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

Dr Stéphane SANQUER

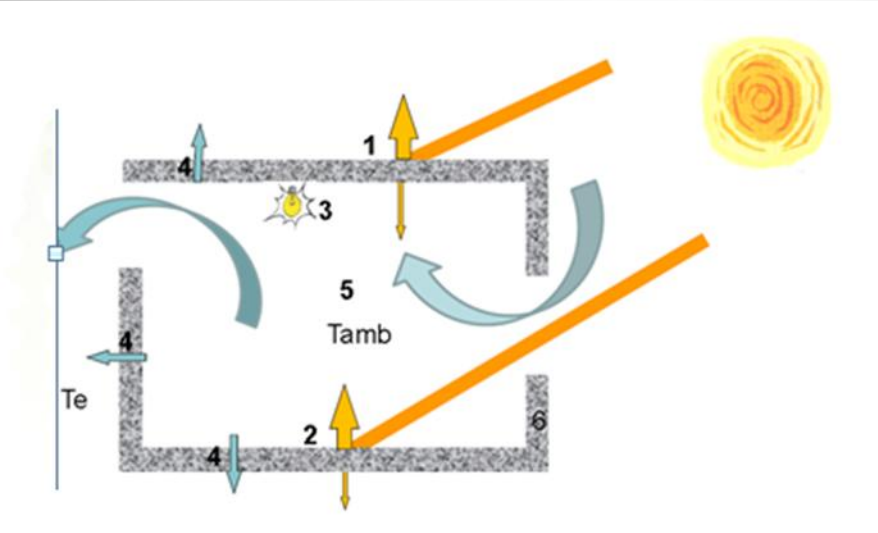
Meteodyn

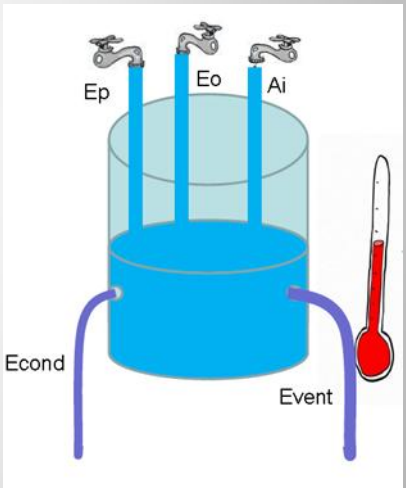
www.meteodyn.com

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

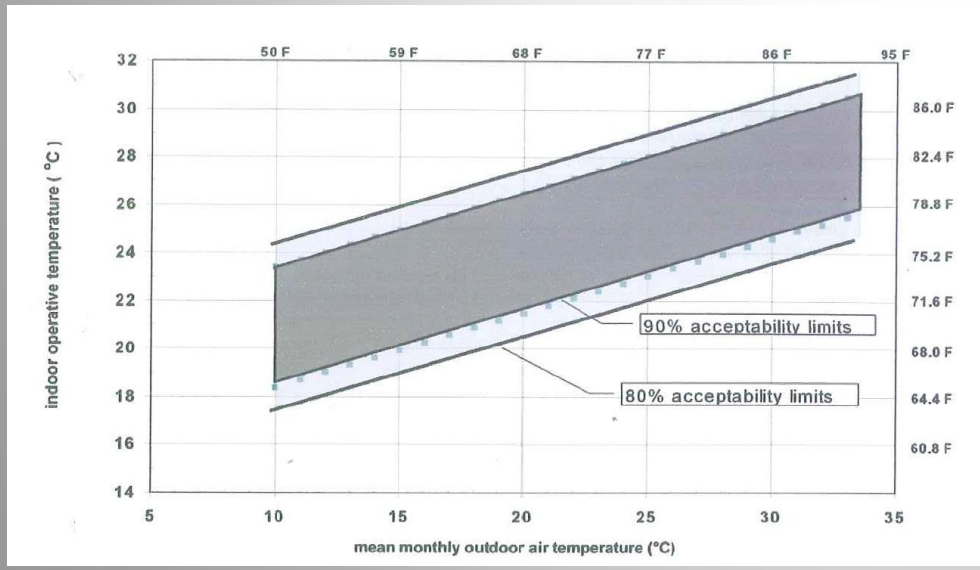
About the thermal indoor comfort

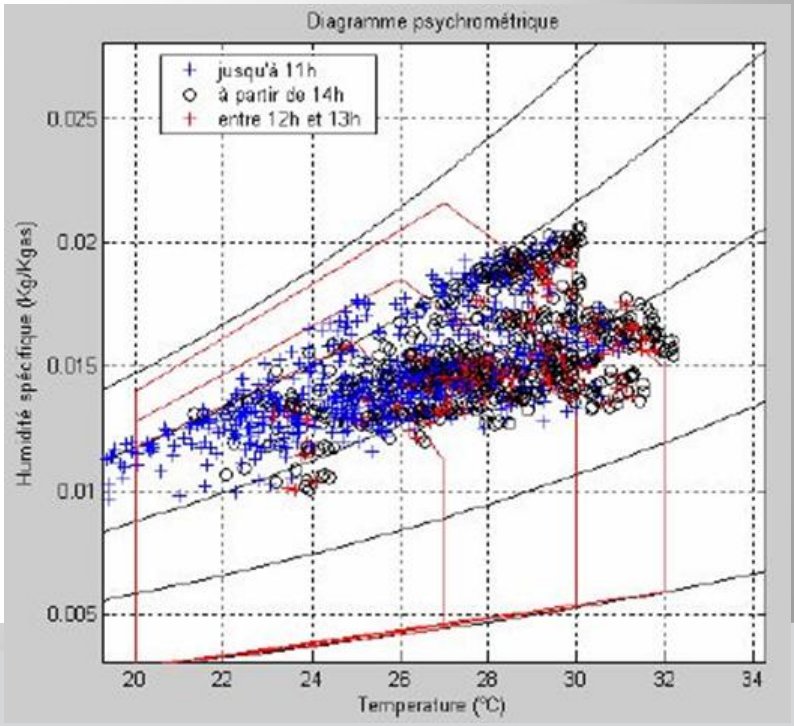
- A building is well designed according to the thermal comfort criteria if :

- 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





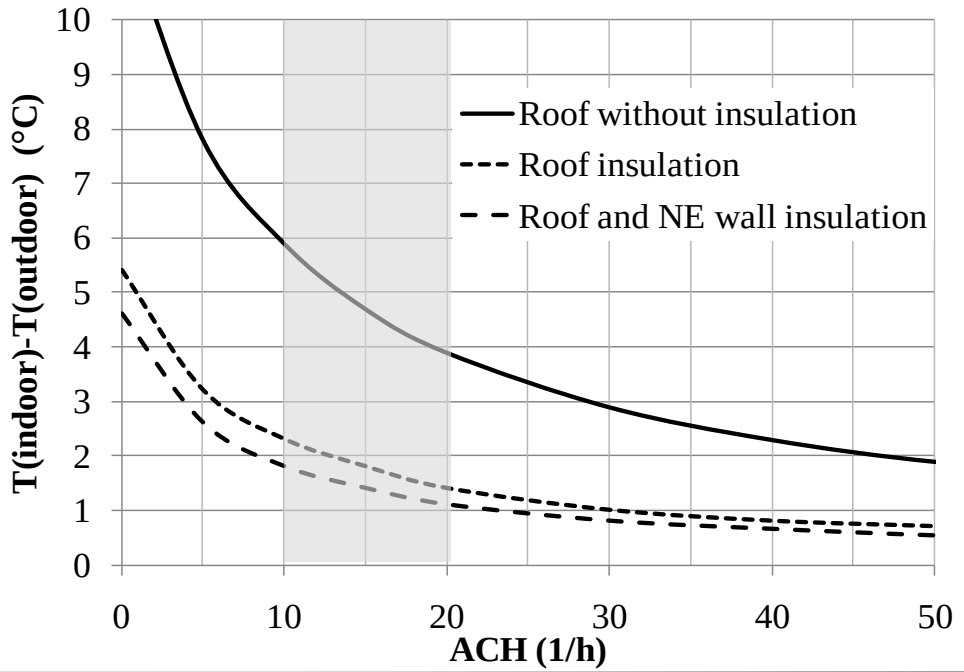
About the thermal indoor comfort

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?

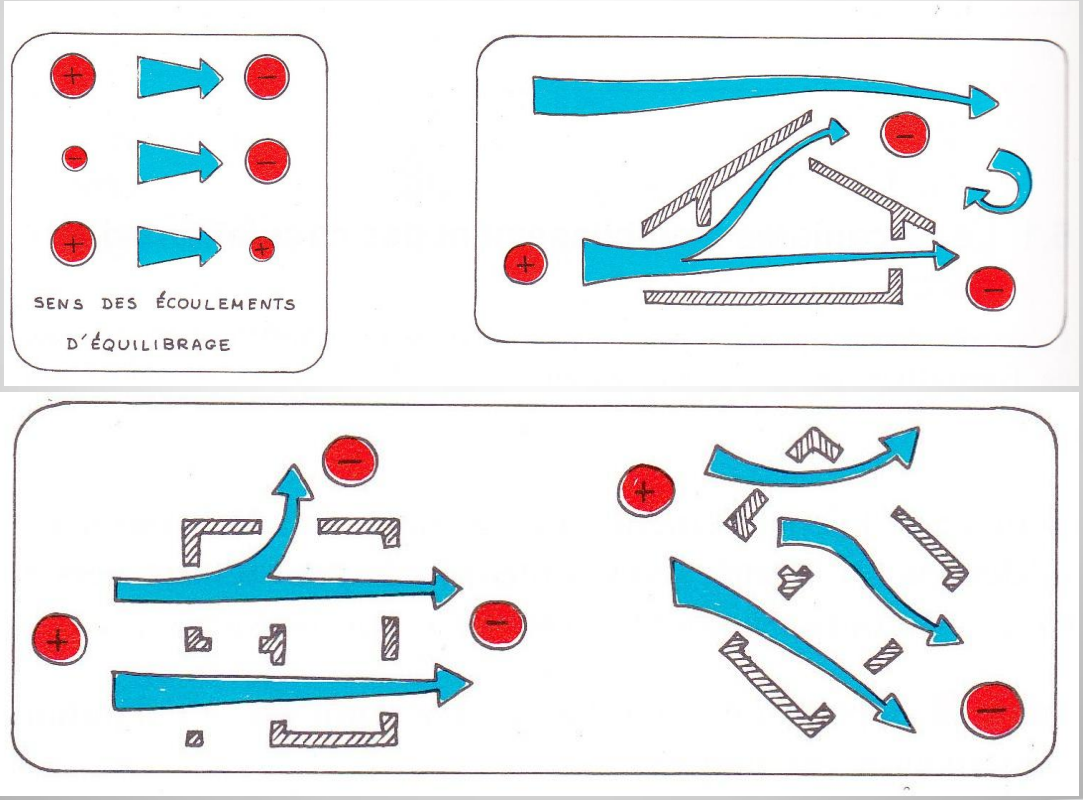
Who ‘s responsible?

Insulation and ventilation as well



Cross ventilation principles

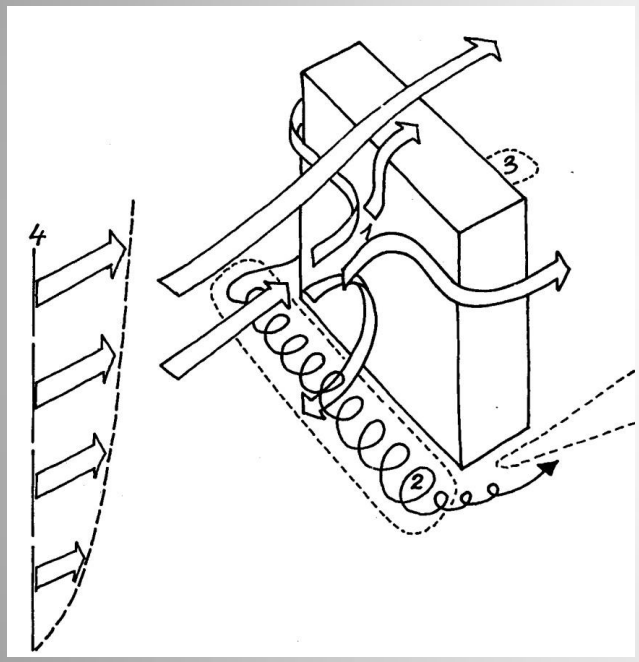
- Flows go from the highest pressure areas to the lowest pressure areas
- Velocity depends on the root square of the pressure gradient



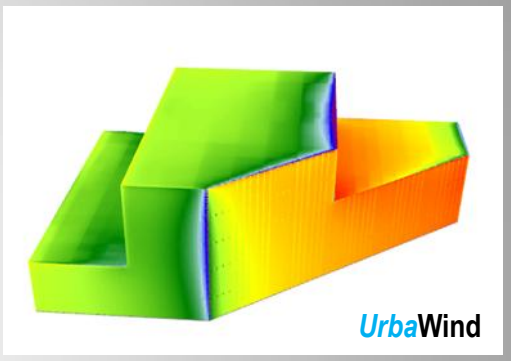
From CSTB guidelines book (Natural ventilation in tropical warm climate)

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

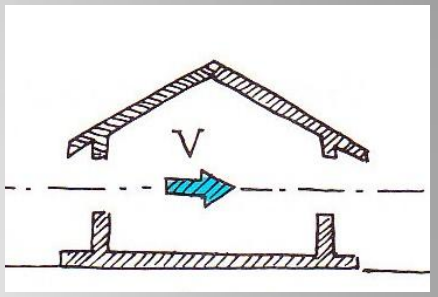
Downstream face: Cp from -0.5 to -0.3

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)

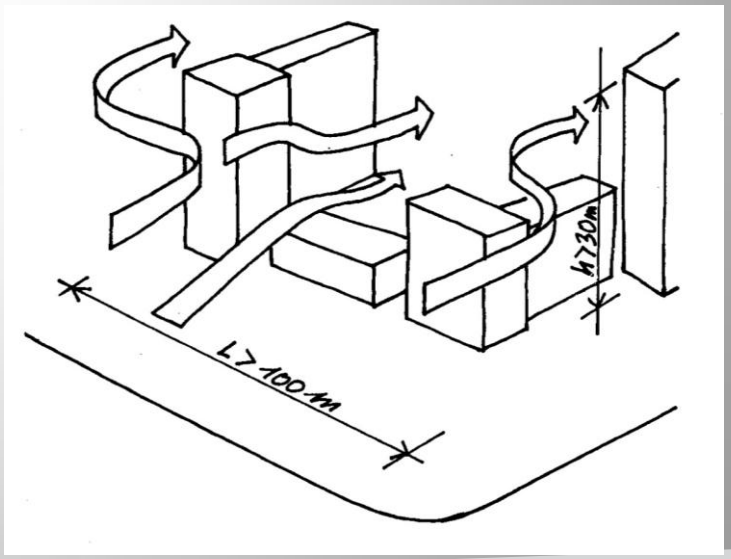
✓Numerical approach (CFD)

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

-External pressure field

-Characteristics of openings (A,C)

-Indoor volume dimensions

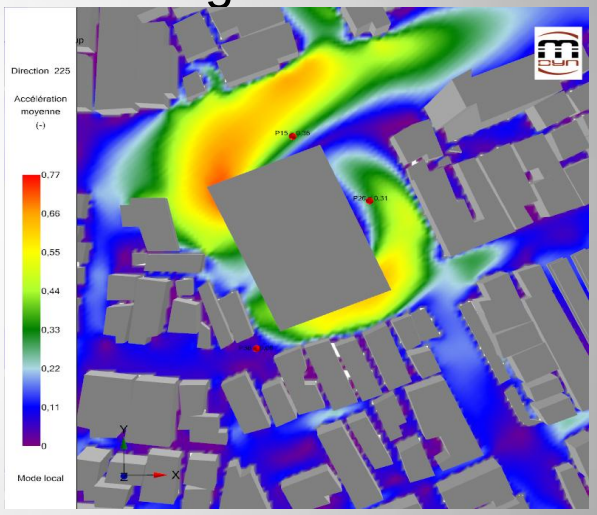


Challenge in Wind Enginering

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

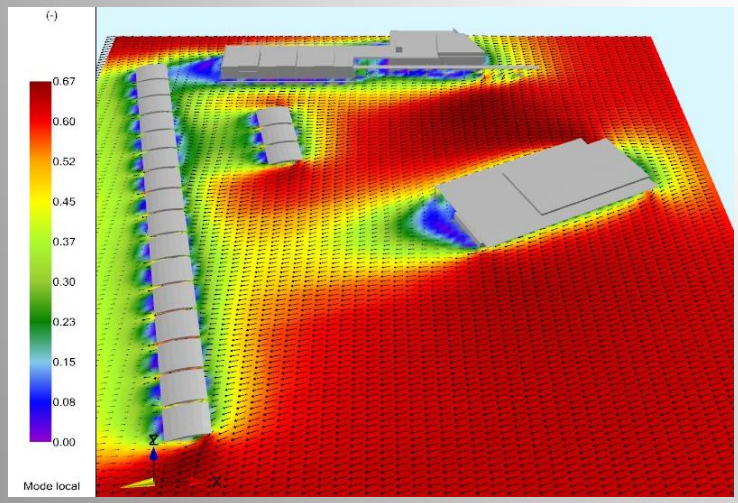
Meteodyn developed UrbaWind, an automatic CFD software for computing the wind between buildings…as well as possible

The CFD Tool: Directional computations

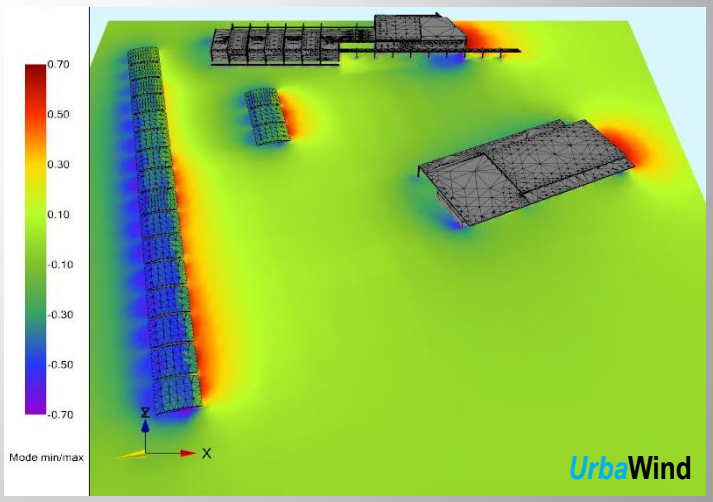
UrbaWind solves the averaged equations of mass and momentum conservations (Navier-Stokes equations) for steady flow and the incompressible fluids.

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

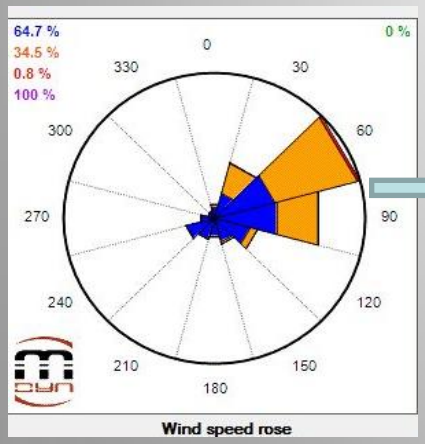
The Network calculation computes ACH based on CFD pressure field

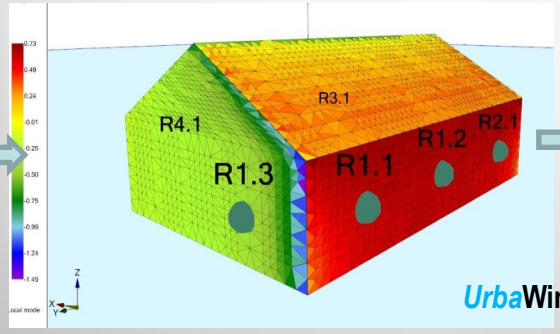
The indoor pressure *Pi* is unknown and the flow rates through the openings are solved by a Newton-Raphson iterative process.

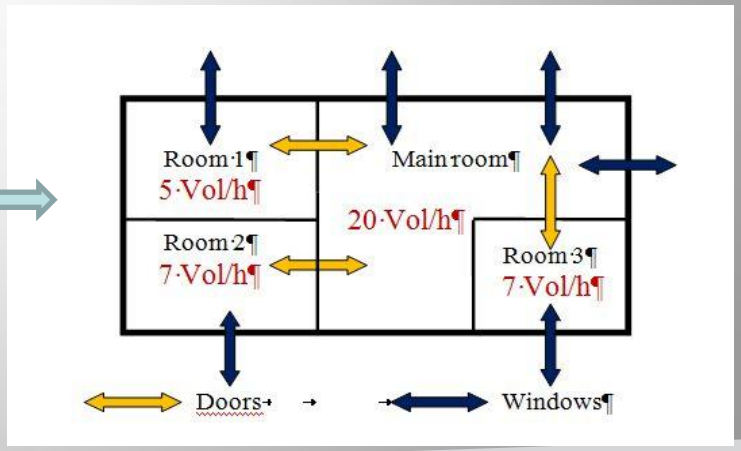
$$P_i^{n+1} = P_i^n - \omega F\left(P_i^n\right) / F'\left(P_i^n\right)$$

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}



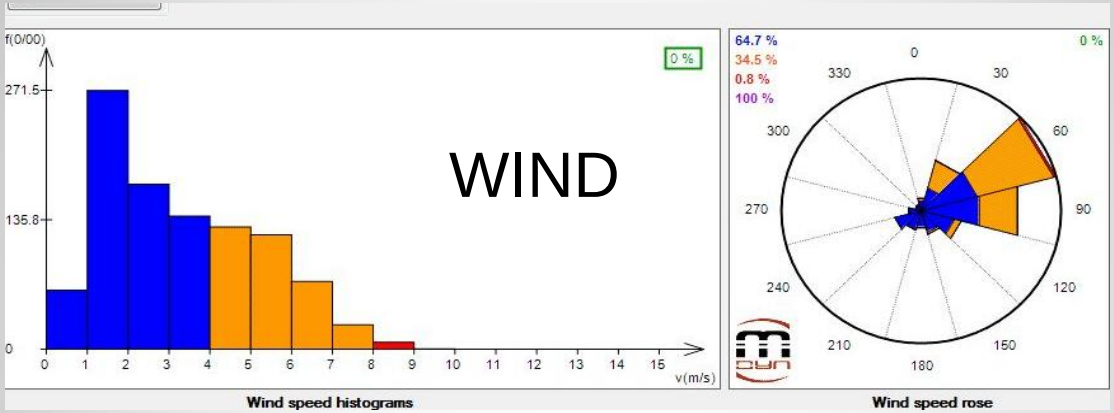


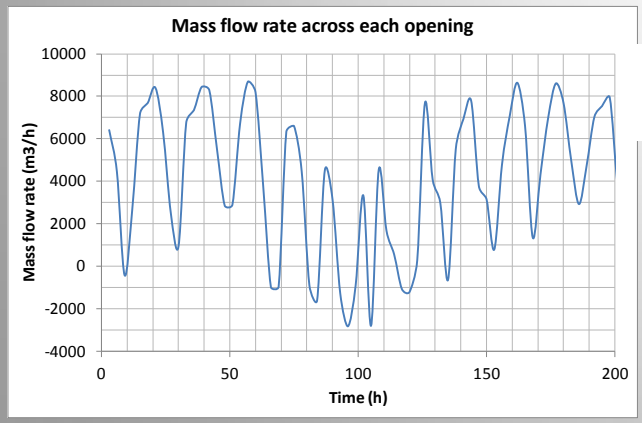


The CFD Tool: Air Change Rate

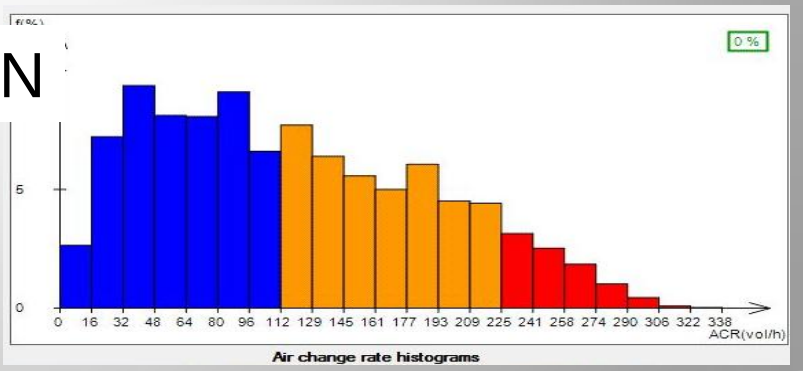
The Network part computes ACH based on CFD pressure field

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





VENTILATION



meteodyn
meteorology & dynamics

Example n°1

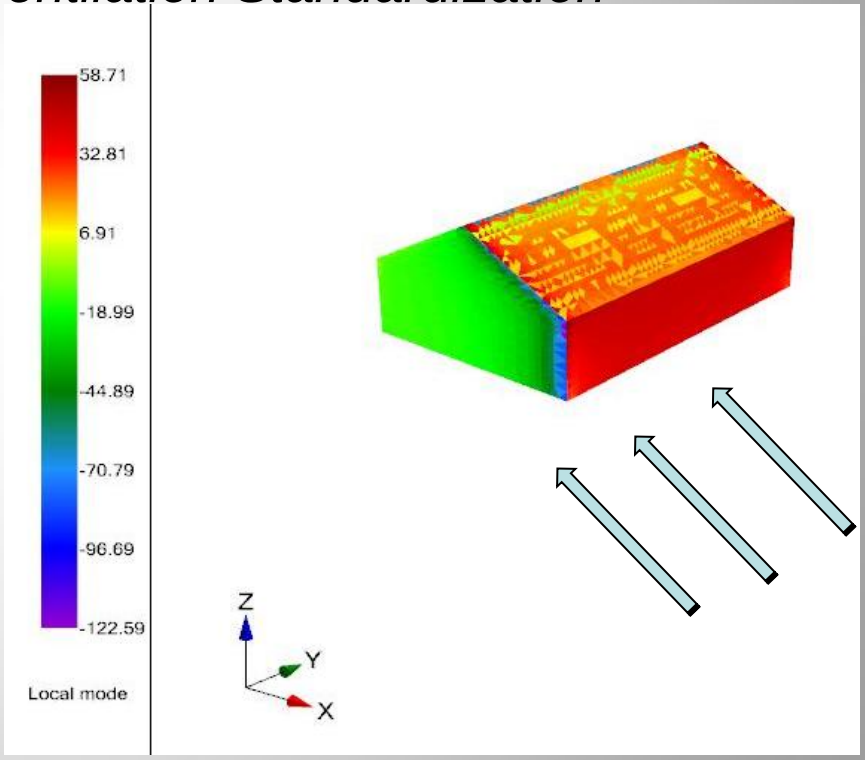
Round robin test
CFD vs experiments (scaledown model)

Round robin test case

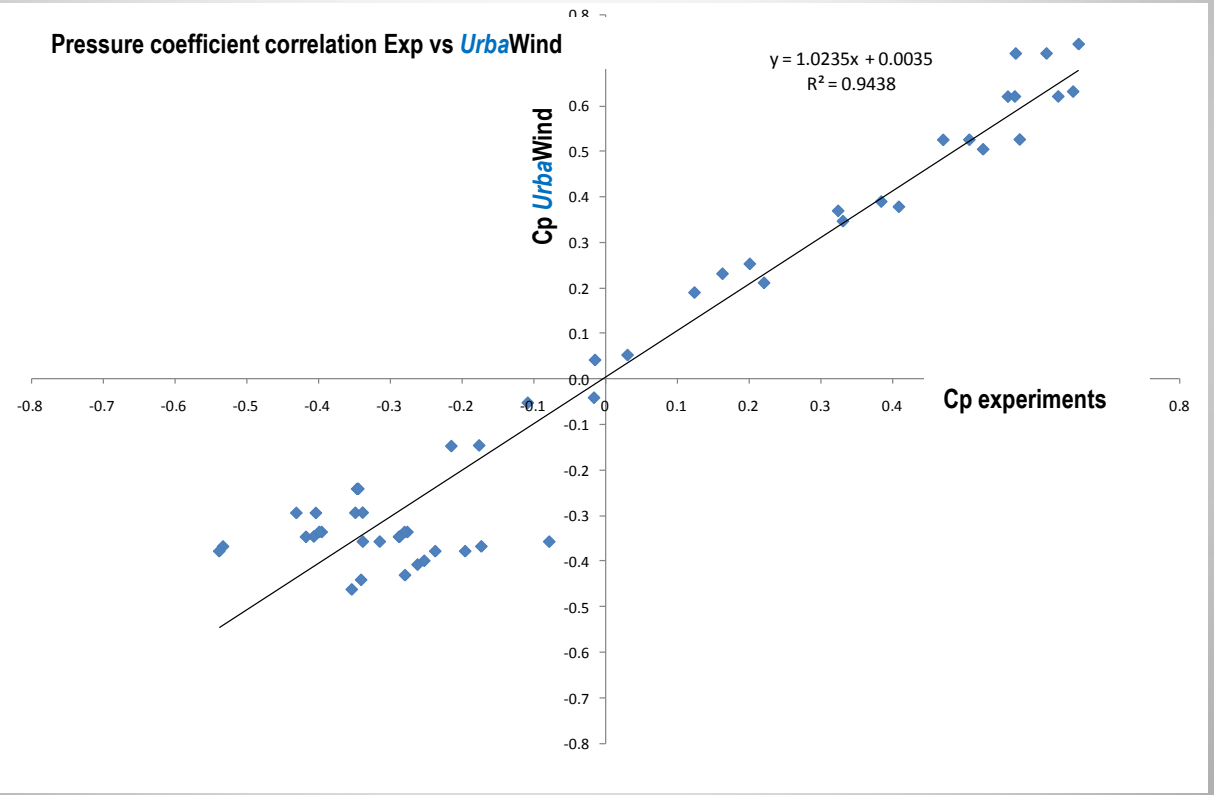
Experimental measurements in Wind tunnel

French Working Group for Natural Ventilation Standardization

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

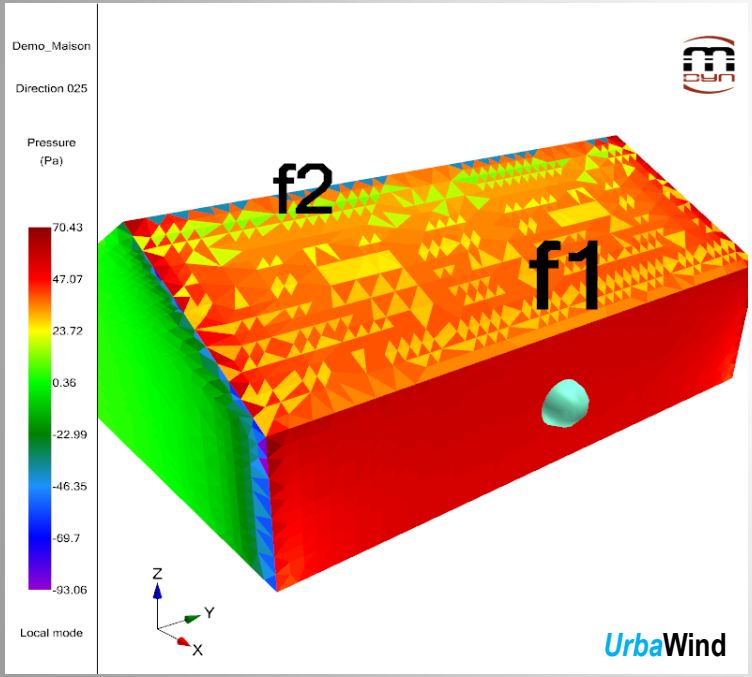


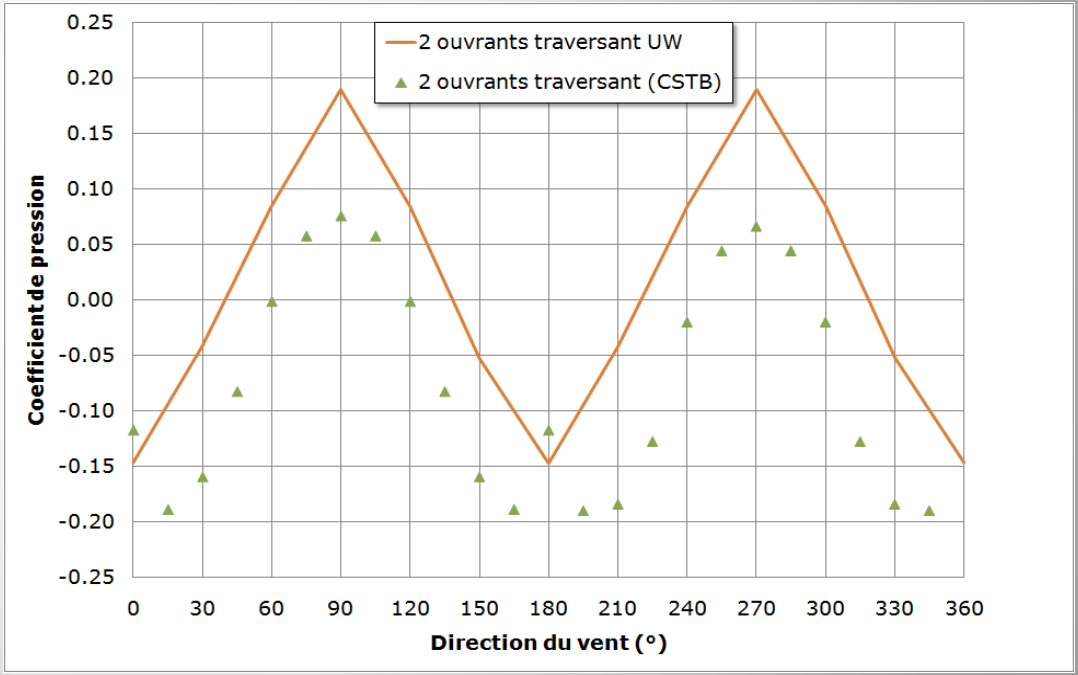
Pressure correlation CFD/Experience



Mass flow rate correlation CFD/Experience

Cross configuration – 2 Windows



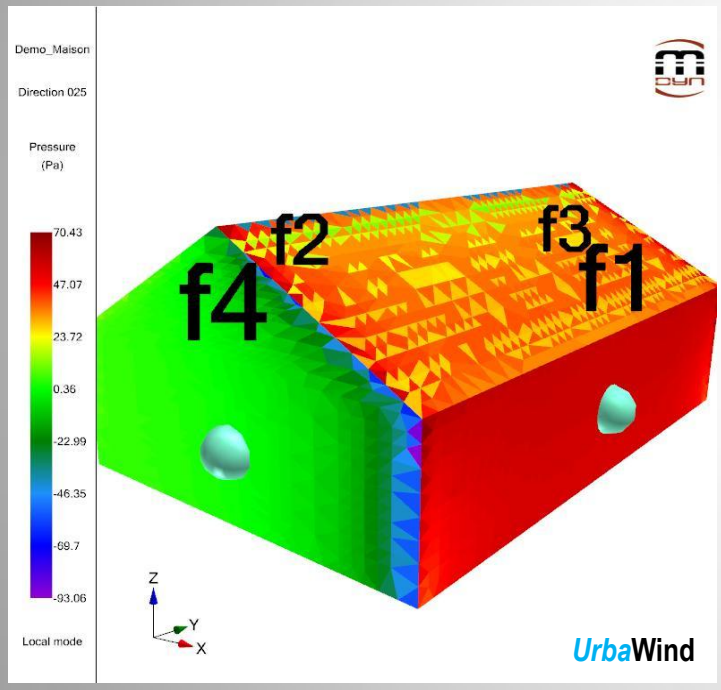


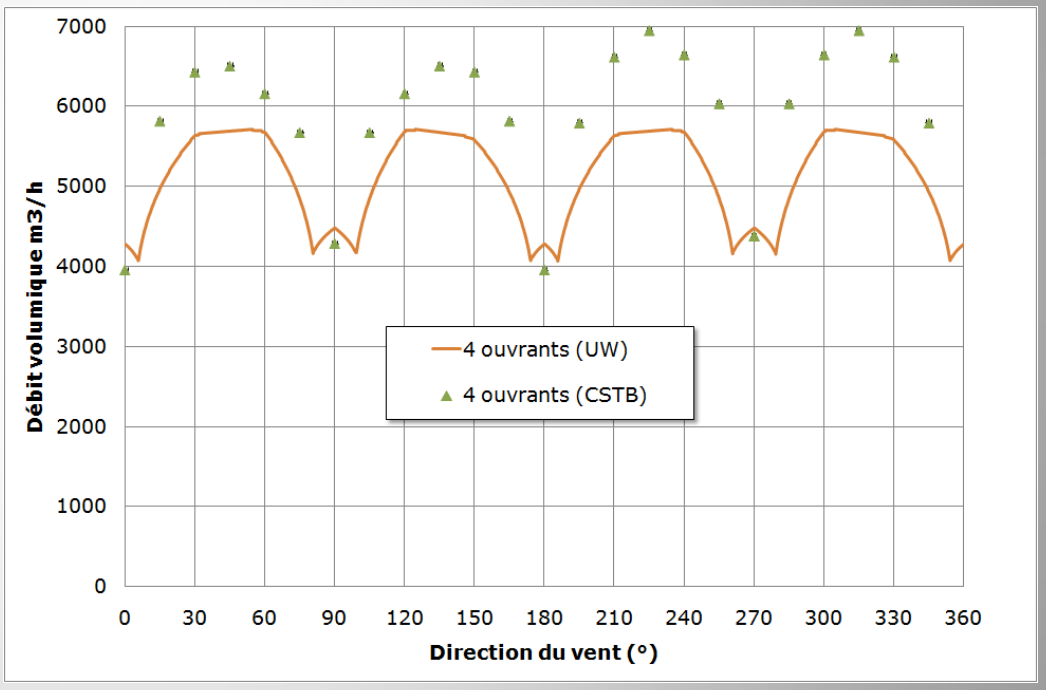
<ACH> (UW)=9 vol/h

<ACH> (Exp)=10 vol/h

Mass flow rate correlation CFD/Experience

Full cross configuration – 4 Windows





<ACH> (UW)=18 vol/h

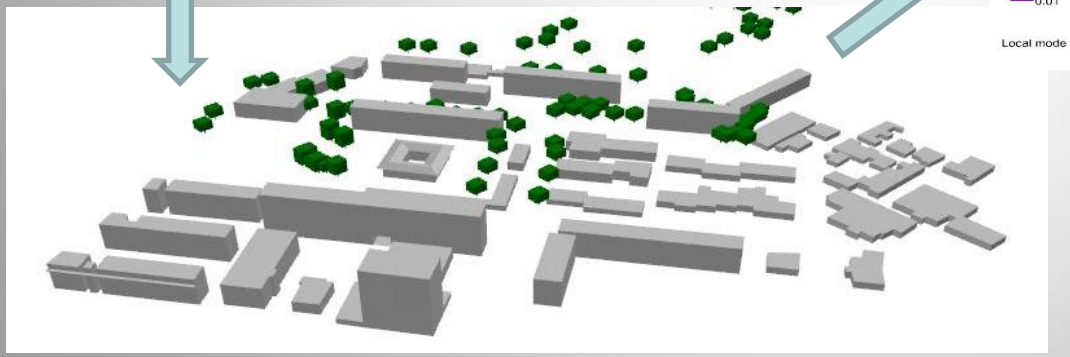
<ACH> (Exp)=21 vol/h

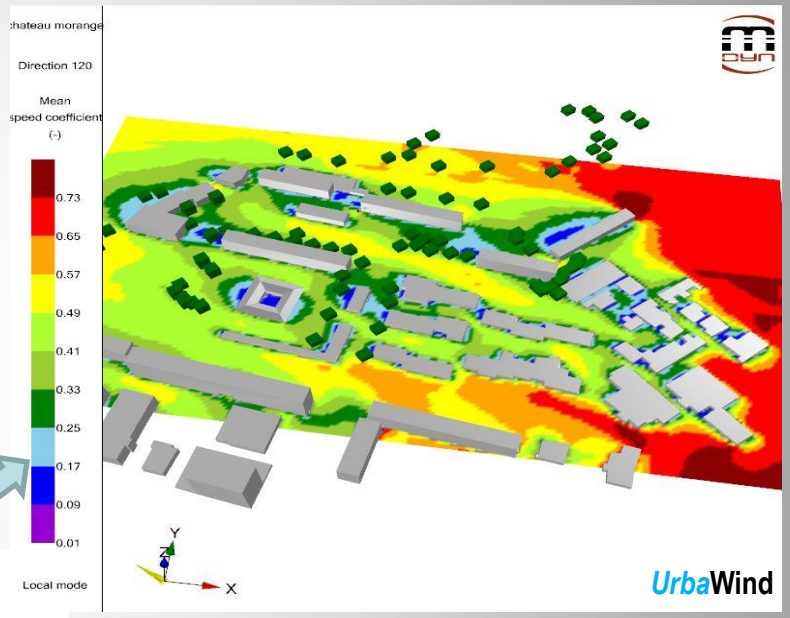
Example n°2

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



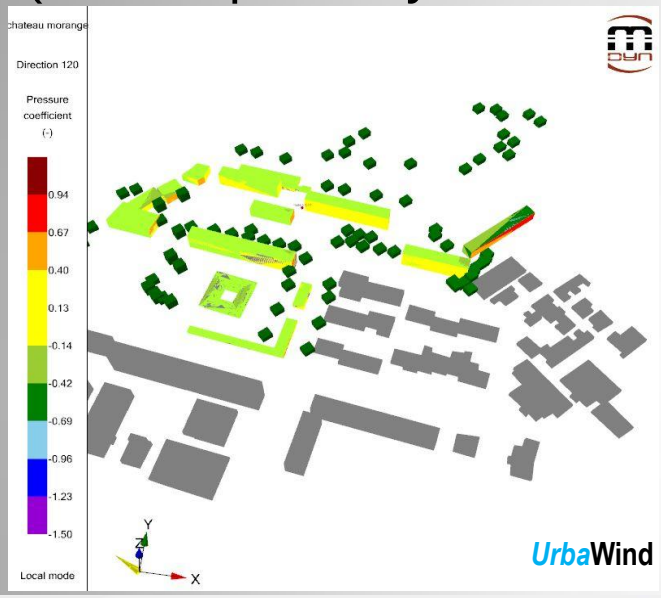


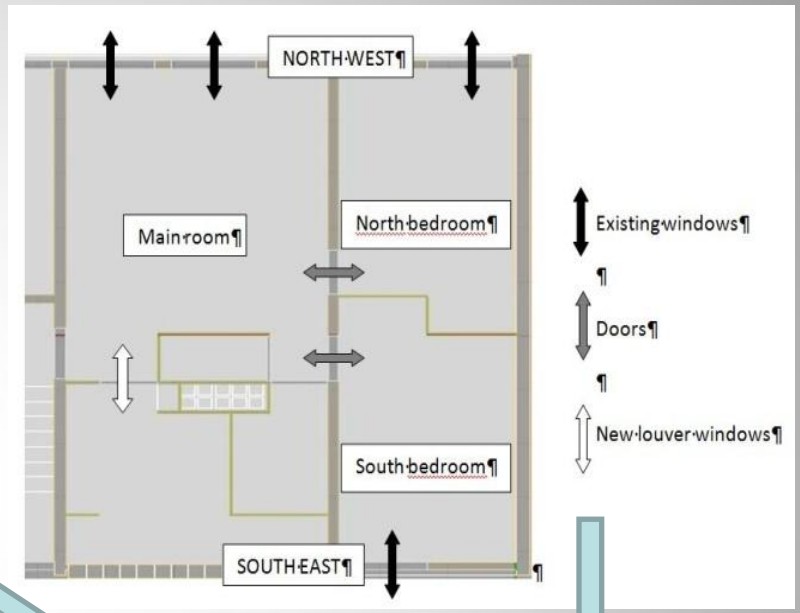
Time of computations :
30'/wind direction

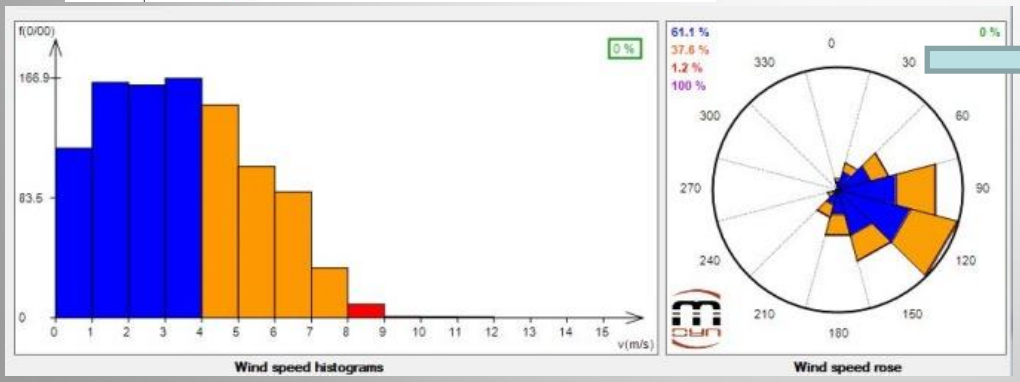
500000 cells

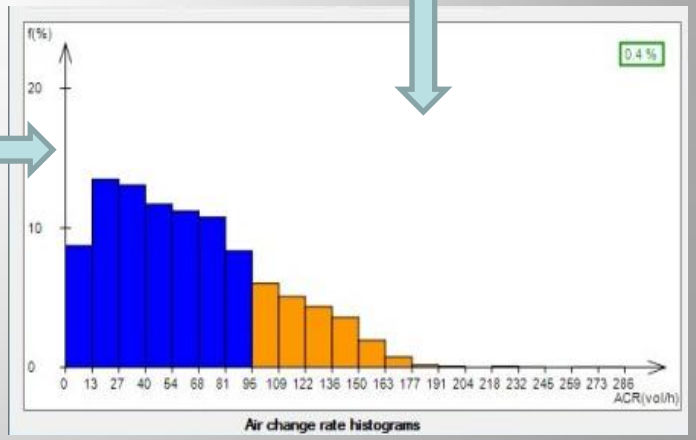
Renovation of urban districts
Natural ventilation potential

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









Renovation of urban districts
Natural ventilation potential

Third step: ACH statistics

Parameters:

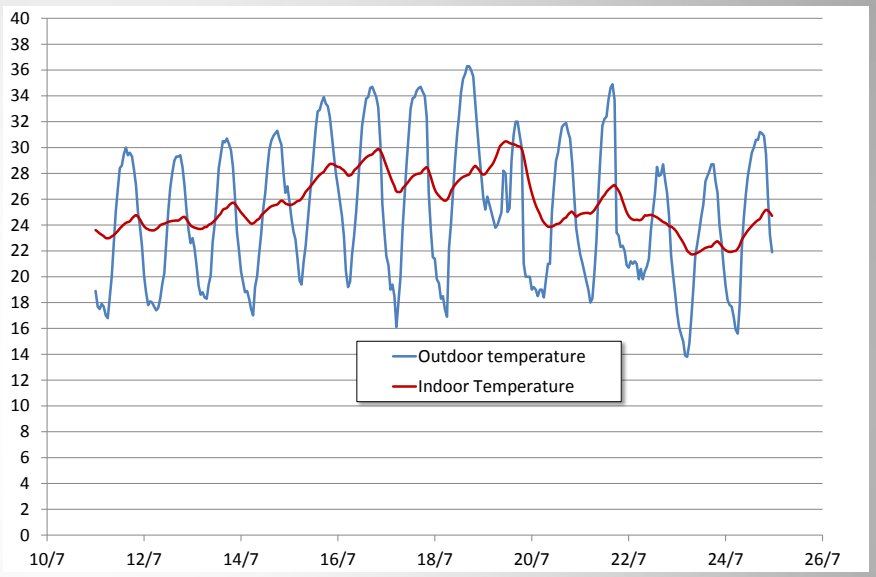
- Position of the openings
- Wall porosity
  Area of the windows
- Internal porosity
  Area of the doors
  Area of the internal openings

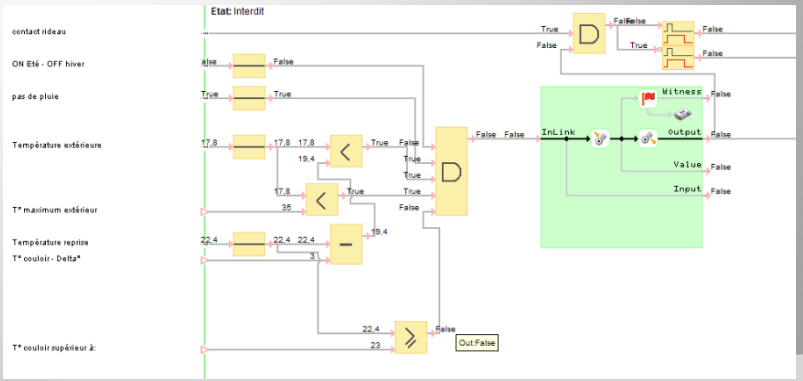
CASES	<ACH>	ACH (P<0.05) ACH MINI
North: 3 windows South: 1 window Doors: opened	65 Vol/h	9 Vol/h
North: 3 windows South: 1 window Doors: enlarged	90 Vol/h	13 Vol/h
North: 3 windows South: 2 windows (1.4 m² + 1 m²) Doors: opened	105 Vol/h	15 Vol/h
North: 3 windows South: 2 windows (1.4 m² + 2 m²) Doors: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

Example n°3

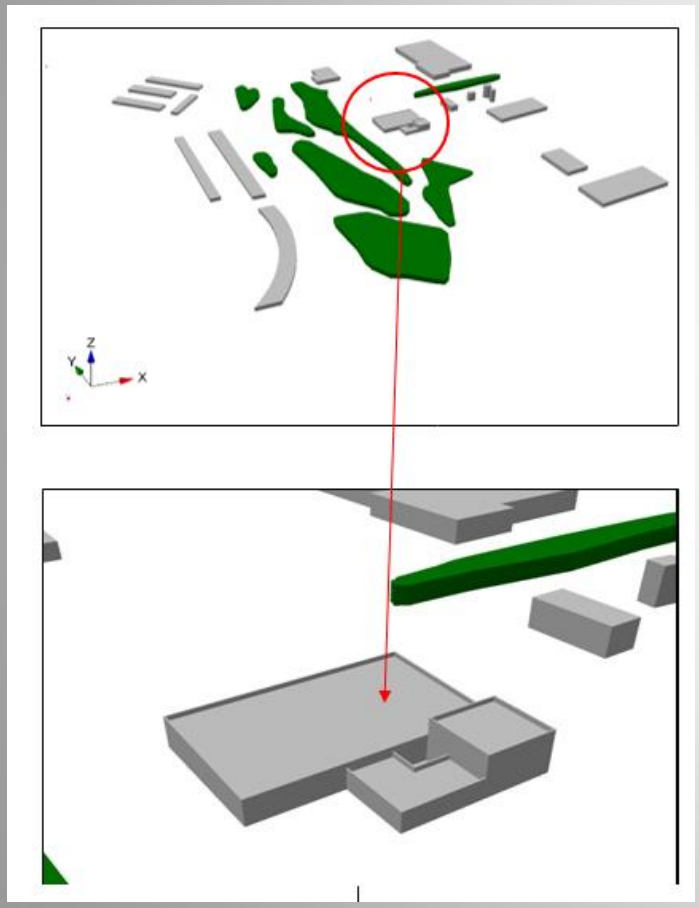
Summer night cooling for an industrial building (wind and stack effects mixed)

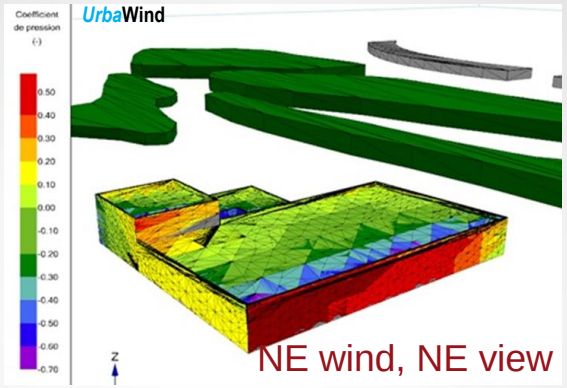
Natural air ventilation (wind and stack effects)

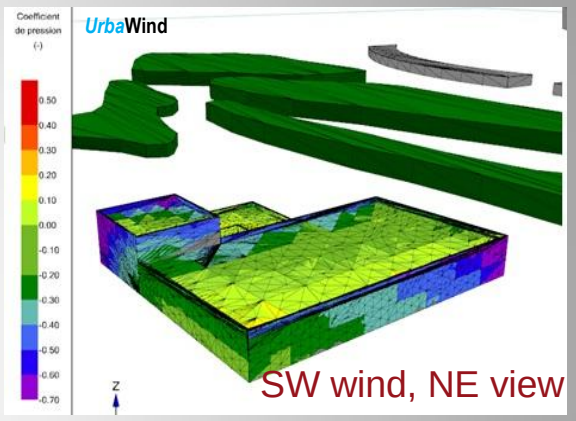




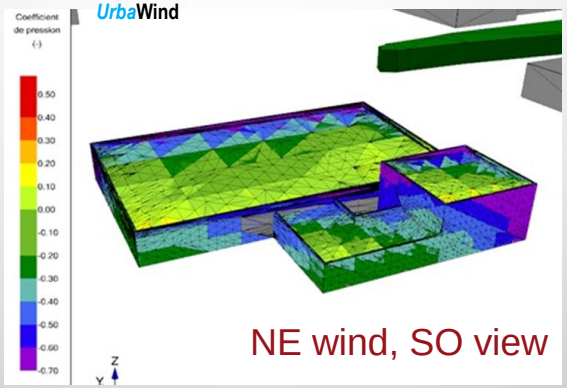
Natural air ventilation (wind effects)

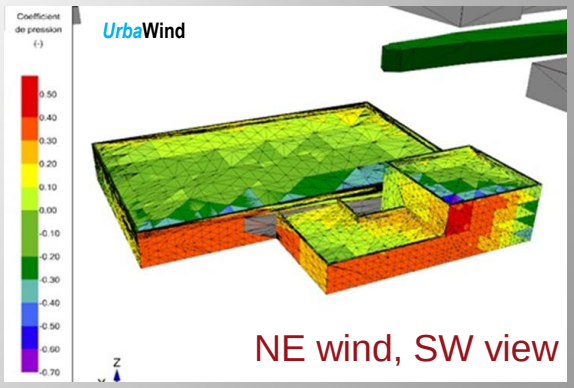




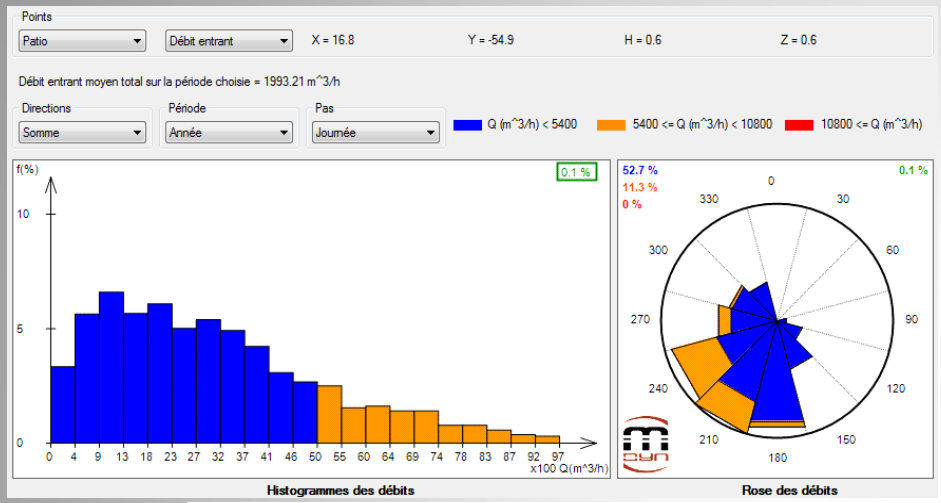


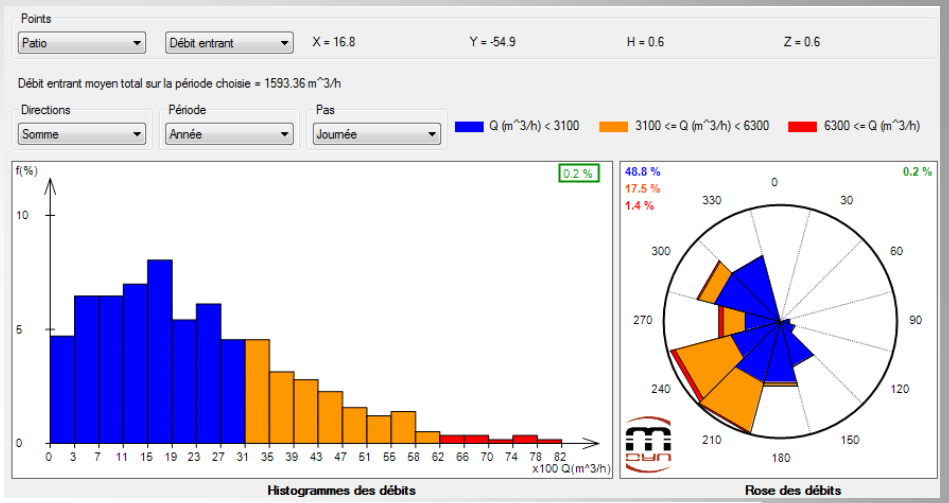
Pressure coefficient





Natural air ventilation (wind effects)



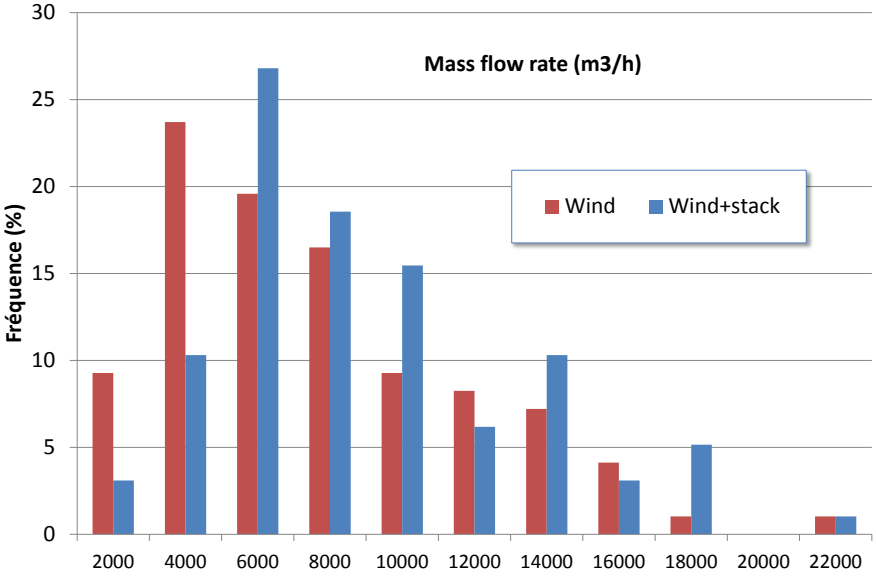


		SUMMER	FREE COOLING
	Average ACH	9600 m^3/h – ACH = 2.0 vol/h	7600 m^3/h ACH = 1.6 vol/h
INDUSTRIAL AREA	Input door	4830 m^3/h	4300 m^3/h
	Output door	4290 m^3/h	2910 m^3/h
	Average ACH	3860 m^3/h ACH = 6.7 vol/h	2900 m^3/h ACH = 5.1 vol/h
OFFICE	Input door	2000 m^3/h	1600 m^3/h
	Output door	1600 m^3/h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

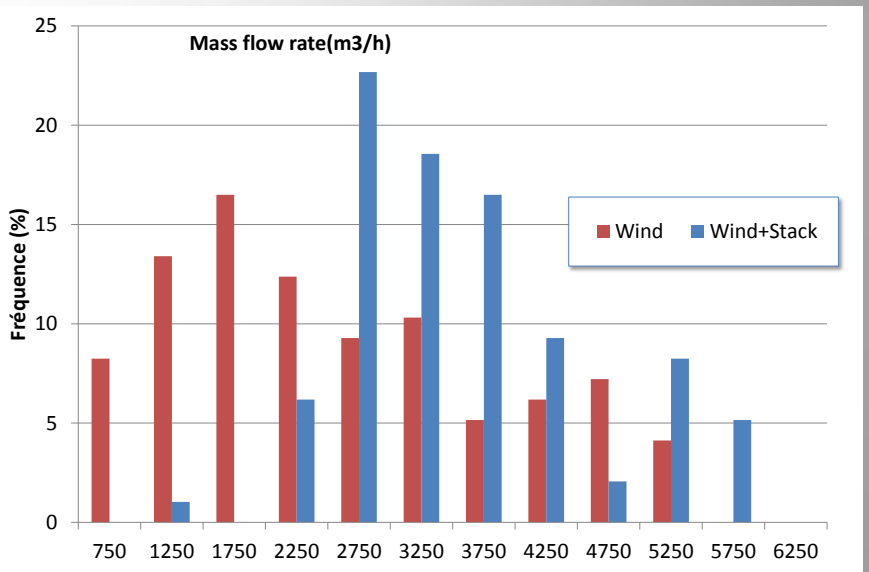
Natural air ventilation (wind and stack effects)

Add thermal pressure gradient due to stack effects

Tall volume (ACH +15%)



2 storeys building (ACH +40%)

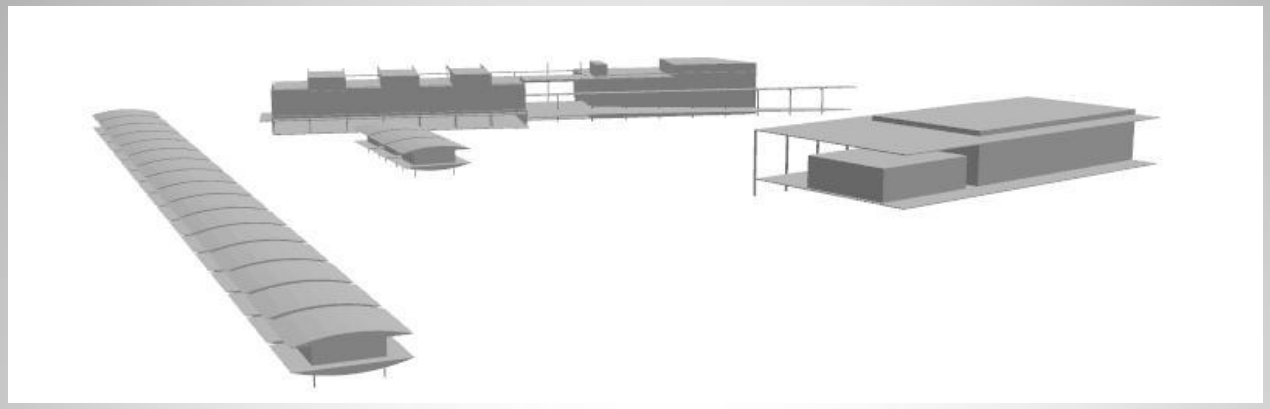


meteodyn
meteorology & dynamics

Example n°4

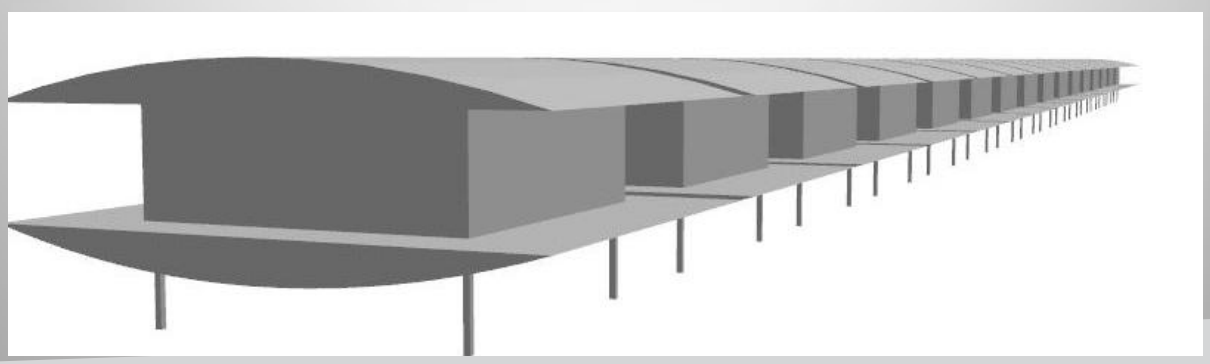
Natural ventilation of a secondary scholl
Kourou – French Guiana

Whole geometry of the secondary school



Optimisation of the cooling of the class rooms

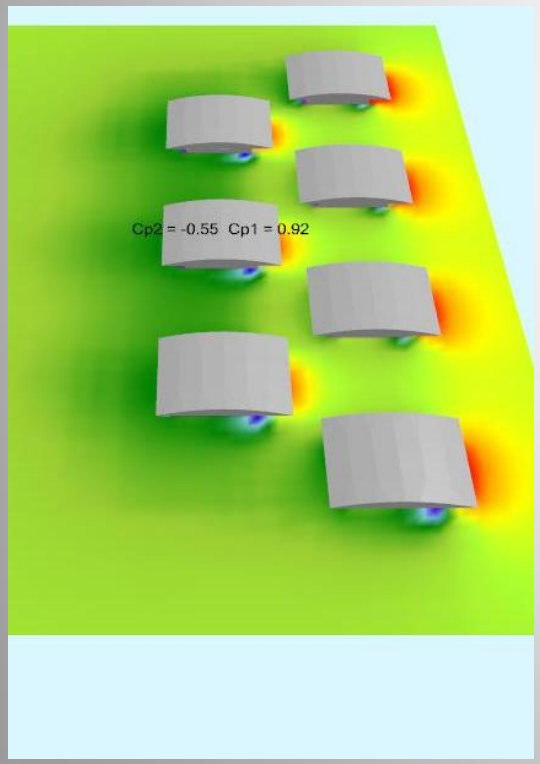
- depends on the configuration (line, V or grid)
- depends on the windows positions and aerodynamic behaviors

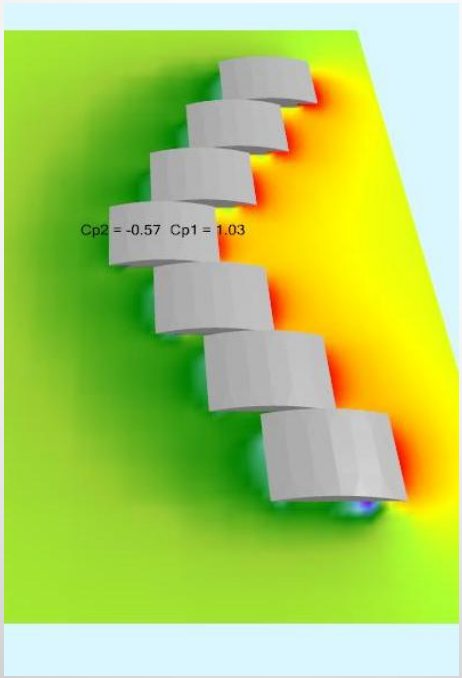


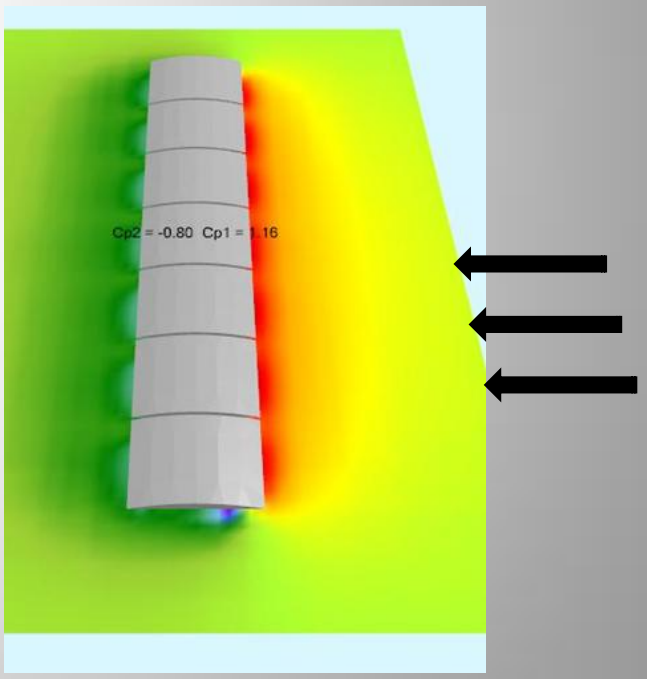
Pressure potentiel depends on configuration configuration

ΔCP=0.8 ΔCP=0.9 ΔCP=1.1

(href=10 m)

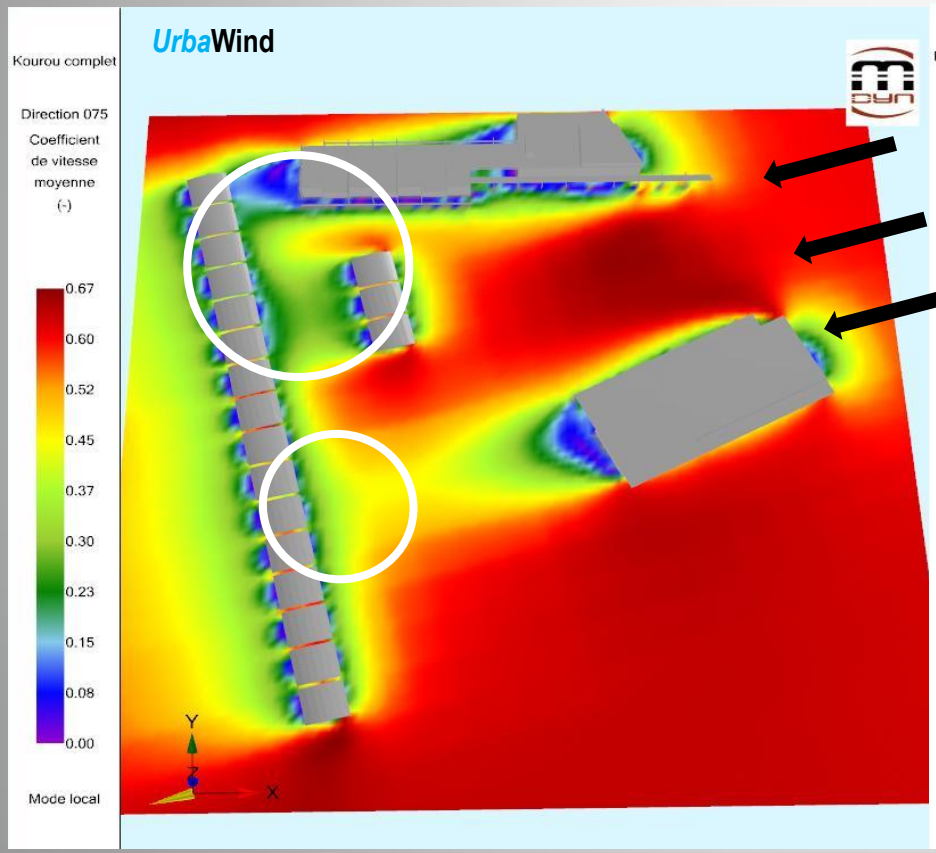




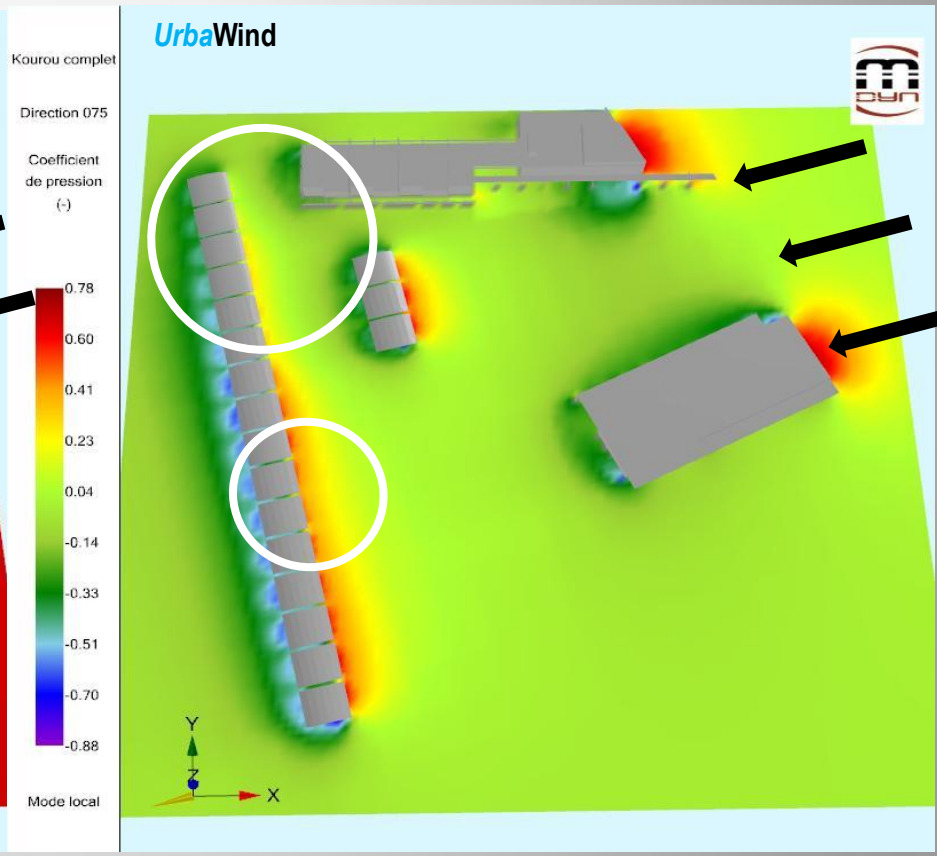


meteodyn
meteorology & dynamics

Mean speed up factor



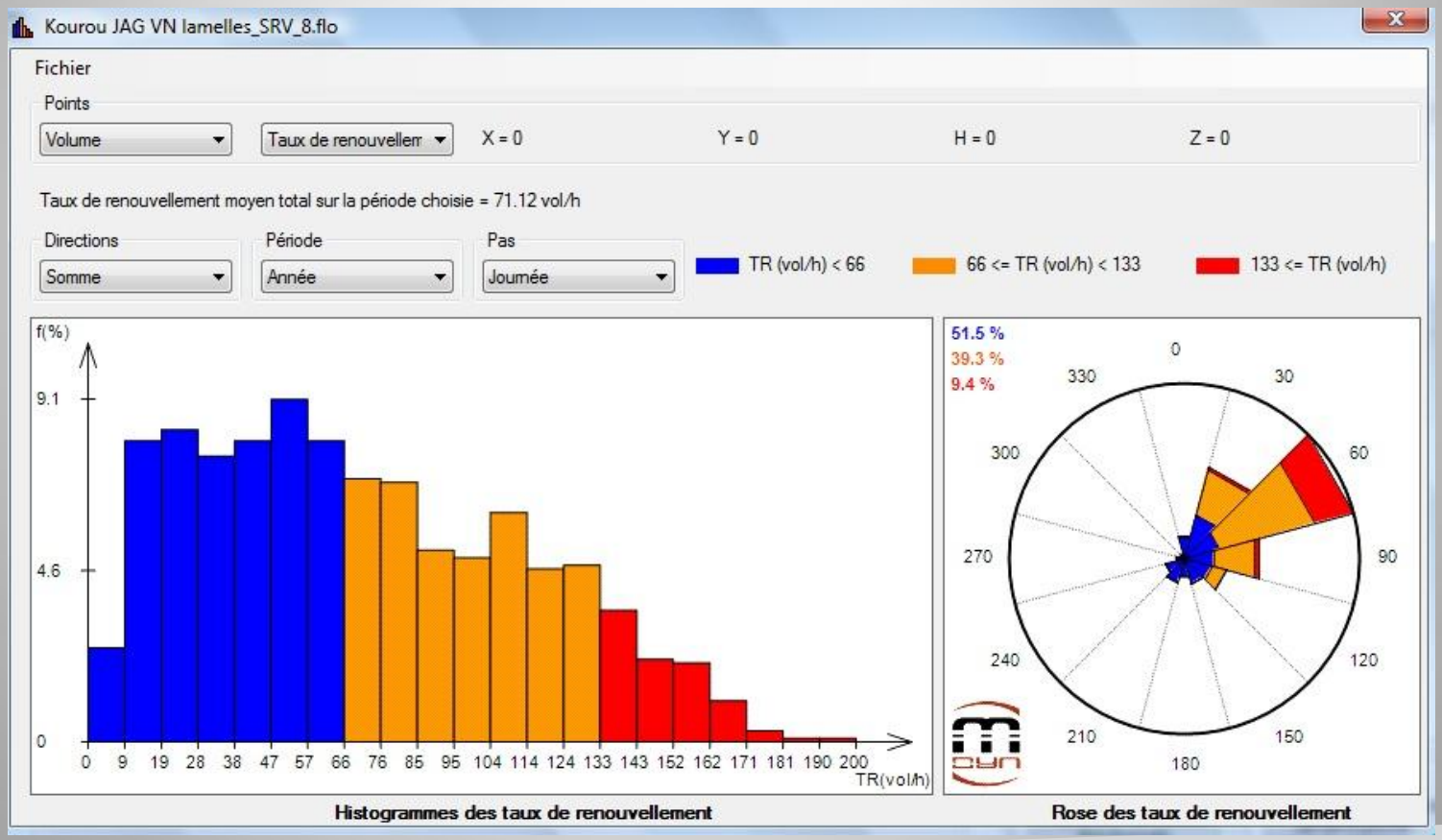
Mean pressure coefficient



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

⇒ ACH average = 71 Vol/h

⇒ 18% of time with ACH< 30 Vol/h



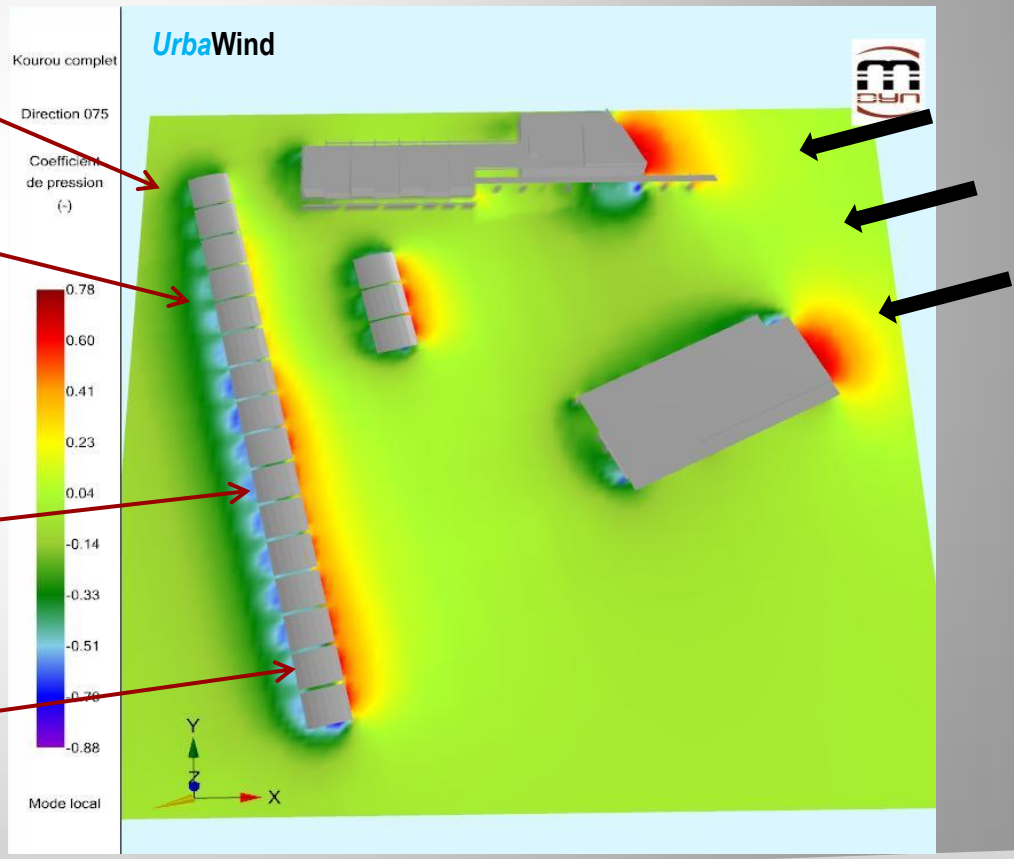
Decreasing of the air change rate compared to the detached configuration without the main bluidings

-18%

-22%

-6%

-9%



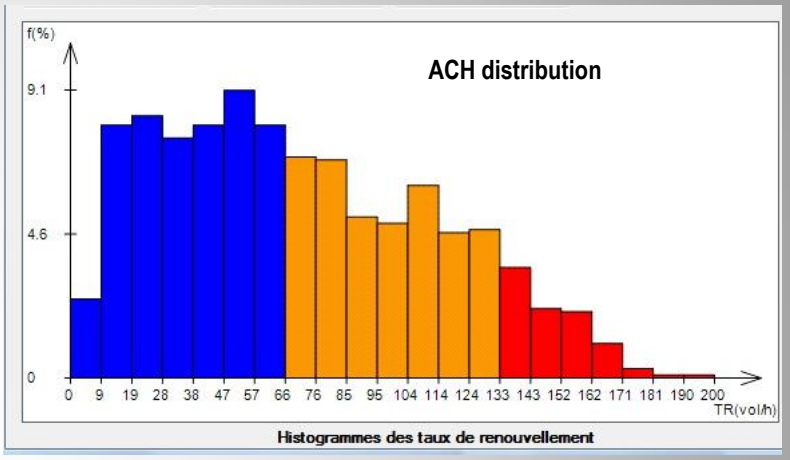
Further data for thermic tools

- ACH Statistics for average models

Distribution, frequence, mean, RMS

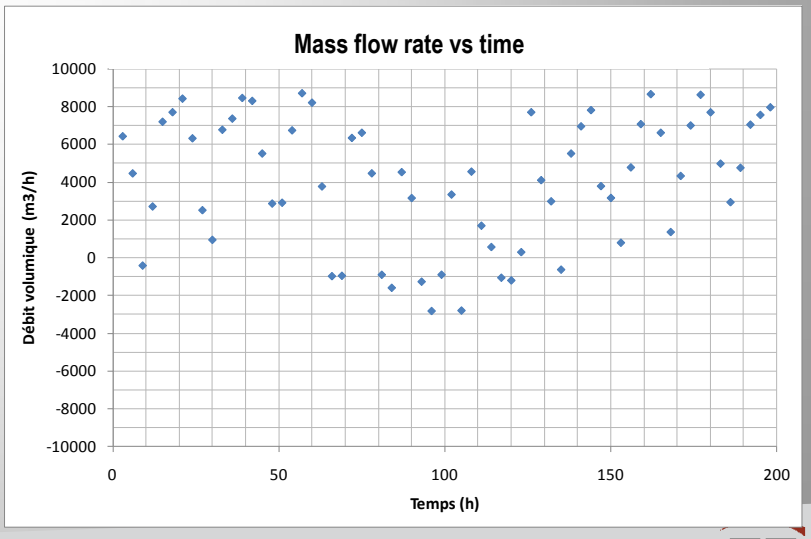
Day and night data, monthly…

- Indoor air velocity statistics



- Time series for the dynamic thermic models

Mass flow rate for each opening



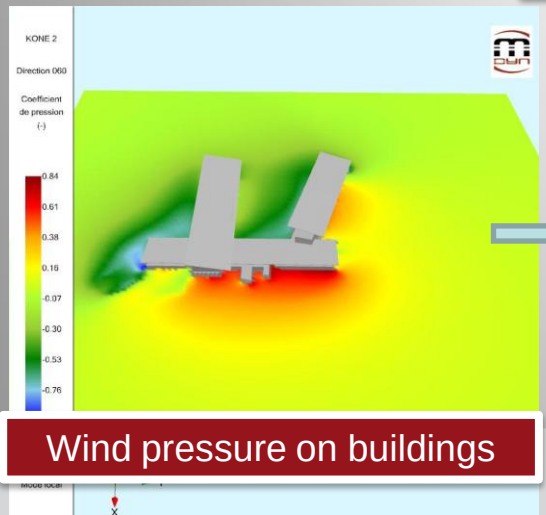
meteodyn
meteorology & dynamics

Others examples

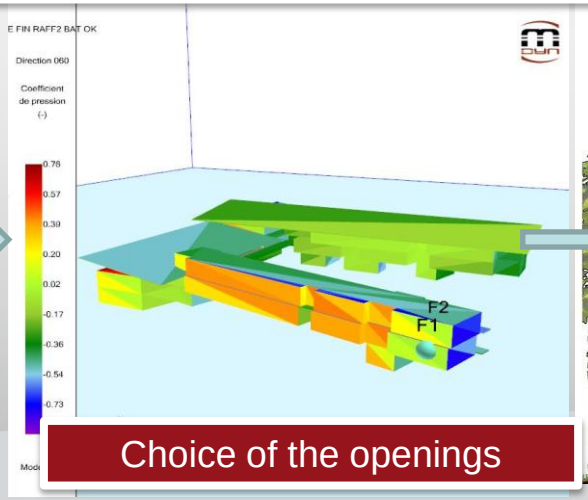
Architectural design competition assistance

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

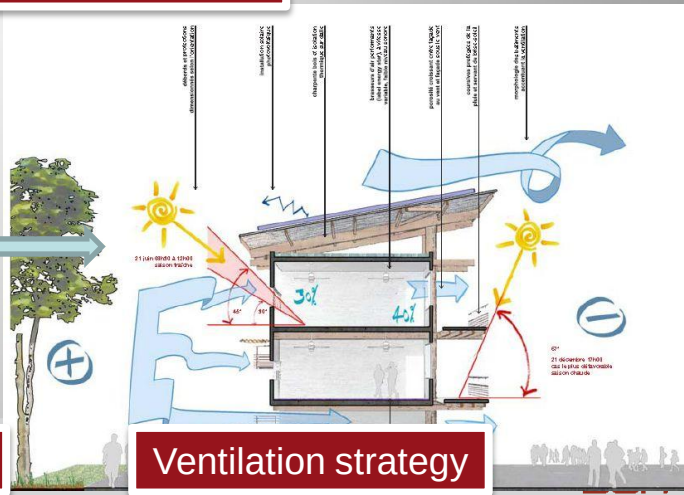
Assistance to define the ventilation strategy



Wind pressure on buildings

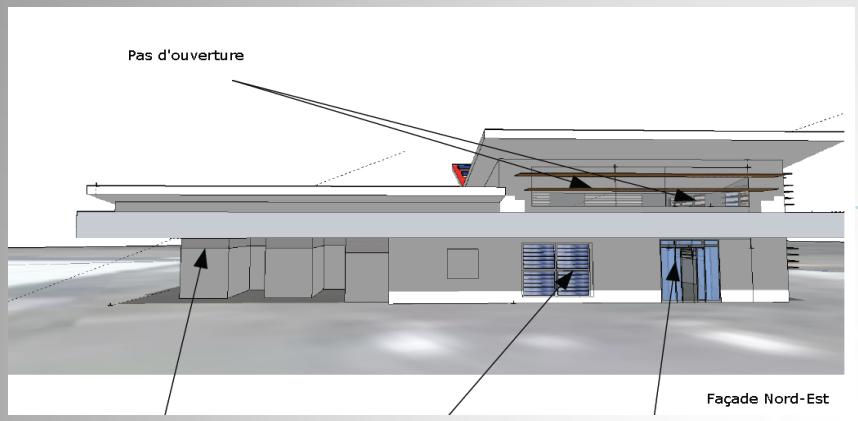


Choice of the openings



Ventilation strategy

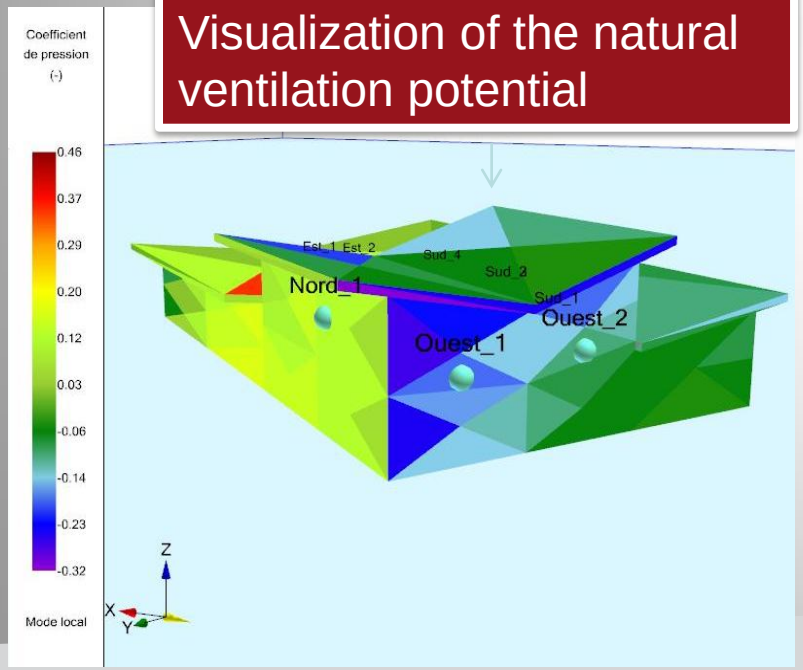
Diagnostic of the preliminary project design

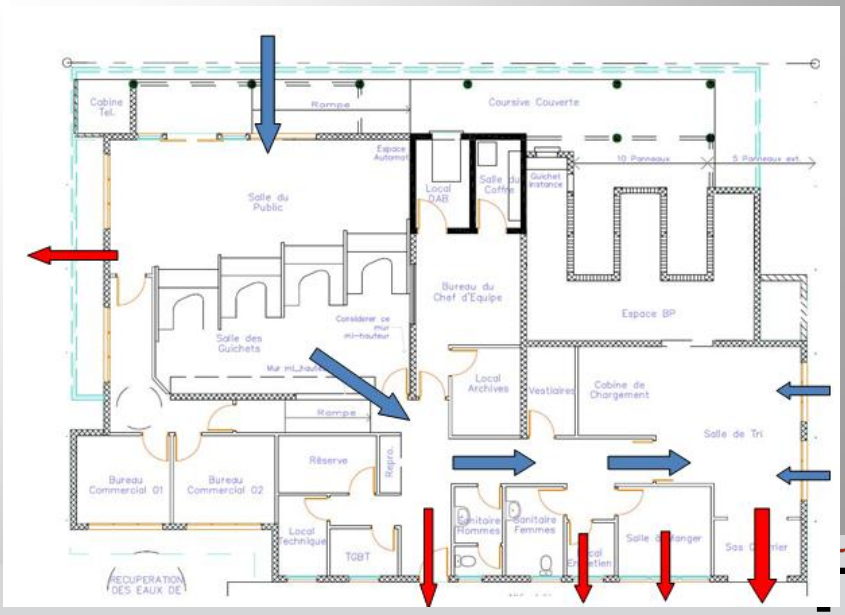


Validation of the project proposed by the Project designer to the Project owner

Diagnostic of the building ventilation scenario and mass flow assessment

Visualization of the natural ventilation potential

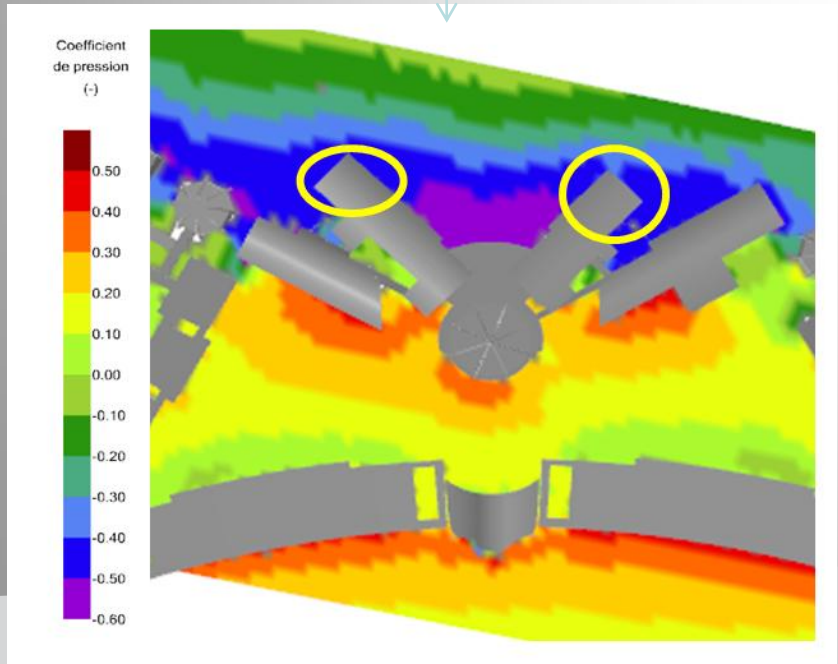




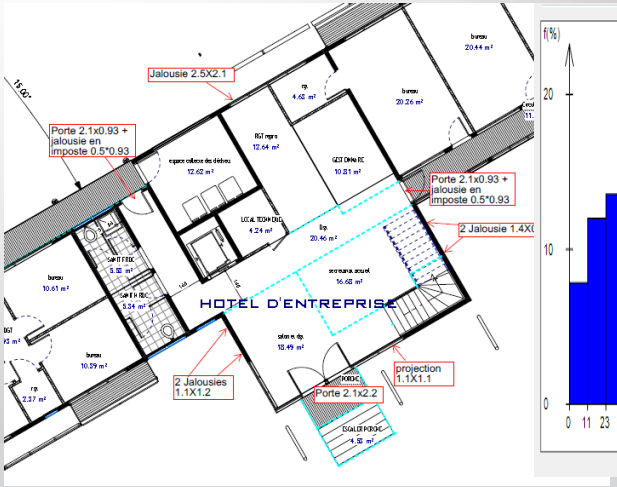
From the preliminary to the detailed project design

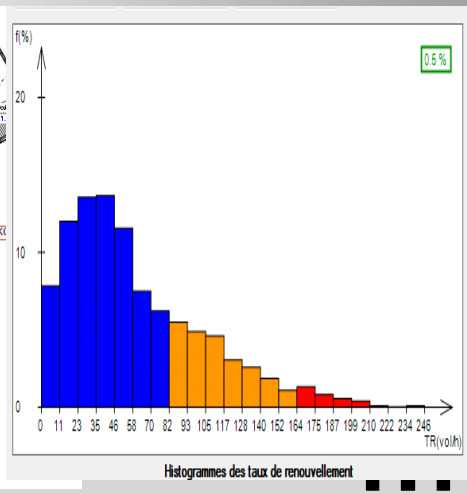
Validation of the project

Visualization of the natural ventilation potential and diagnostic



Interior architectures and openings validation
Data extraction for thermal software





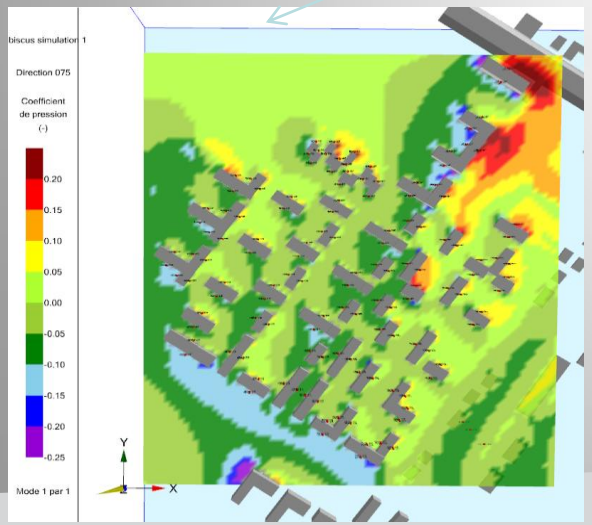
Histogrammes des taux de renouvellement

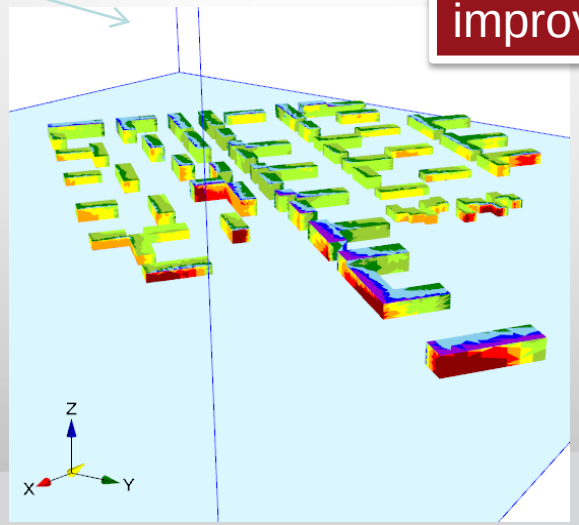
Design of “green” district

Planners’ project

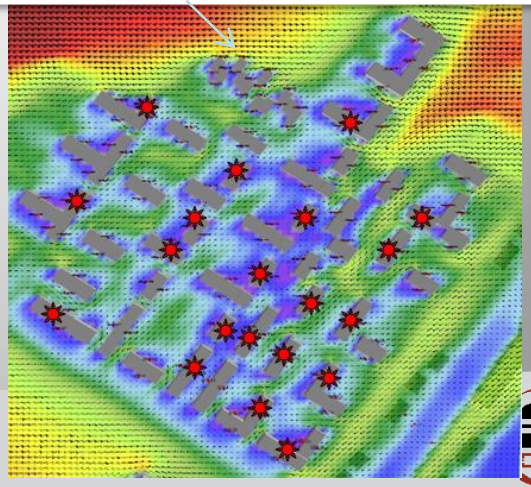
Time of computations :
120’/wind direction
3 Millions cells

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