed UrbaWind, an automatic CFD software for computing the wind between buildings…as well as possible

# *The CFD Tool: Directional computations*

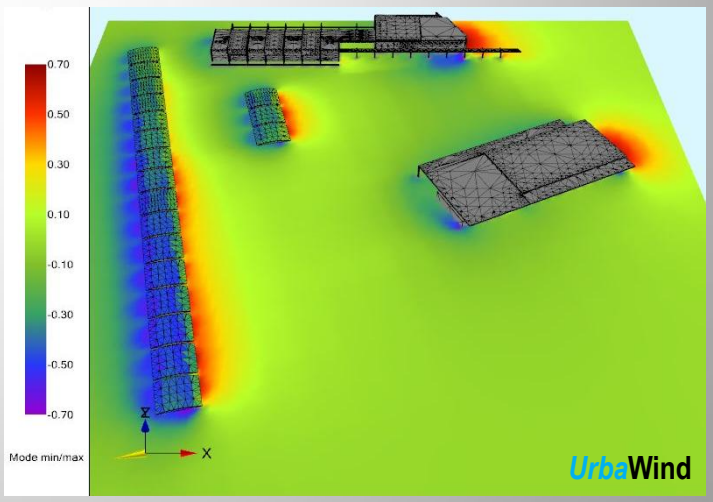
UrbaWind solves the averaged equations of mass and momentum conservations (Navier-Stokes equations) for steady flow and the incompressible fluids.

**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

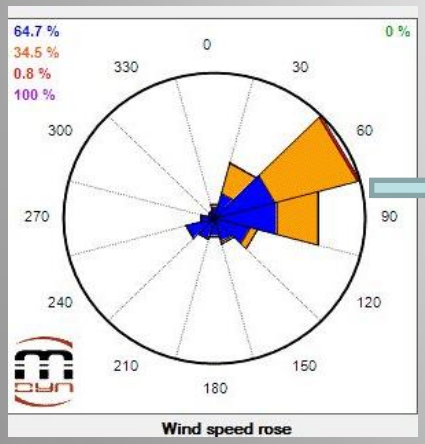
**The Network calculation computes ACH based on CFD pressure field**

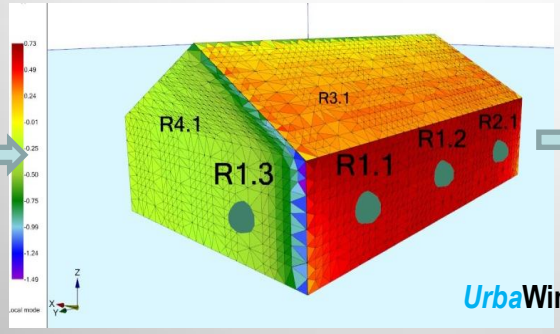
The indoor pressure *Pi* is unknown and the flow rates through the openings are solved by a Newton-Raphson iterative process.

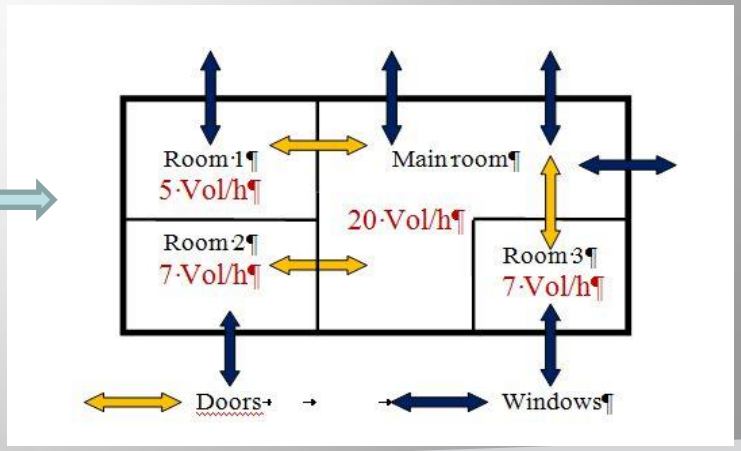
$$P_i^{n+1} = P_i^n - \omega F\left(P_i^n\right) / F'\left(P_i^n\right)$$

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

In the case of a multi-volume configuration, the k openings' aerodynamic area *Ak* is replaced by an equivalent aerodynamic surface taken into account the door aerodynamic surface $A_{door}$



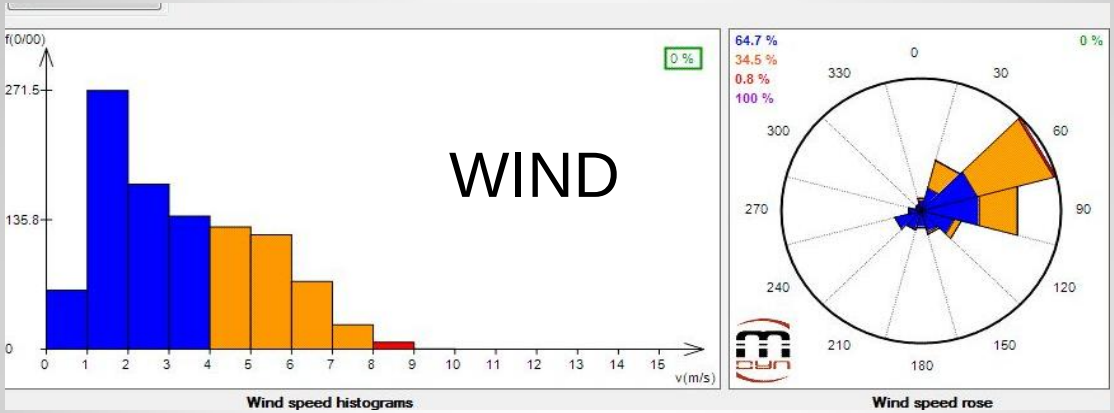



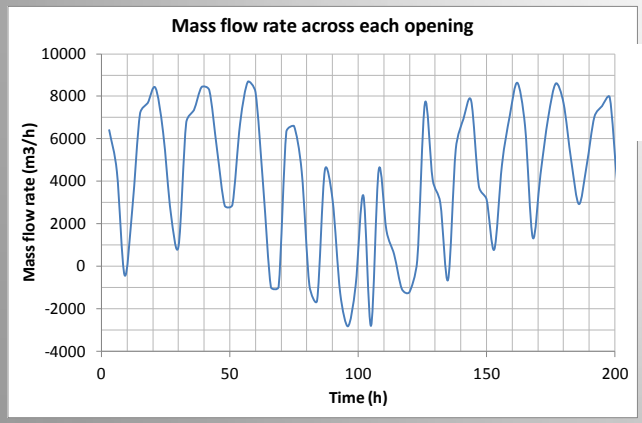



# The CFD Tool: Air Change Rate

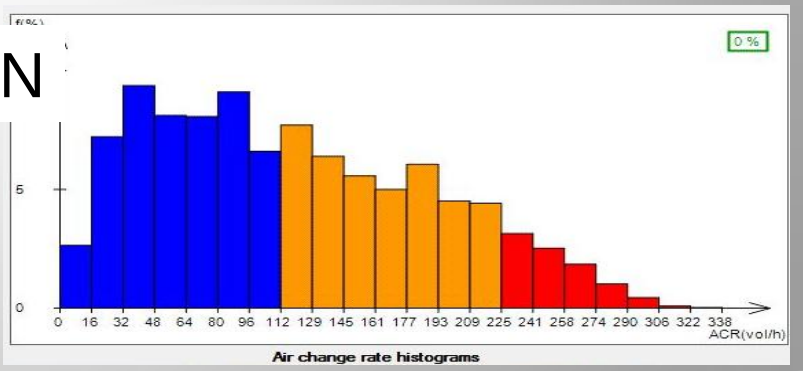
**The Network part computes ACH based on CFD pressure field**

**Urba*Wind*** provides wind roses, distribution and time series of the air Change Rate




VENTILATION



meteodyn
meteorology & dynamics

*Example n°1*

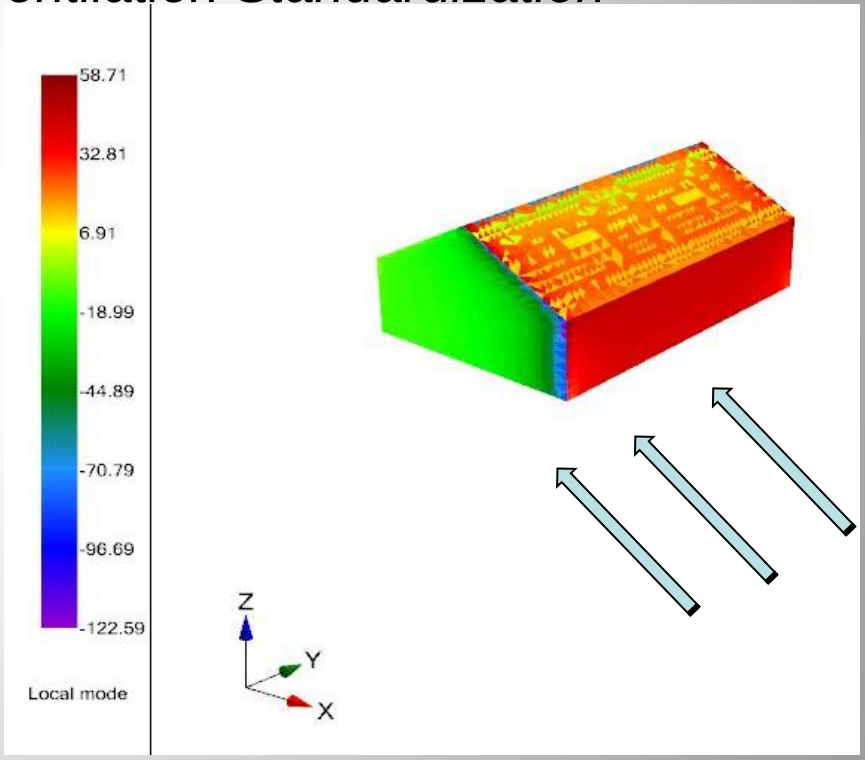
# Round robin test
# CFD vs experiments (scaledown model)

# Round robin test case

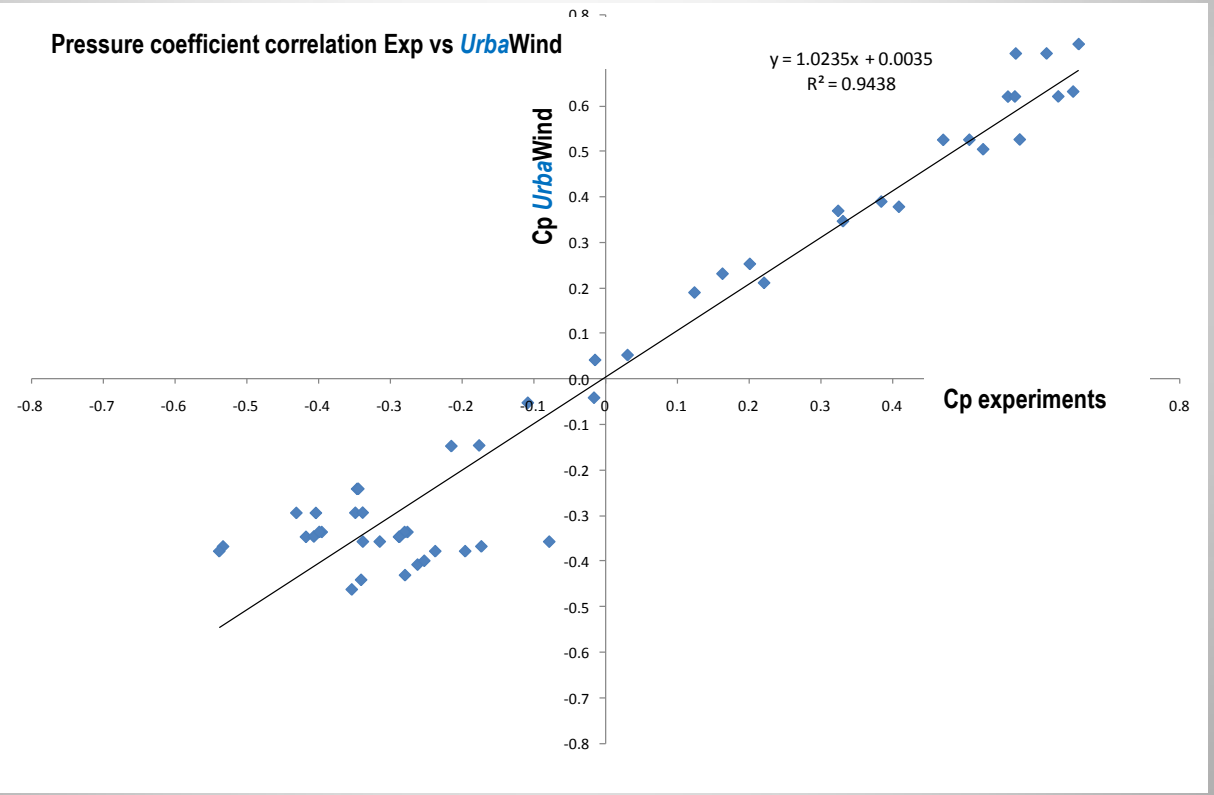
Experimental measurements in Wind tunnel

*French Working Group for Natural Ventilation Standardization*

- ✓ Detached simple house
- ✓Sub-urban wind
- ✓Pressure and mass flow rate comparisons

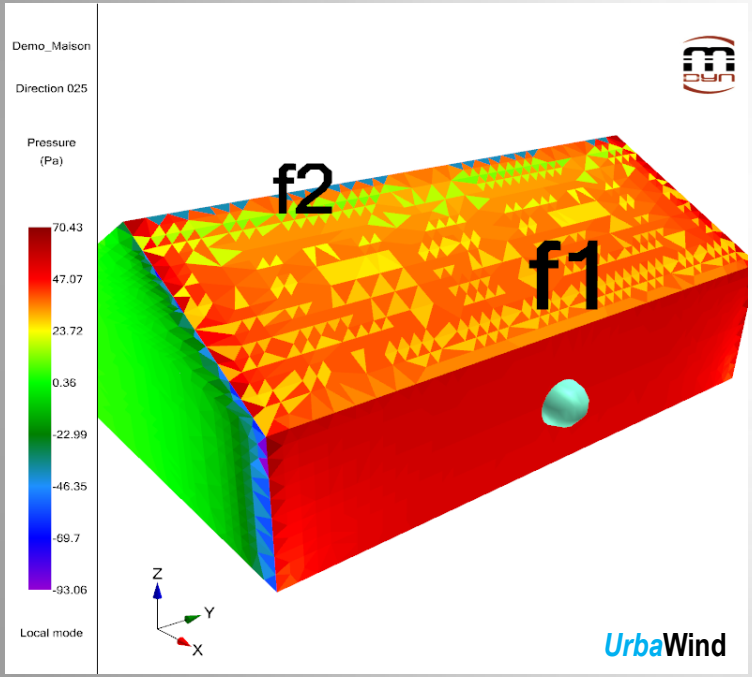


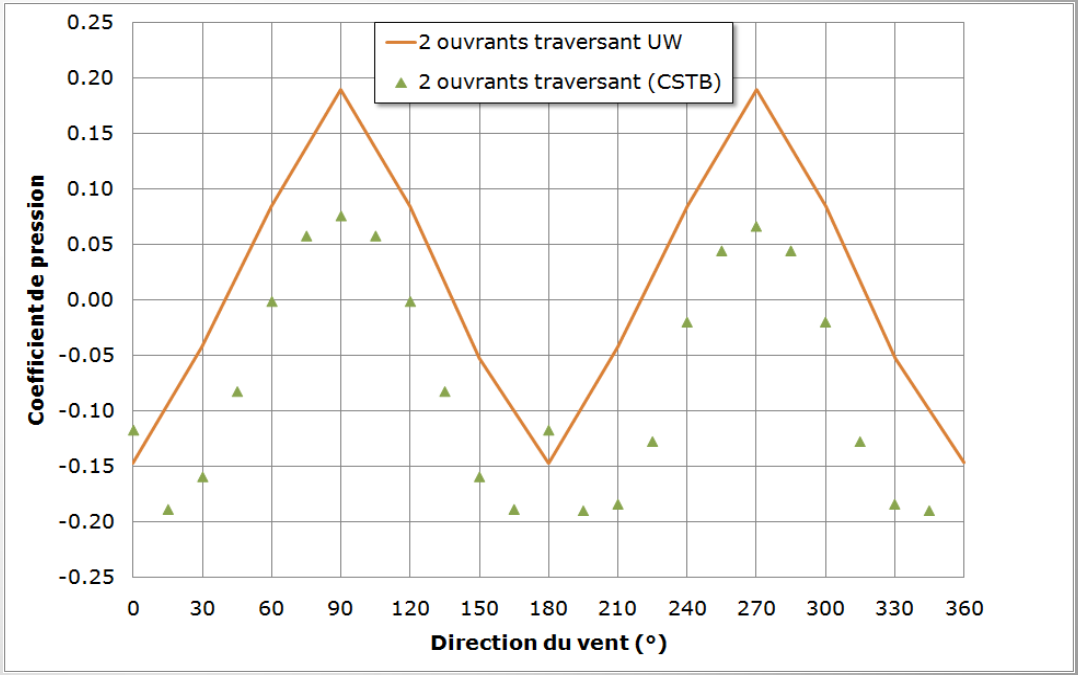
# Pressure correlation CFD/Experience



# *Mass flow rate correlation CFD/Experience*

Cross configuration – 2 Windows



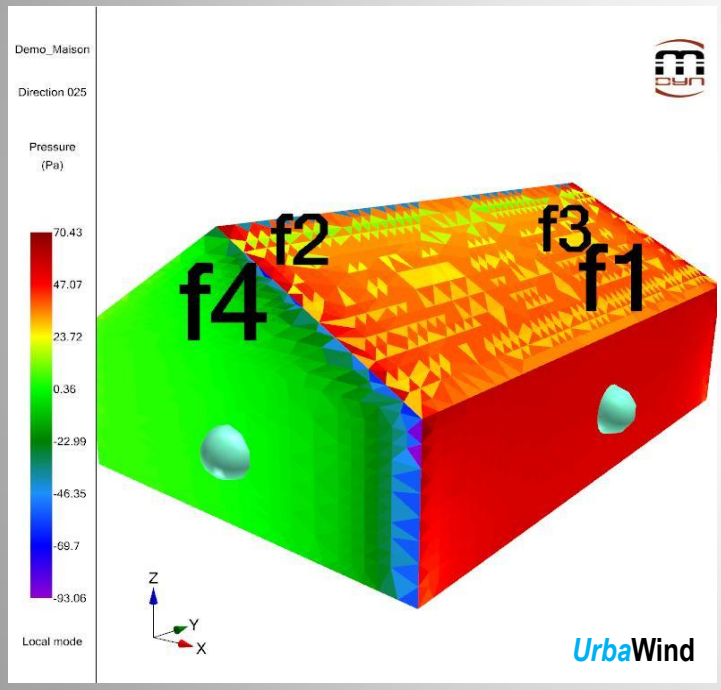



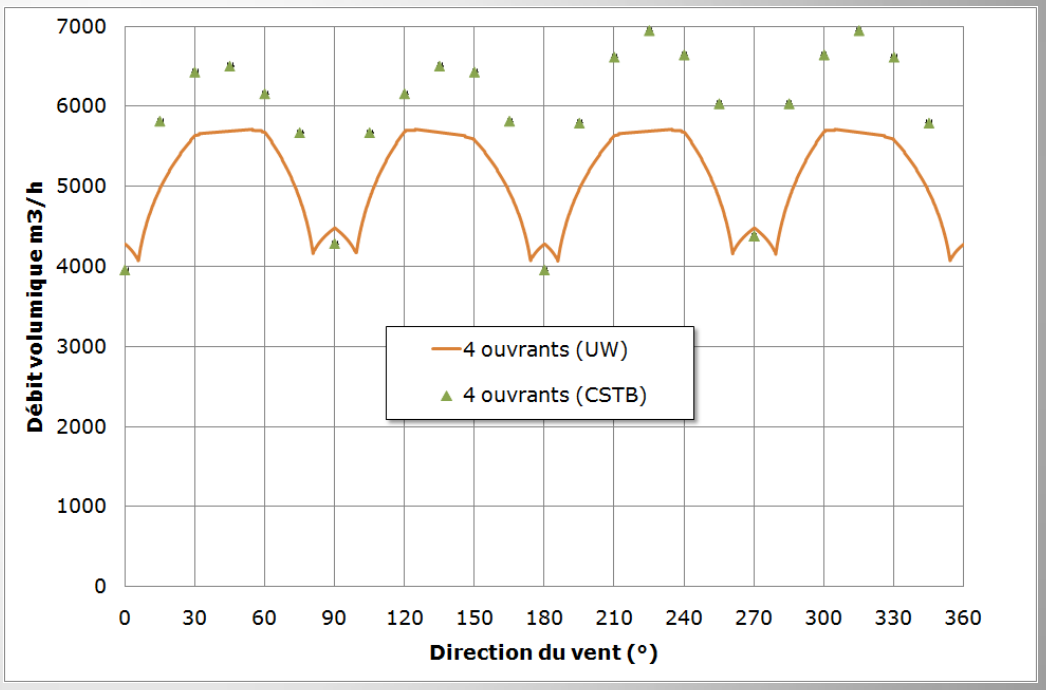

<ACH> (UW)=9 vol/h

<ACH> (Exp)=10 vol/h

# *Mass flow rate correlation CFD/Experience*

Full cross configuration – 4 Windows




<ACH> (UW)=18 vol/h

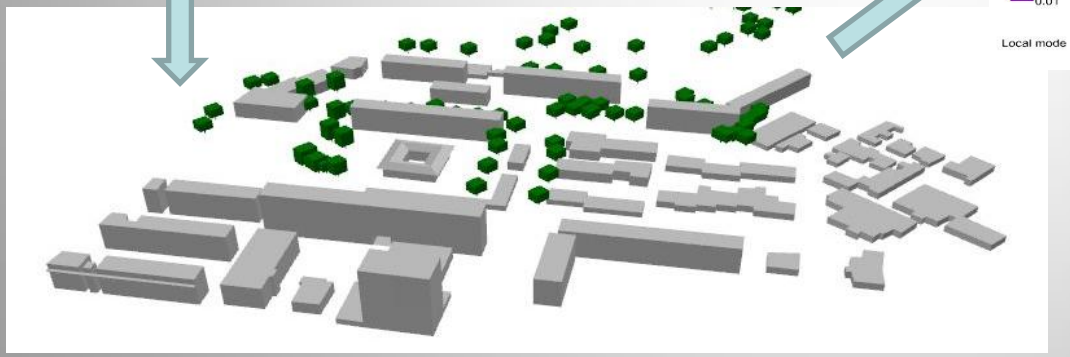
<ACH> (Exp)=21 vol/h

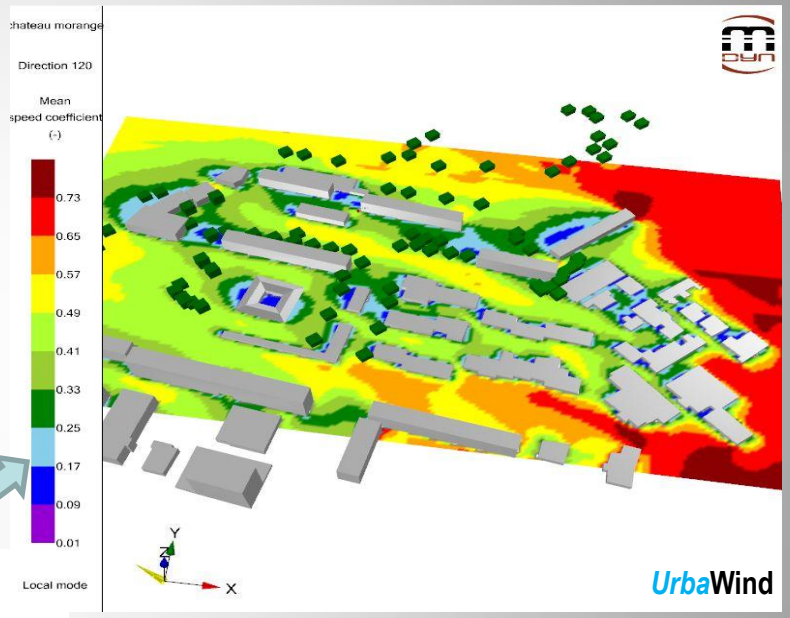
*Example n°2*

# 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



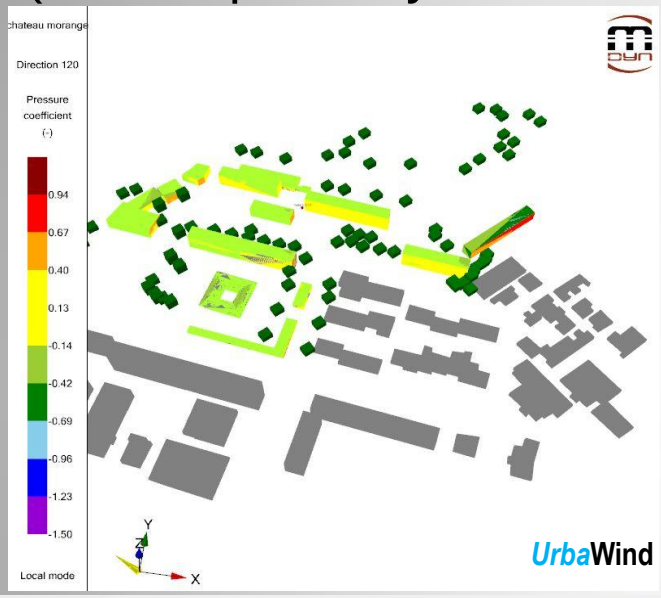


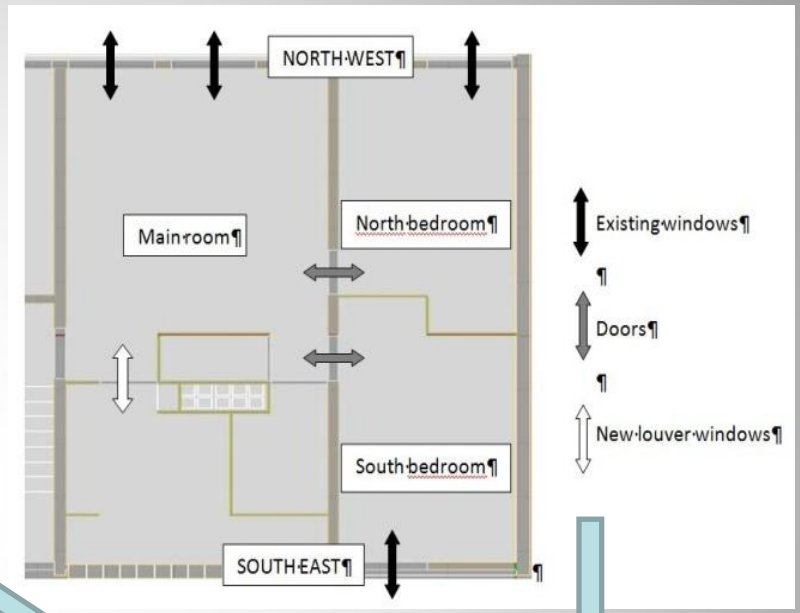

Time of computations :
30'/wind direction

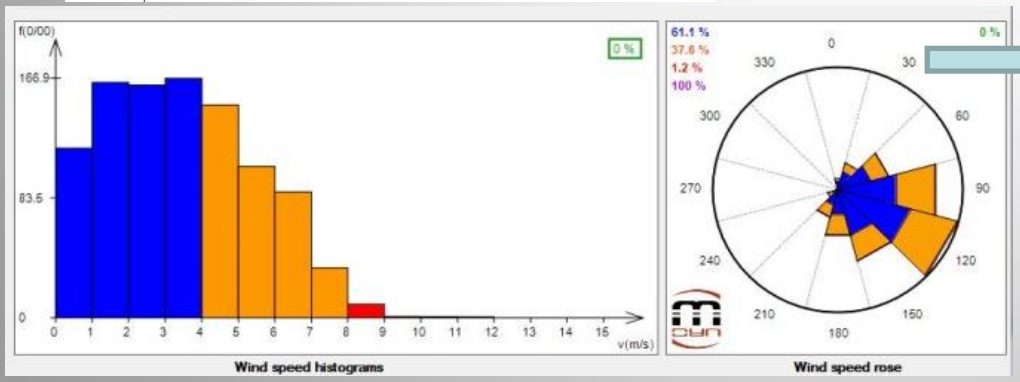
500000 cells

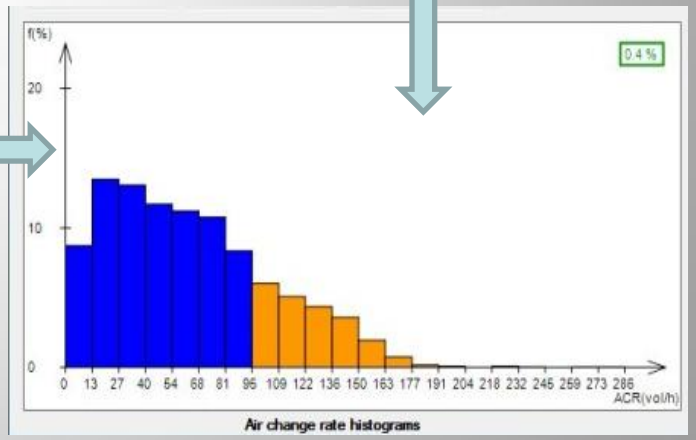
# Renovation of urban districts
# Natural ventilation potential

Second step: ACH computations
(time step : every hour of a year)



# Renovation of urban districts
# Natural ventilation potential

Third step: ACH statistics

Parameters:

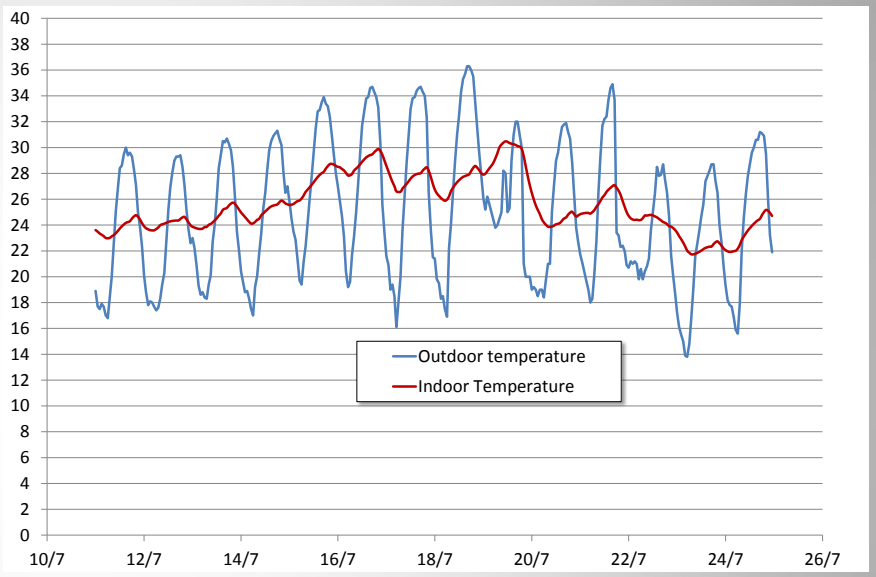
- Position of the openings
- Wall porosity
  Area of the windows
- Internal porosity
  Area of the doors
  Area of the internal openings

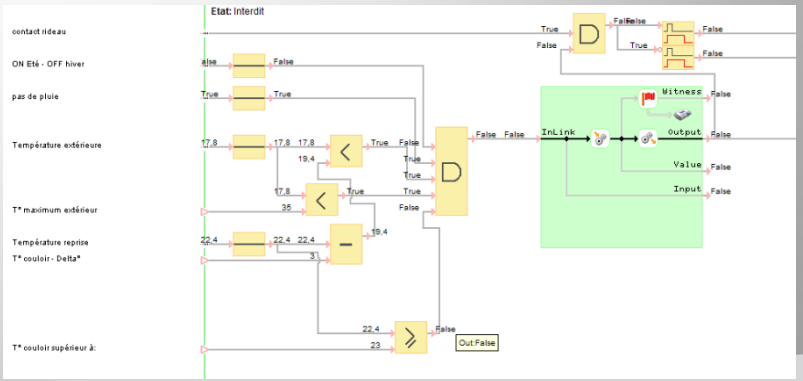
| CASES | <ACH> | ACH (P<0.05) ACH MINI |
|---|---|---|
| North: 3 windows<br>South: 1 window<br>Doors: opened | 65 Vol/h | 9 Vol/h |
| North: 3 windows<br>South: 1 window<br>Doors: enlarged | 90 Vol/h | 13 Vol/h |
| North: 3 windows<br>South: 2 windows<br>(1.4 m² + 1 m²)<br>Doors: opened | 105 Vol/h | 15 Vol/h |
| North: 3 windows<br>South: 2 windows<br>(1.4 m² + 2 m²)<br>Doors: opened | 140 Vol/h | 19 Vol/h |
| North: 3 windows<br>South: 2 windows<br>(1.4 m² + 1 m²)<br>Doors: closed<br>(louver 0.5 m²<br>above the door) | 80 Vol/h | 10 Vol/h |
| North: 3 windows<br>South: 2 windows<br>(1.4 m² + 2 m²)<br>Doors: closed<br>(louver 0.5 m²<br>above the door) | 115 Vol/h | 15 Vol/h |

*Example n°3*

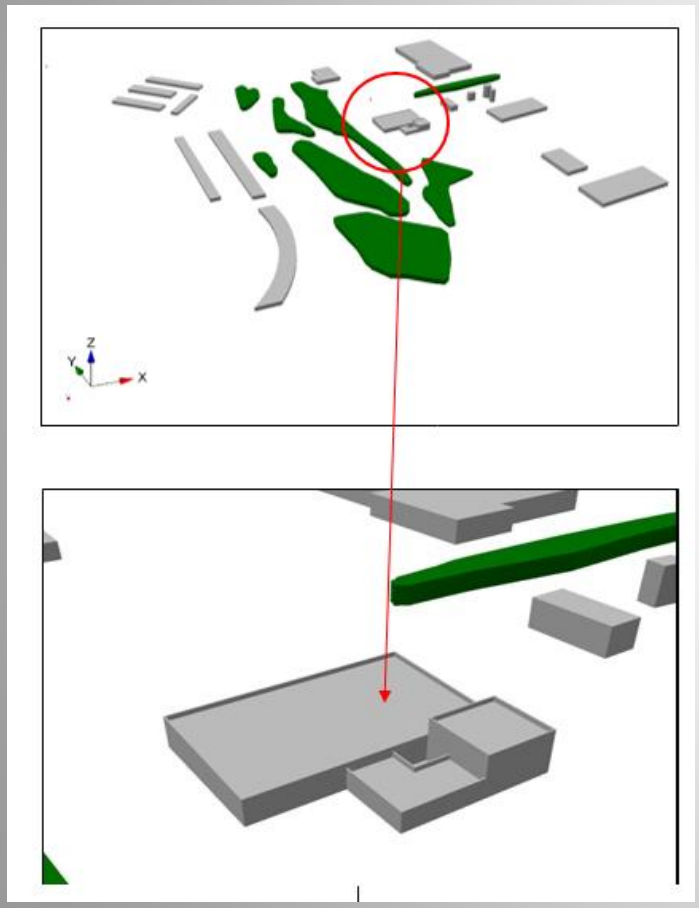
# Summer night cooling for an industrial building (wind and stack effects mixed)

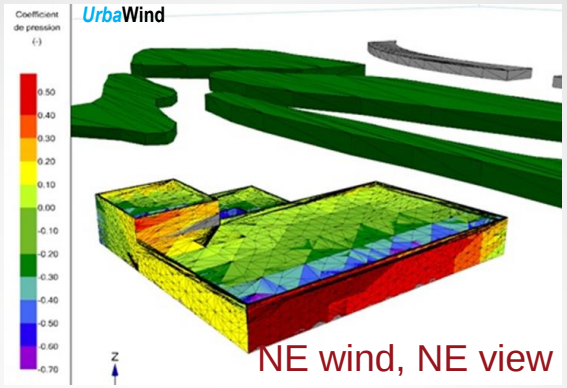
# Natural air ventilation (wind and stack effects)

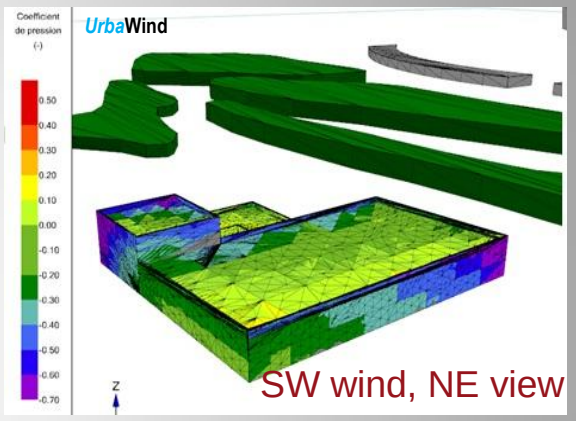


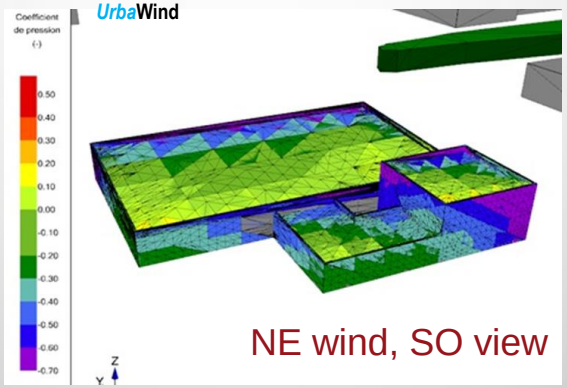
# Natural air ventilation (wind effects)

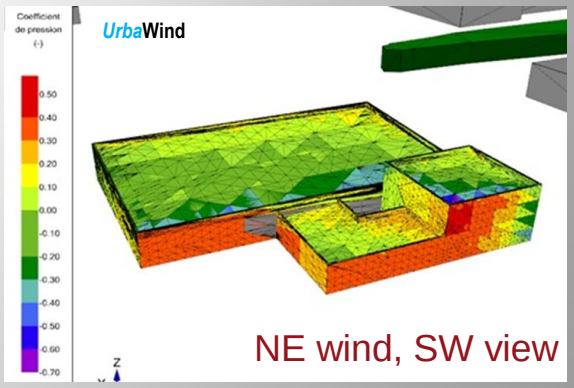




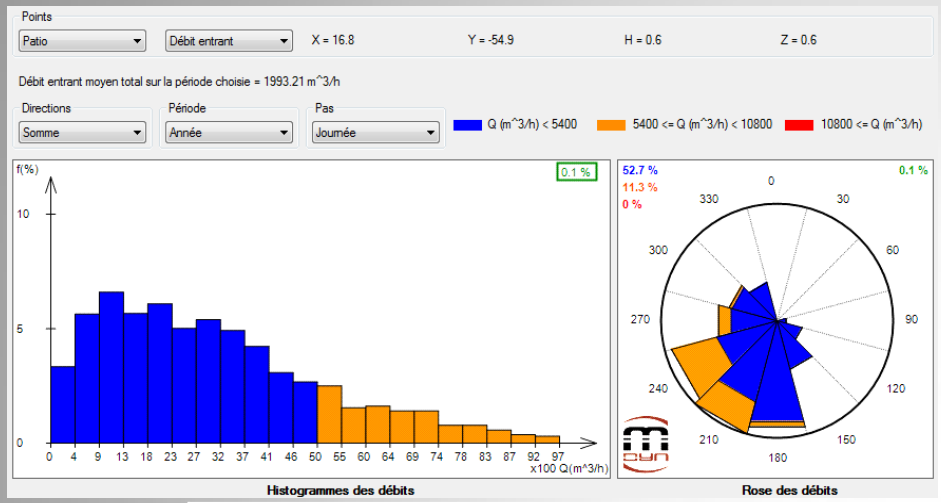



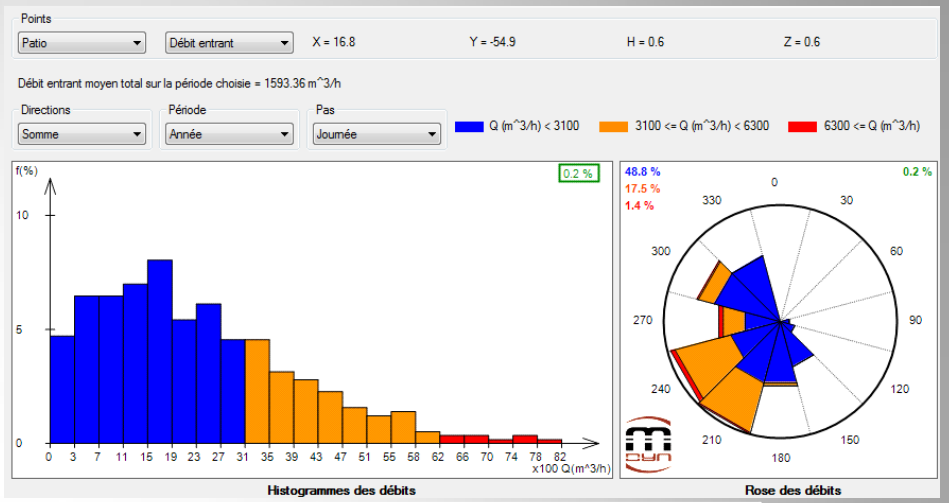

Pressure coefficient



# Natural air ventilation (wind effects)



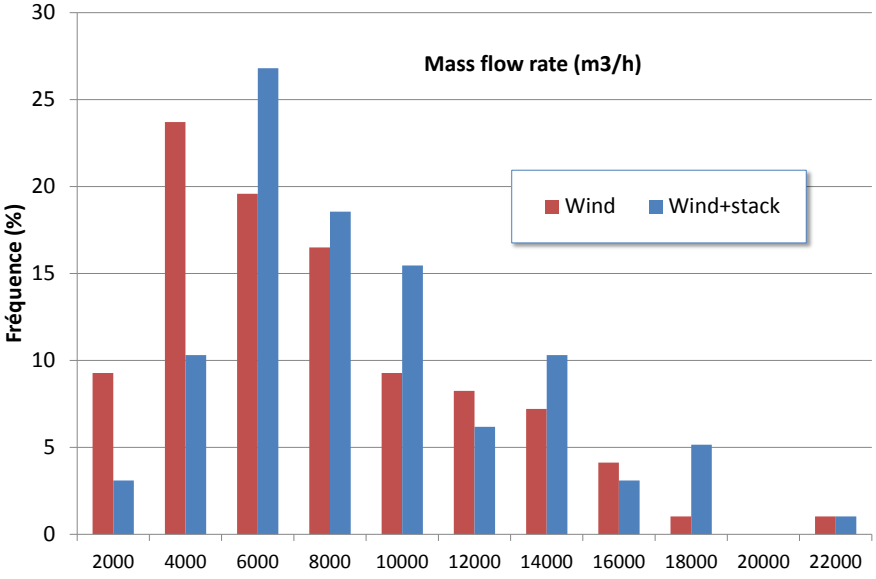




| | | SUMMER | FREE COOLING |
|---|---|---|---|
| | Average ACH | 9600 $m^3/h$ – ACH = 2.0 vol/h | 7600 $m^3/h$ ACH = 1.6 vol/h |
| **INDUSTRIAL AREA** | Input door | 4830 $m^3/h$ | 4300 $m^3/h$ |
| | Output door | 4290 $m^3/h$ | 2910 $m^3/h$ |
| | Average ACH | 3860 $m^3/h$ ACH = 6.7 vol/h | 2900 $m^3/h$ ACH = 5.1 vol/h |
| **OFFICE** | Input door | 2000 $m^3/h$ | 1600 $m^3/h$ |
| | Output door | 1600 $m^3/h$ | 1000 $m^3/h$ |

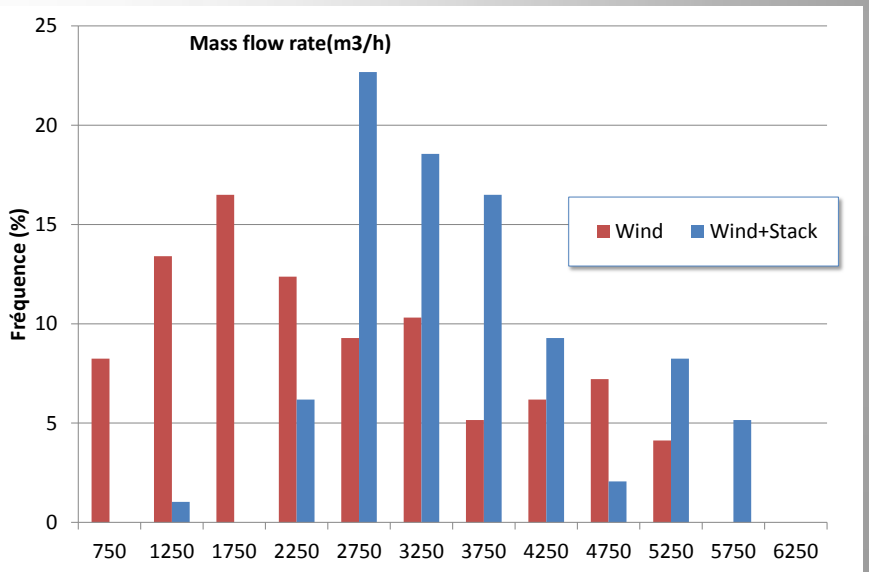
# Natural air ventilation (wind and stack effects)

## Add thermal pressure gradient due to stack effects

Tall volume (ACH +15%)




2 storeys building (ACH +40%)

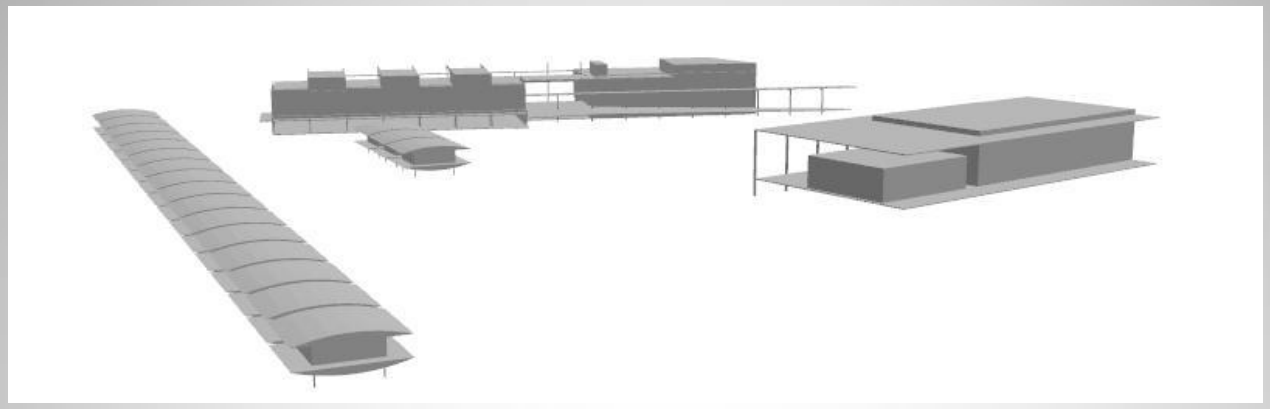


meteodyn
meteorology & dynamics

*Example n°4*

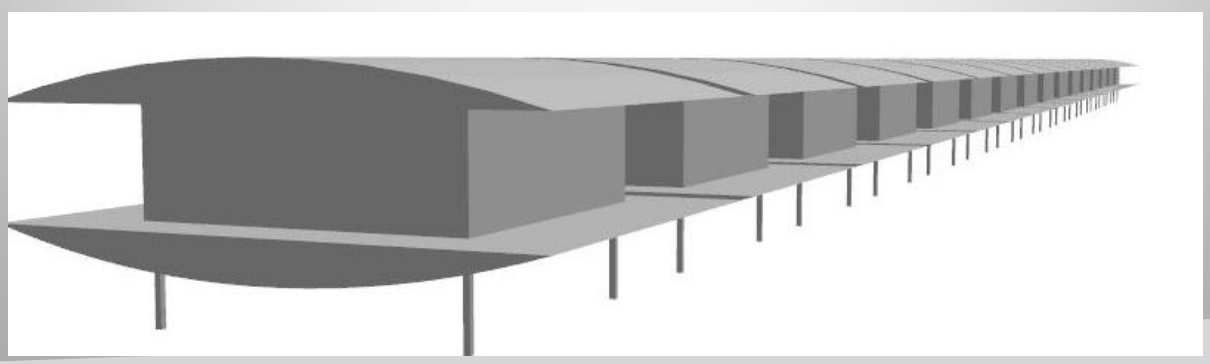
# Natural ventilation of a secondary scholl
# Kourou – French Guiana

## Whole geometry of the secondary school



## Optimisation of the cooling of the class rooms

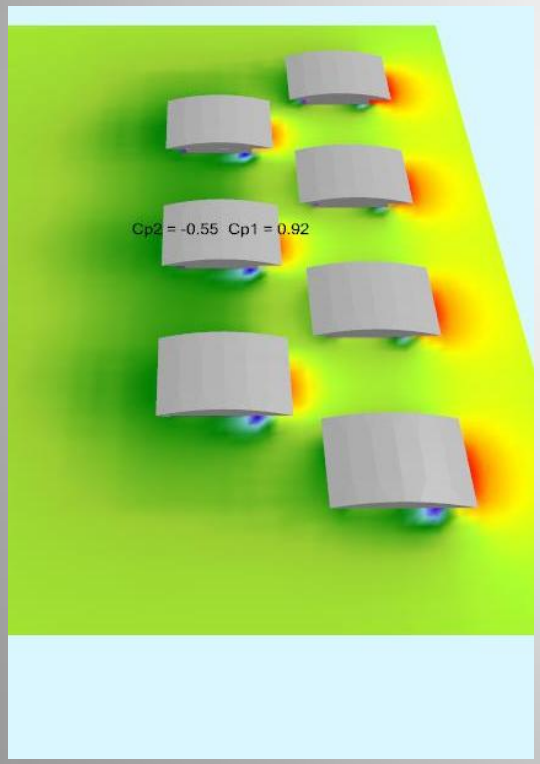
- depends on the configuration (line, V or grid)
- depends on the windows positions and aerodynamic behaviors

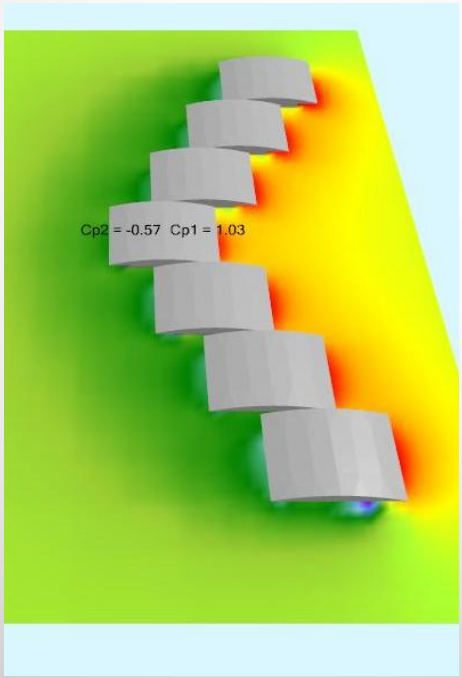


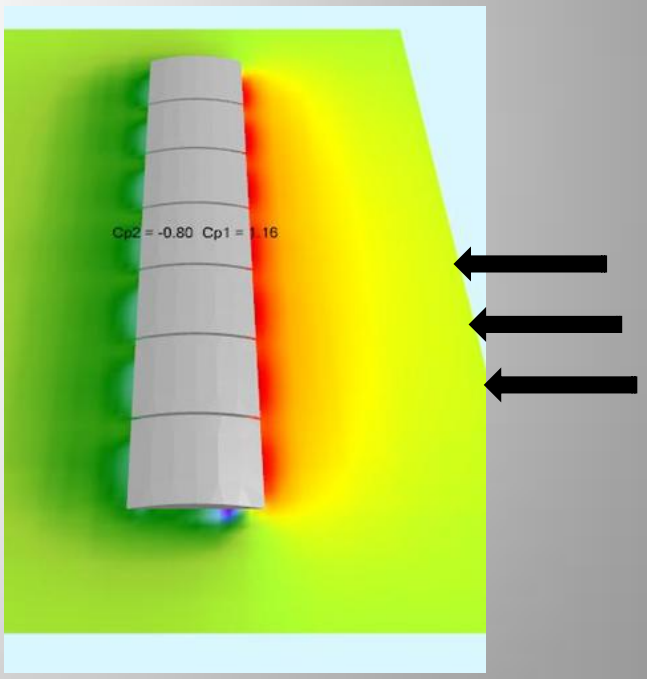
Pressure potentiel depends on configuration configuration

ΔCP=0.8 ΔCP=0.9 ΔCP=1.1

(href=10 m)

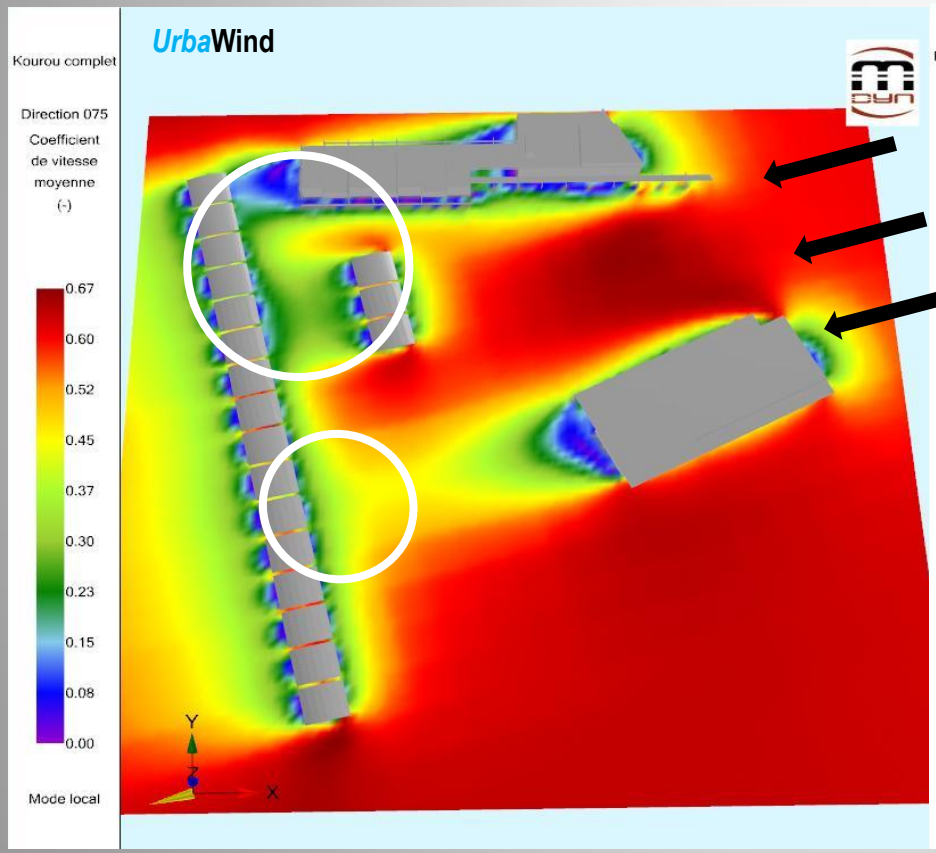


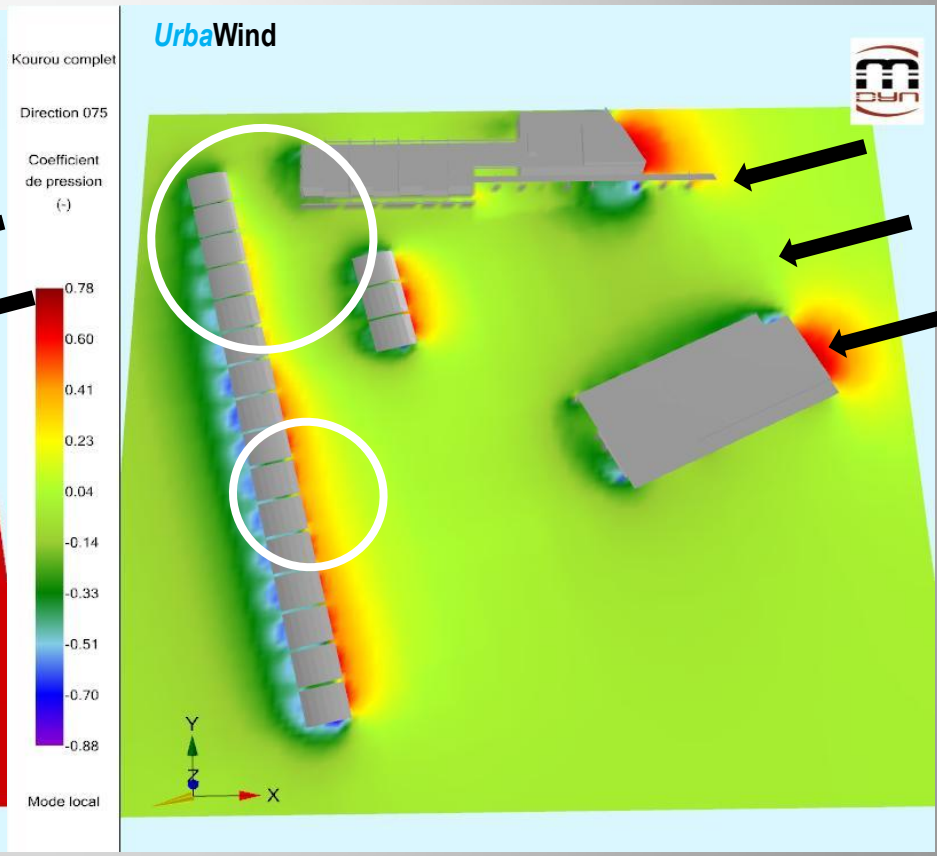



meteodyn
meteorology & dynamics

## Mean speed up factor



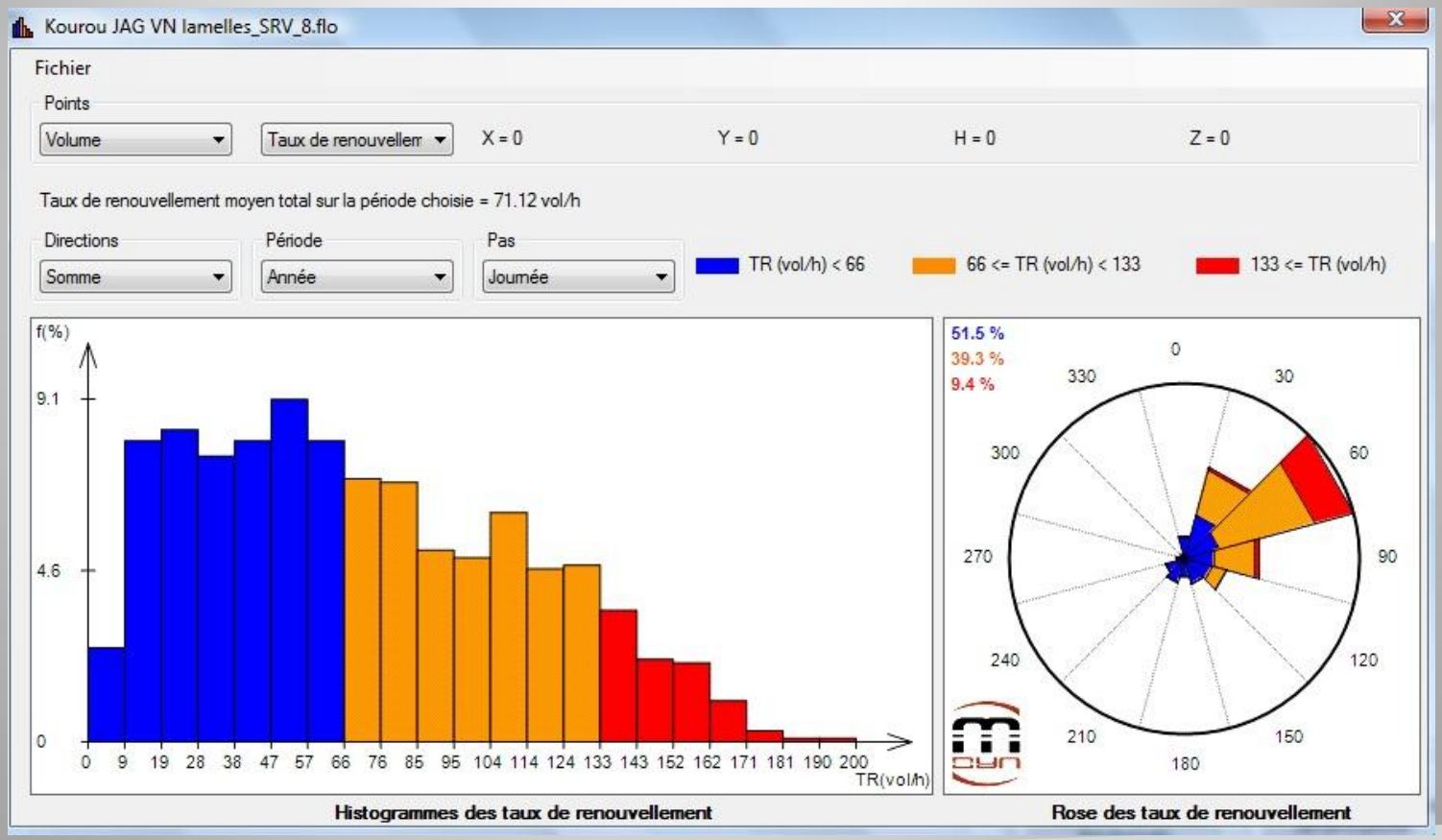

## Mean pressure coefficient



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

⇒ ACH average = 71 Vol/h

⇒ 18% of time with ACH< 30 Vol/h



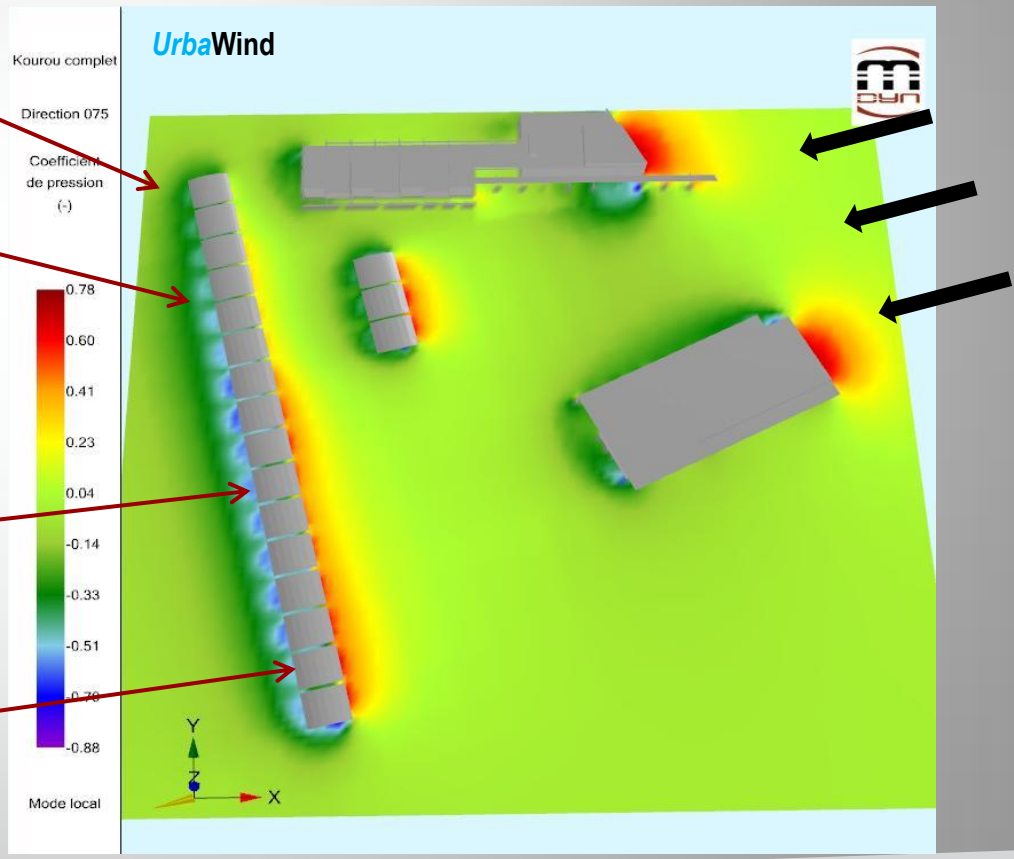
Decreasing of the air change rate compared to the detached configuration without the main bluidings

-18%

-22%

-6%

-9%



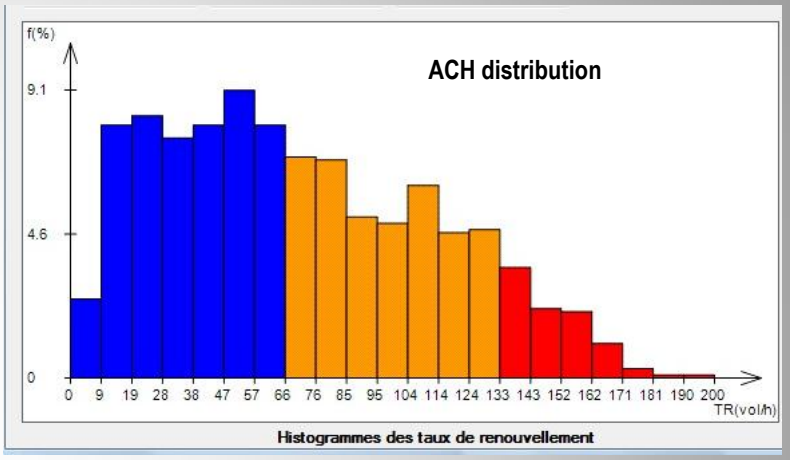
# Further data for thermic tools

- ACH Statistics for average models

*Distribution, frequence, mean, RMS*

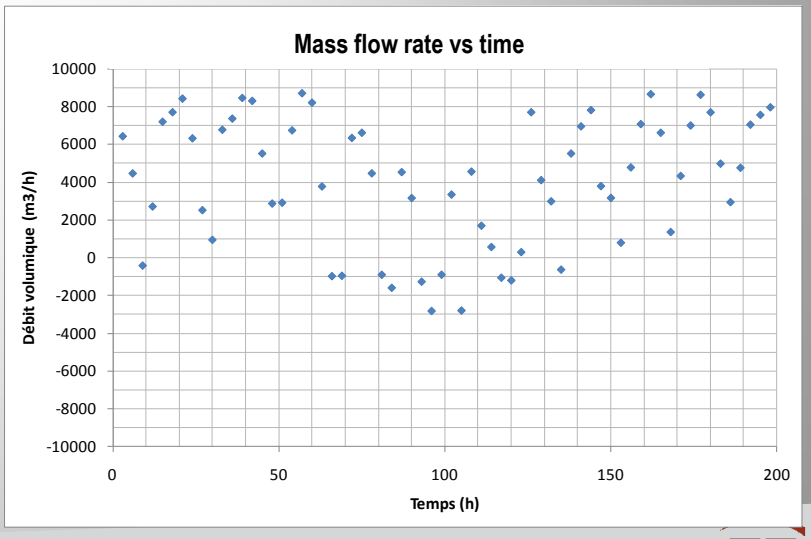
*Day and night data, monthly…*

- Indoor air velocity statistics




- Time series for the dynamic thermic models

*Mass flow rate for each opening*



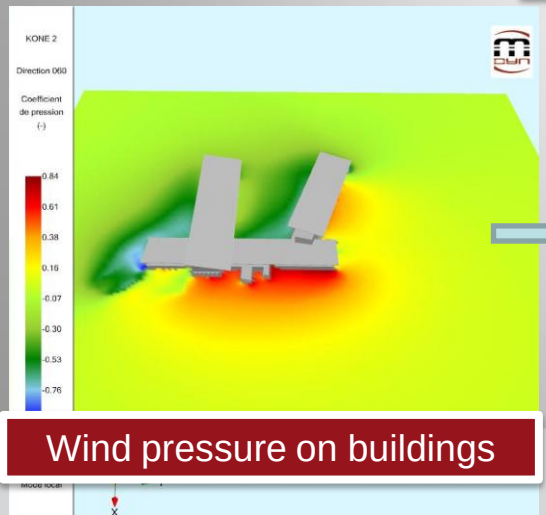
meteodyn
meteorology & dynamics

# *Others examples*

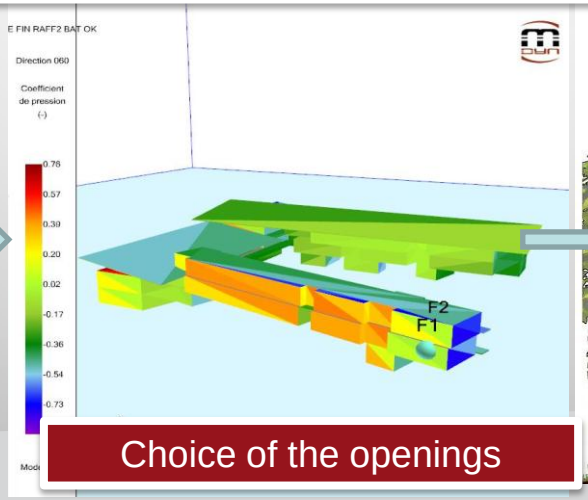
# Architectural design competition assistance


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

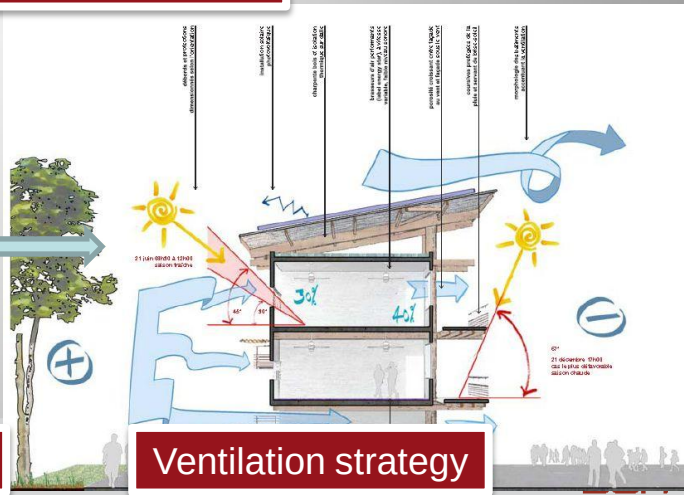
Assistance to define the ventilation strategy




Wind pressure on buildings

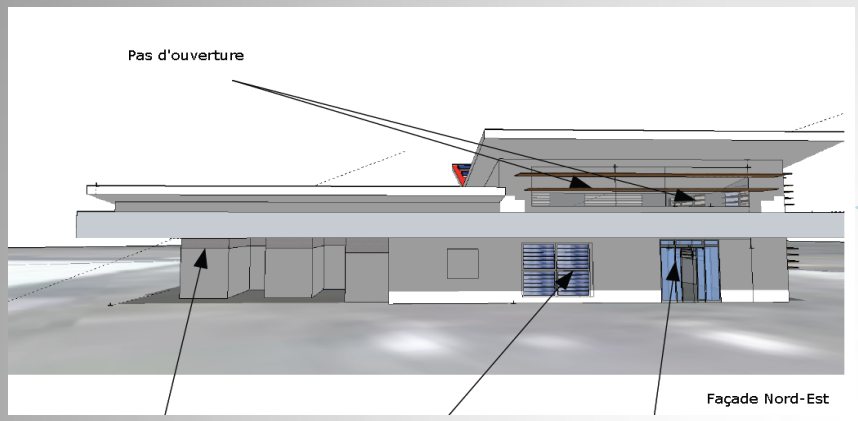



Choice of the openings




Ventilation strategy

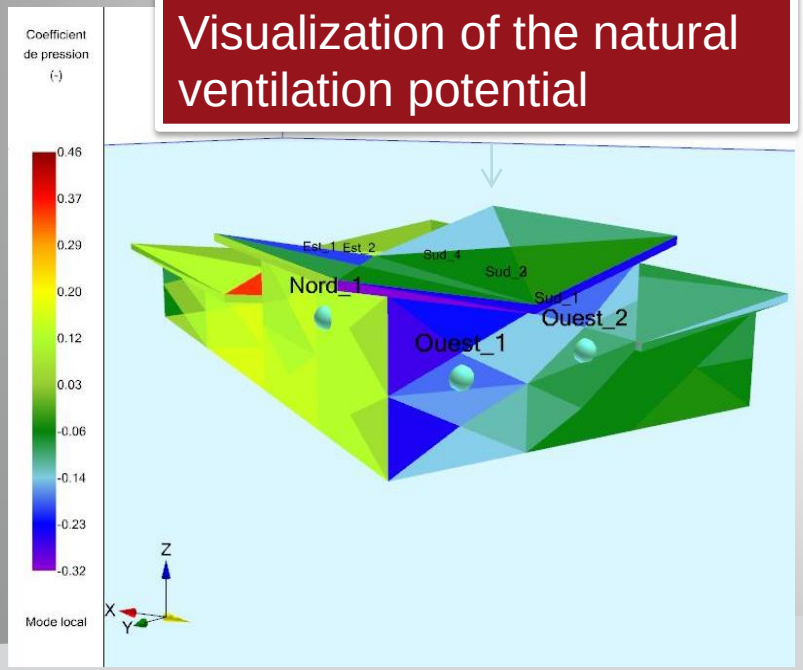
# Diagnostic of the preliminary project design

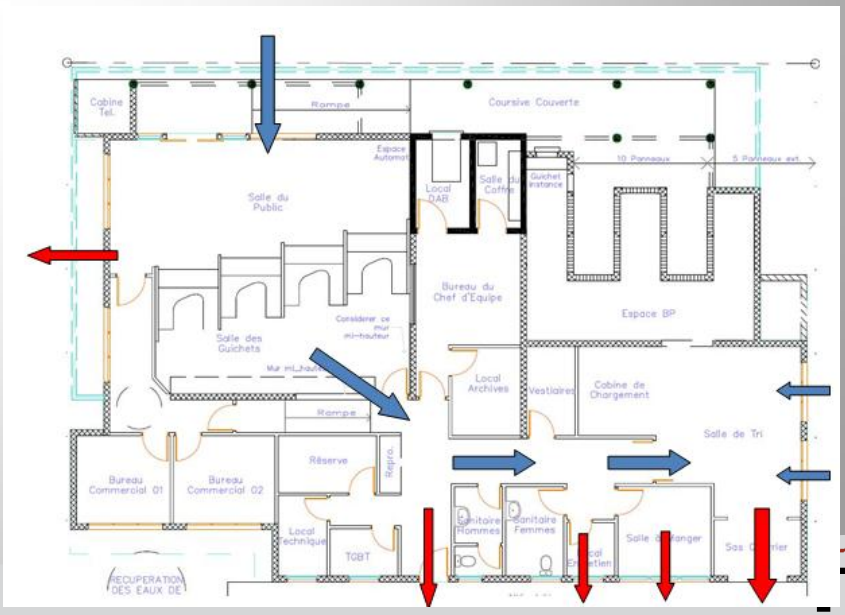



Validation of the project proposed by the Project designer to the Project owner

Diagnostic of the building ventilation scenario and mass flow assessment

Visualization of the natural ventilation potential

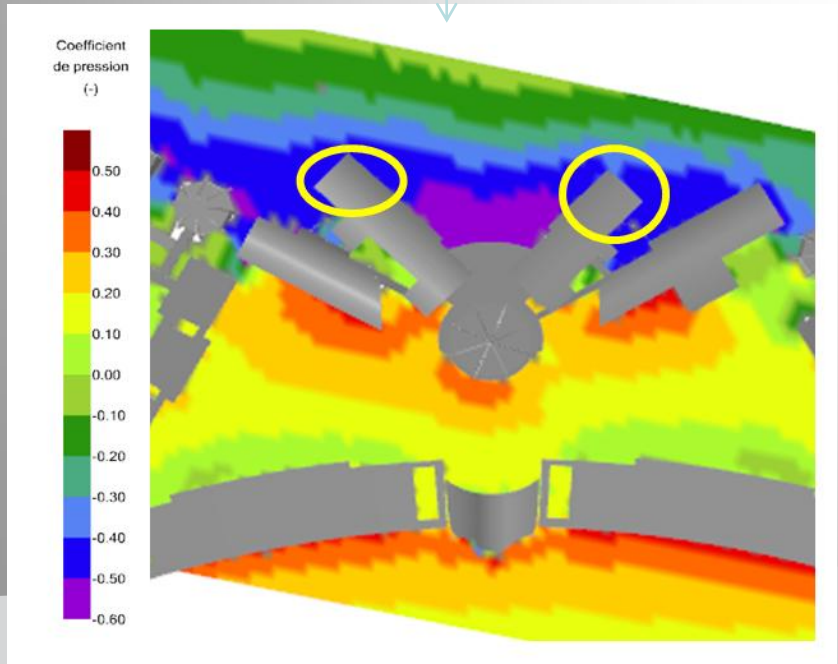


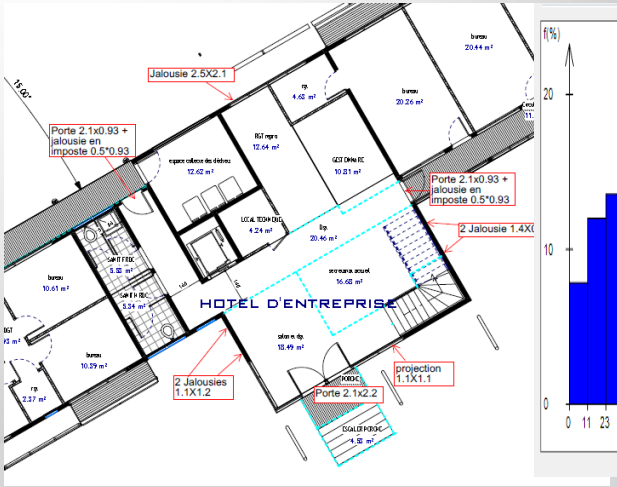
# From the preliminary to the detailed project design

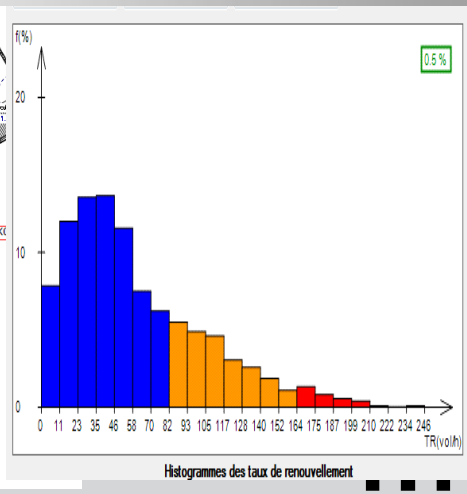
## Validation of the project

## Visualization of the natural ventilation potential and diagnostic




## Interior architectures and openings validation
## Data extraction for thermal software



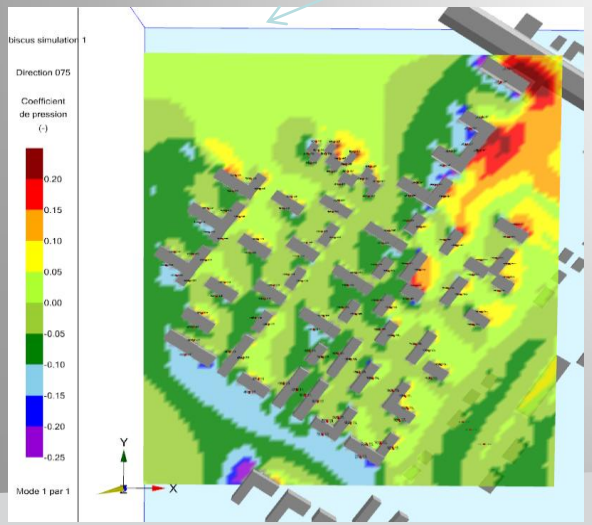

Histogrammes des taux de renouvellement

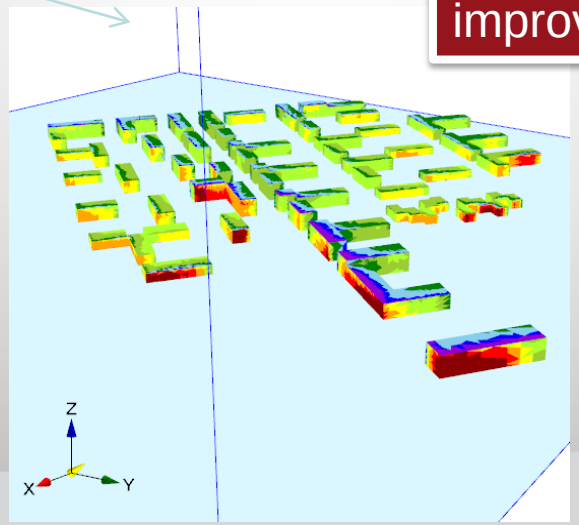
# Design of “green” district

Planners’ project

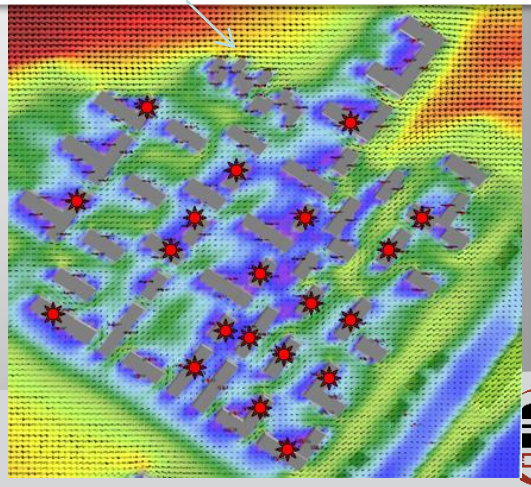
Time of computations :
120’/wind direction
3 Millions cells

Natural ventilation potential of the buildings




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



# Keep in touch

stephane.sanquer@meteodyn.com

www.meteodyn.com

info@meteodyn.com