EVALUATION OF WIND PRESSURE COEFFICIENTS ON FACADES AND OPENINGS TO CALCULATE NATURAL AIR FLOW RENEWAL AND THERMAL COMFORT IN BUILDINGS

Guillaume Dupont

Meteodyn America Inc., Philadelphia (PA)

Our activities

Development and Commercialization of CFD software dedicated to climatology

Consulting and expertise

Trainings and research programs

Our activities

Wind Energy

Construction Security

Urban Planning

Transportation Security

Background – Natural ventilation

✓ Reduce the energy consumption in buildings located in warm tropical climates in territories overseas.

✓ In La Reunion Island, 17% of buildings use HVAC – this rate has doubled over the last 5 years.

✓ French energy agency ADEME needs rules and tools for existing buildings in order to make buildings comfortable without artificial cooling.

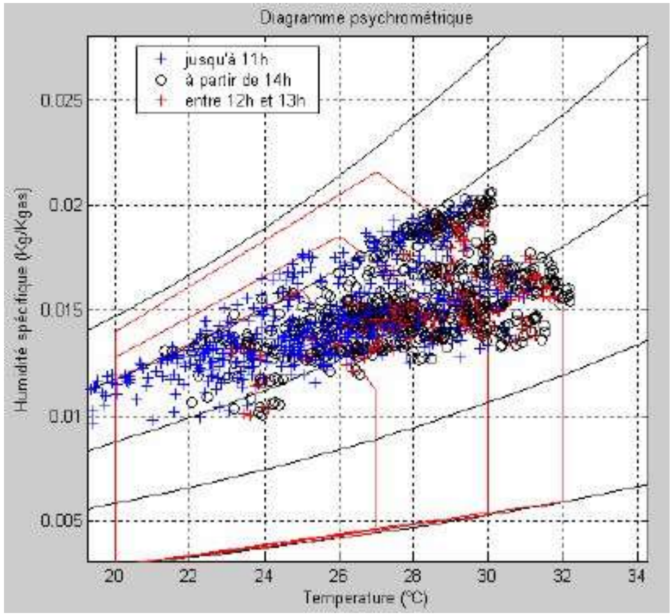
✓ Designers and architects need simple methods to assess the indoor thermal comfort in warm tropical climates.

⇒ ADEME developed BATIPEI. This tool quickly and easily indicates if air conditioning is needed.

Thermal comfort

The thermal comfort depends on:
- ✓ Indoor temperature
- ✓ Air flow on occupants
- ✓ Air humidity

The indoor temperature depends on:
- ✓ Air change rate
- ✓ Thermal characteristics of an envelope



Givoni's diagram: Thermal dynamic simulation in an office on La Réunion Island during the summer (Garde R., 2006)

In warm tropical climate, a building is well designed according to the thermal comfort criteria if:

- ✓ An Indoor mean temperature is close to the mean outdoor temperature
- ✓ A maximum temperature is lower than the acceptable temperature

How to calculate the indoor temperature?

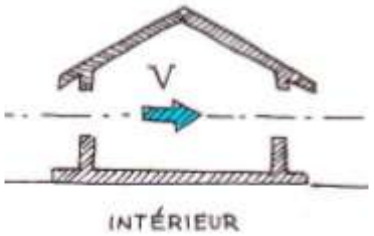
✓ Dynamic thermal modeling simulates the instantaneous physical behaviors of buildings with high accuracy.
✓ Numerous results are produced which requires an expert to link results to input data.
✓ Each parametric variation gives a whole variation and requires professional interpretation.

✓ BATIPEI was developed as a simple average method (Abdesselam, 1997) for tropical warm climates.
✓ Various parts of the building are identified within the energy balance to allow users to make adjustments based on comfort.
✓ Both approaches are complementary: the decision depends on the building complexity and the budget devoted to design.
✓ BATIPEI is used as a pedagogical method for less experienced designers.

How to calculate the Air Change Rate?

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

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



Aynsley formula (1977) 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

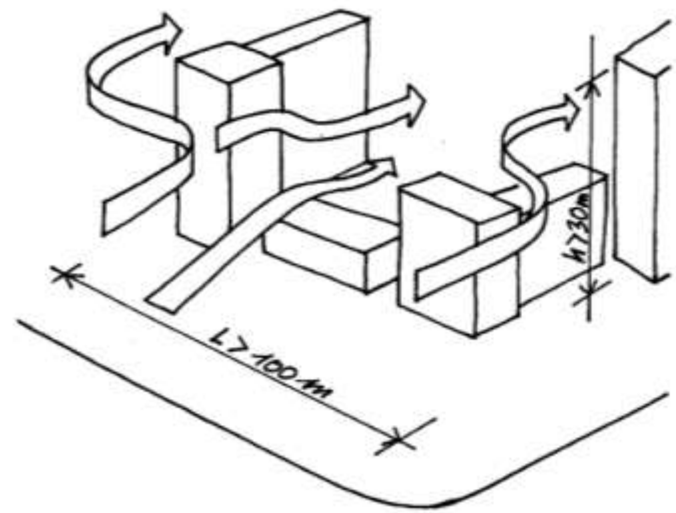
We need U_{WIND} and Cp_1 and Cp_2 to calculate the mass flow rate.

Tables (Liddament, Eurocode) and parametric models can be used for standard cases, that means for simple, isolated buildings.

meteodyn
meteorology & dynamics

How to calculate the Air Change Rate?

In urban configurations, wind velocity and pressure on buildings may not be easily evaluated.
Tables and analytic models cannot be used.
✓Experimental approach (Wind tunnel)
✓Numerical approach (CFD)



Mass flow rate could be evaluated with a network model providing:
- External pressure field
- Characteristics of openings (A,C)
- Indoor volume dimensions

Objective

Develop a simple method to assess the comfort levels in buildings in urban areas with warm tropical climates.

A CFD-Network tool combined with a thermal tool

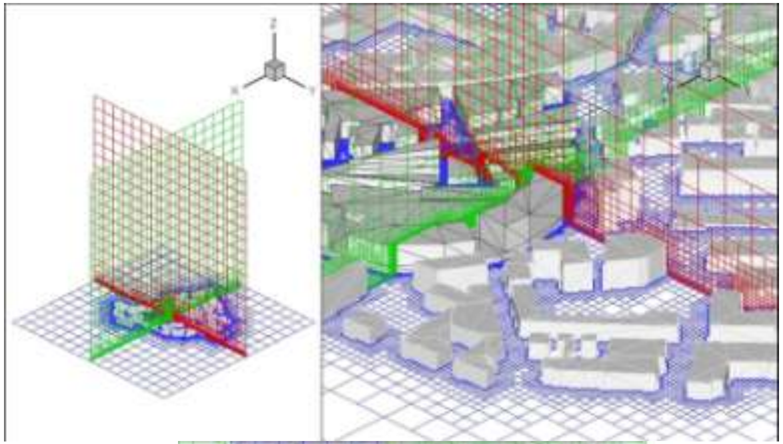
✓Computation of mass flow rates across the openings according to the local climatology: ***UrbaWind***
✓Computation of the mean overheating temperature as a comfort criteria: **BATIPEI**

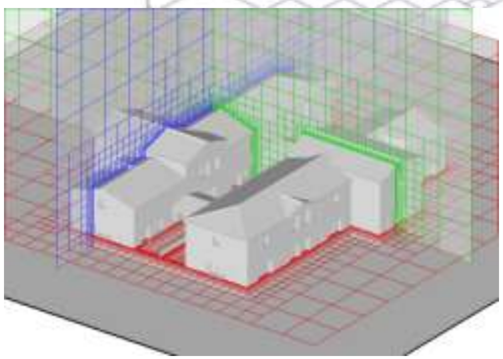
Case study: renovation of an entire block

meteodyn
meteorology & dynamics

The combined CFD-mean balance method
The CFD Tool: meshing

- ✓ **Automatic** and non-structured
- ✓ Horizontal and vertical **refinement** at key locations (points or physical surfaces)
- ✓ Default: 50 cm horizontal, 20 cm vertical
- ✓ For this application, only the outdoor spaces are meshed
- ✓ Typical Radius: 300 m => 1 M cells





The combined CFD-mean balance method
The CFD Tool: directional computations

The CFD calculation computes 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.

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

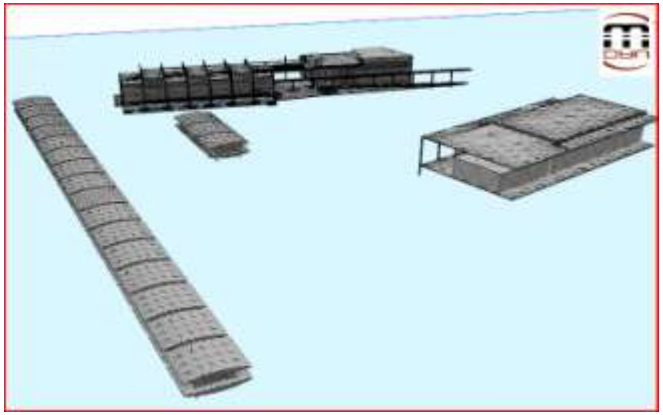
✓ The turbulent fluxes are parameterized by using the turbulent viscosity considered as the product of a length scale by a speed scale which are both characteristic lengths of the turbulent fluctuations.

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

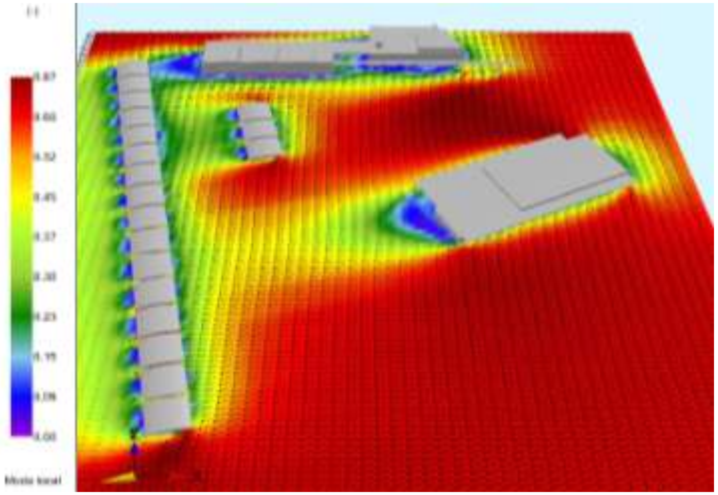
L_T varies linearly with the distance at the nearest wall (ground and buildings).

The combined CFD-mean balance method
The CFD Tool: directional computations

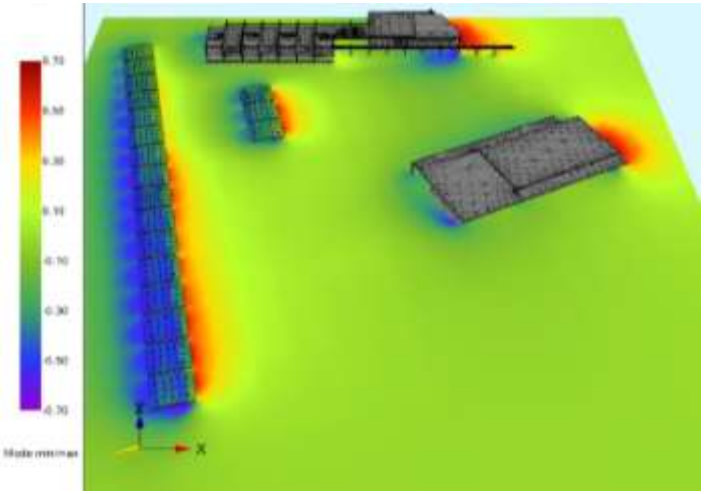
The CFD calculation computes the outside flow and the pressure field



Velocity field



Pressure field



The combined CFD-mean balance method
The CFD Tool: Air Change Rate

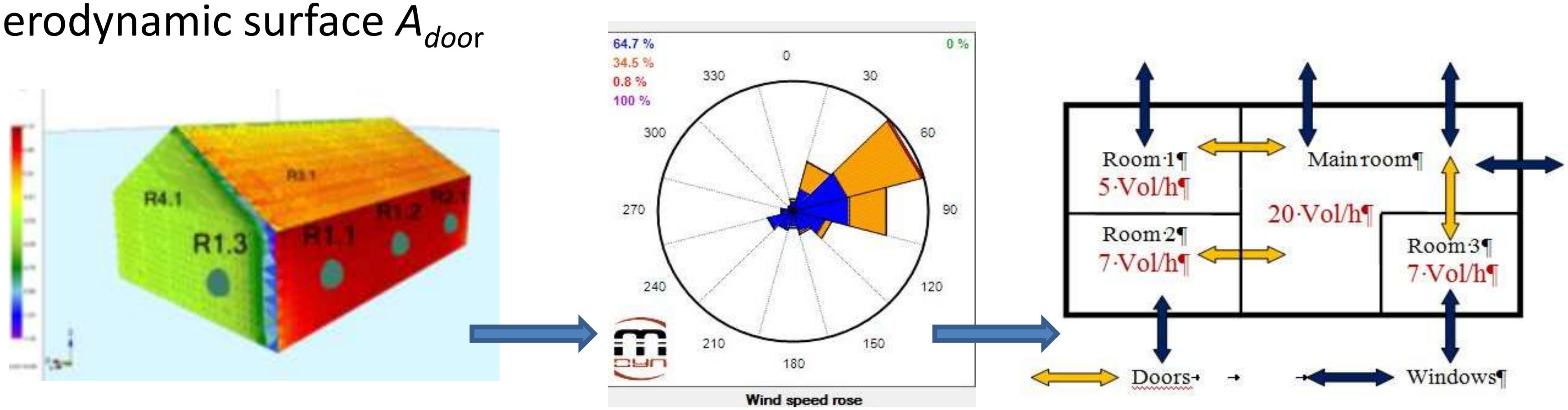
The Network calculation computes ACH based on CFD pressure field

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.

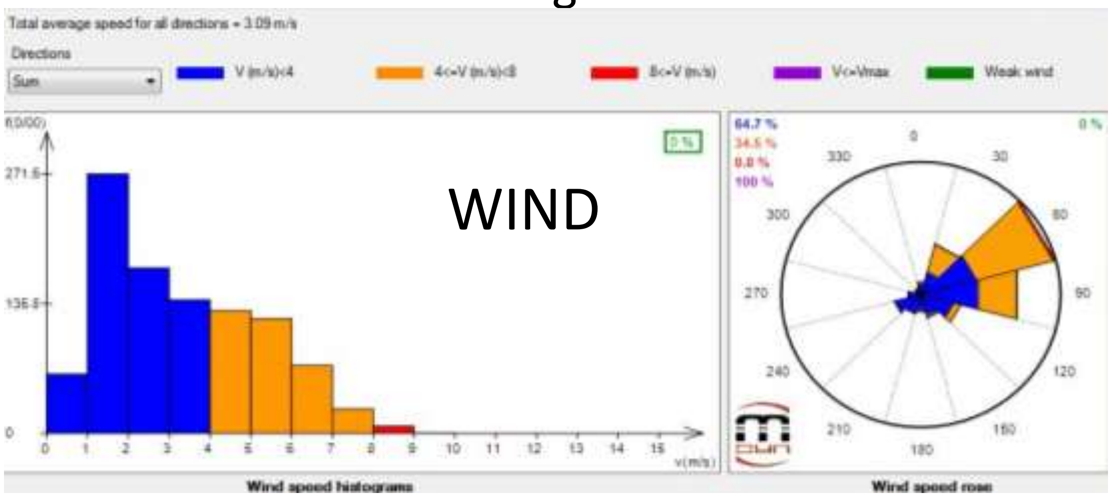
In the case of a multi-volume configuration, the k openings' aerodynamic area *Ak* is replaced by an equivalent aerodynamic surface taken into account the door aerodynamic surface A_{door}

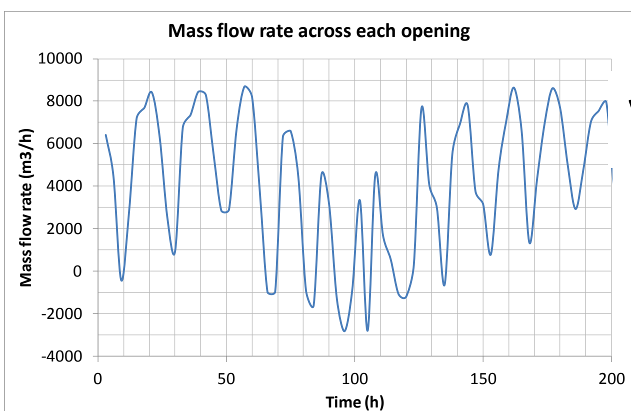


The combined CFD-mean balance method
The CFD Tool: directional computations

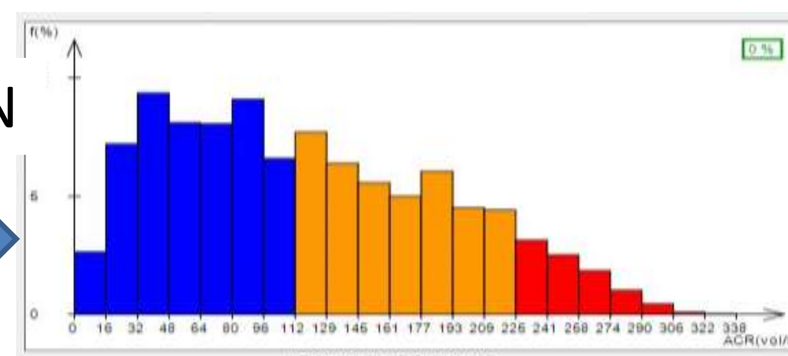
The Network part computes ACH based on CFD pressure field

UrbaWind provides wind roses, and distribution time series of the Air Change Rate



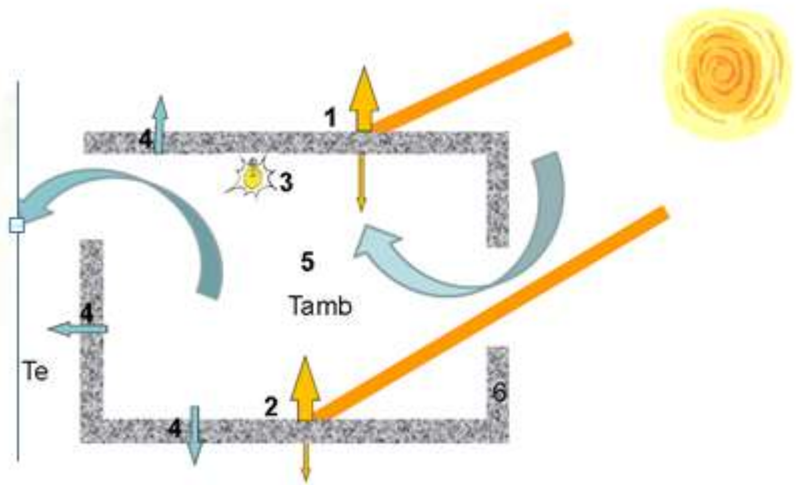


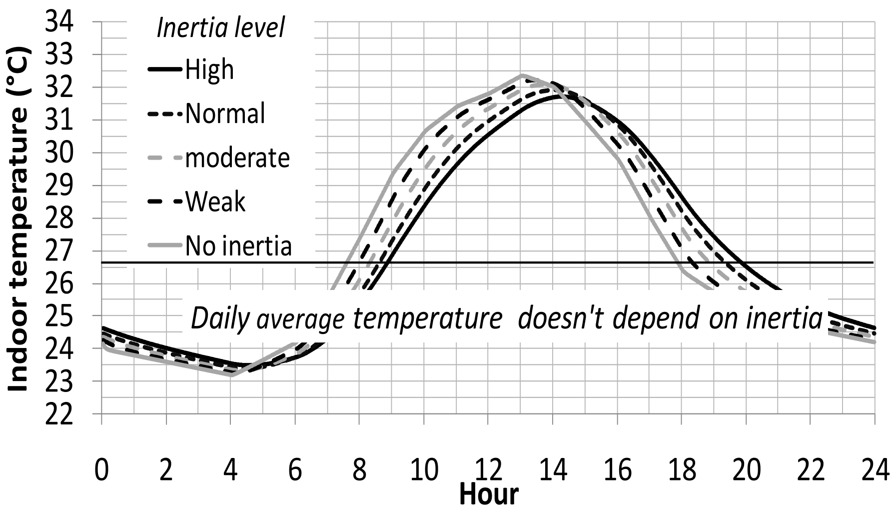
VENTILATION



The combined CFD-mean balance method
The Thermal Tool: Computation of the mean overheating of air indoor

- ✓ Requirement on Tmax becomes a requirement on ΔTs, the daily mean overheating
- ✓ Developed and validated for warm, oceanic tropical climates (BATIPEI©)
- ✓ Regardless of the thermal inertia, comfort is reached if ΔTs does not exceed 2°C
- ✓ The influence of inertia on ΔTmax is lower than ½°C: second order parameter compared to the influence of ACH



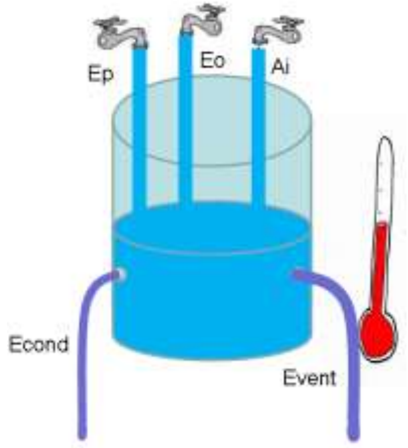


The combined CFD-mean balance method
The Thermal Tool: Computation of the mean overheating of air indoor

The energy balance written on a daily cycle is:

✓The gains: the solar radiation received by the room's indoor air from the wall by conduction (E_{sun}), transmitted directly through the openings (E_o), and the internal gains (E_{int}).
✓The losses given to the environment by conduction through the envelope (E_c) or with the air change rate (E_{ach}).

$$E_{sun} + E_o + E_{int} = E_c + E_{ach}$$



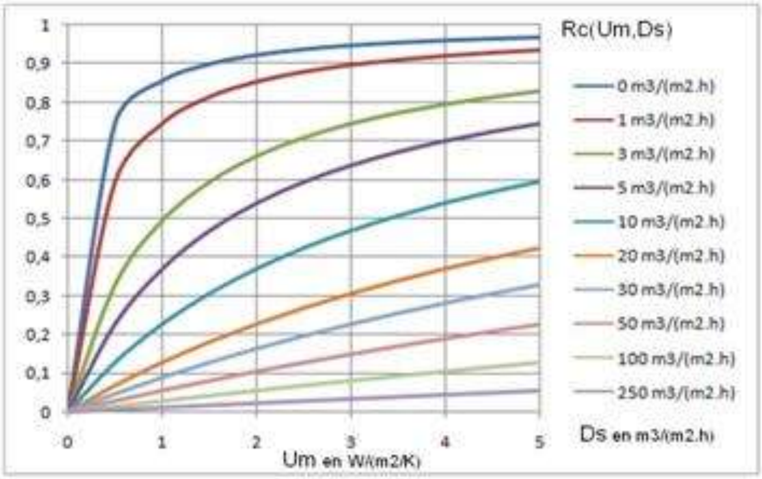
The combined CFD-mean balance method
The Thermal Tool: Computation of the mean overheating of air indoor

ΔTs, the mean daily overheating is estimated without ventilation

$$\Delta T_S(D=0) = \frac{1}{U_m A}\left[\sum_j A_j \frac{U_j}{h_{o\,j}} \frac{E_{w\,j}}{T} + \sum_j A_j \left(\sum_i \frac{E_{so\,i}}{T}\right)\left(1-\frac{U_j}{h_{i\,j}}\right)\right]$$

$$D = ACH\ V/A$$

$$\Delta T_S = R_C(U_m, D) \times \Delta T_S(D=0)$$



Um: the mean conductance of the building

D: specific mass flow rate

The more insulated the building is (low value of U_m), the more efficient the air change rate is.

For medium sized isolated buildings ($2 < U_m < 4$), the mean overheating is reduced by about 2/3 as soon as ACH is in the range 10 to 20 volumes an hour.

The combined CFD-mean balance method

The Thermal Tool: a simple tool for designers

meteodyn
meteorology & dynamics

Area, Conductance, Shadow, Color — Overheating

The roof and the walls

PAROIS OPAQUES	Interventions envisagées	Surface	Conductance	Masques	Couleur	Ventilation bardage/comble	Transmission solaire	Poids thermique	Ensol Moy en Wh	Surchauffe en °C
Toiture		185.42	0.51	1.00	0.80	0.60	0.01	0.168	7099.00	0.61
Plancher		185.42	0.00				0.00	0.000	0.00	0.00
Façades										
Nord		42.87	3.18	1.00	0.30	1.00	0.07	0.242	3405.30	2.43
Nord EST		0.00	0.00	1.00	0.00	1.00	0.00	0.000	3255.56	0.00
EST		42.69	3.18	1.00	0.30	1.00	0.07	0.241	3083.63	2.19
Sud EST		0.00	0.00	1.00	0.00	1.00	0.00	0.000	2268.35	0.00
Sud		33.57	3.18	1.00	0.30	1.00	0.07	0.190	1430.89	0.80
Sud ouest		0.00	0.00	1.00	0.00	1.00	0.00	0.000	2261.70	0.00
Ouest		43.92	1.66	1.00	0.30	1.00	0.04	0.133	3094.72	0.63
Ouest Nord		0.00	0.00	1.00	0.00	1.00	0.00	0.000	3250.01	0.00
										6.66

The openings

OUVERTURES	Interventions envisagées	Surface	Conductance	Masques	Facteur de transmission		FtxFmasque solaire	Pondération surface	Ensol Moy	Surchauffe en °C
Nord		1.68	5.00	1.00	0.68		0.68	0.003	3405.30	0.25
Nord EST		0.00	0.00	1.00	0.00		0.00	0.000	3255.56	0.00
EST		2.52	0.00	1.00	0.80		0.80	0.005	3083.63	0.40
Sud EST		0.00	0.00	1.00	0.00		0.00	0.000	2268.35	0.00
Sud		1.68	5.00	1.00	0.68		0.68	0.003	1430.89	0.11
Sud ouest		0.00	0.00	1.00	0.00		0.00	0.000	2261.70	0.00
Ouest		10.68	0.00	0.45	0.80		0.36	0.019	3094.72	0.77
Ouest Nord		0.00	0.00	1.00	0.00		0.00	0.000	3250.01	0.00
		16.56	1.01						Total ouvertures	**1.52**

The internal gains

Apports internes	Interventions envisagées	Quantité	Ratio	nb heures	Energie dissipée	Surchauffe en °C
Occupants		4.00	70.00	15.00	4200.00	0.31
Eclairage		15.00	60.00	3.00	2700.00	0.20
Appareils		5.00	500.00	3.00	7500.00	0.55
					Total apports internes	**1.07**

Results: ACH=0

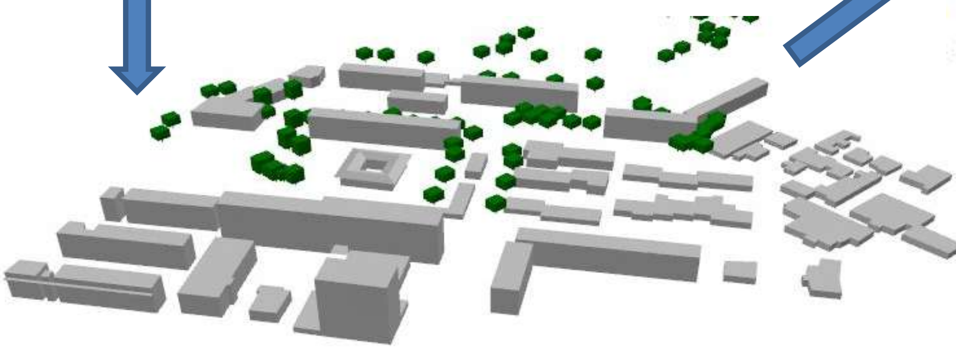
Surchauffe totale potentielle sans renouvellement d'air	**9.25**

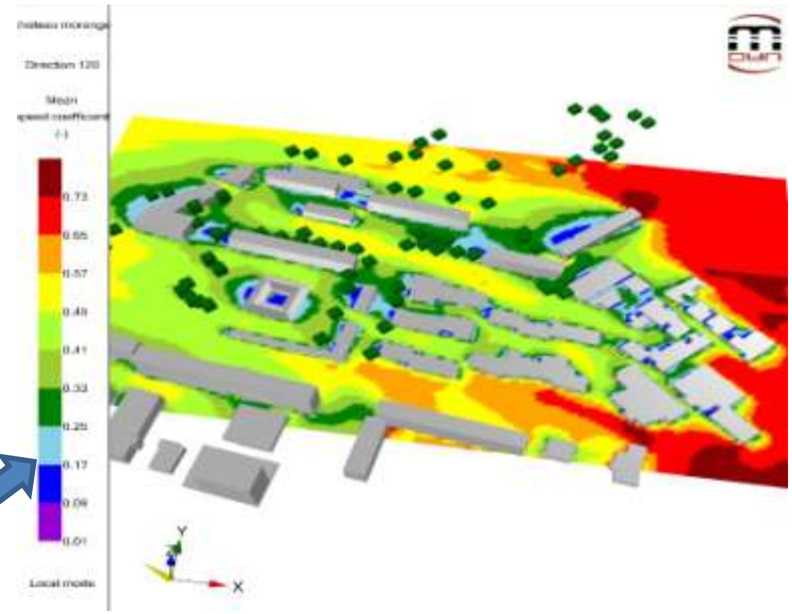
ACH(min)
ACH(mean)

SURCHAUFFE TOTALE AVEC VENTILATION NATURELLE	Interventions envisagées	Surface plancher	volume	Renouvellement d'air	en vol/h	coefficient Rc	Surchauffe avec vent .en °C
		60.00	135.00	Conventionnel	10	0.[illegible]5	**5.09**
				Calculé	30	0.29	**2.68**

Case Study: an urban block on La Reunion Island

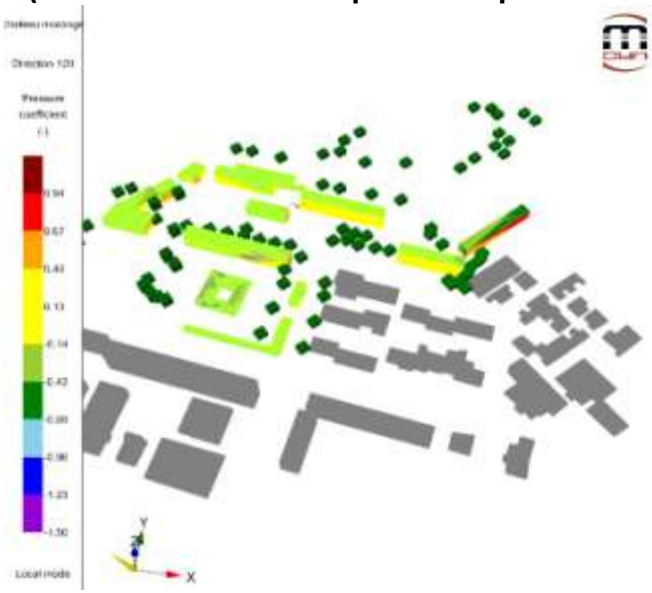
First step: block geometry and directional computations (12 directions)

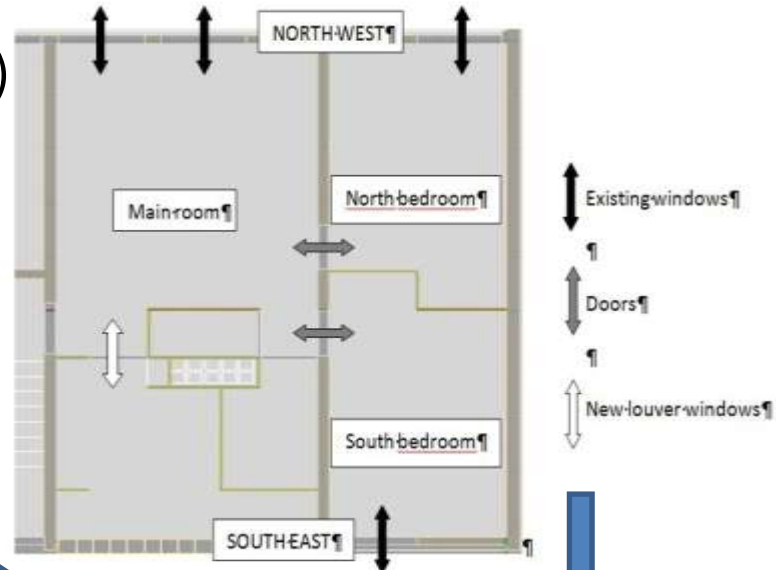


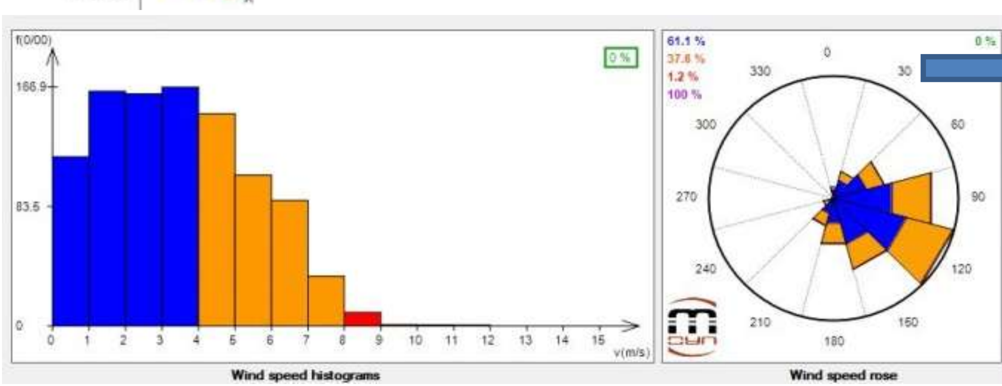


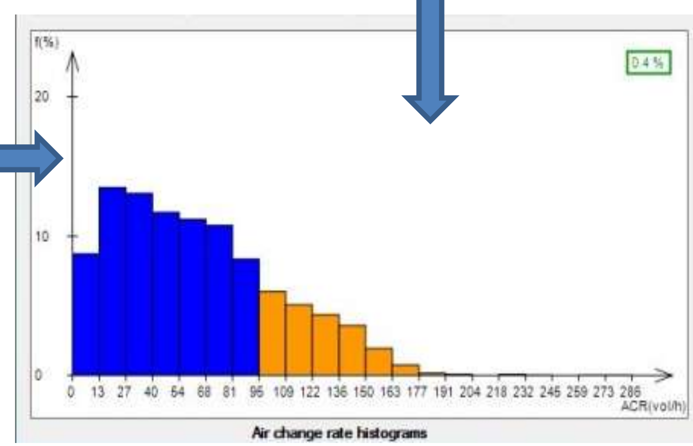
Case Study: an urban block on La Reunion Island

Second step: ACH computations
(each time step is equal to one year)









meteodyn
meteorology & dynamics

Case Study: an urban block on La Reunion Island

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

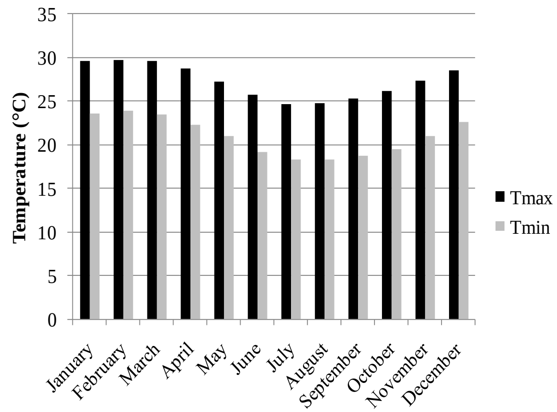
CASES	<ACH>	ACH (P<0.05) ACH MINI
North: 3 windows South: 1 window Doors: opened	65 Vol/h	9 Vol/h
North: 3 windows South: 1 window Doors: enlarged	90 Vol/h	13 Vol/h
North: 3 windows South: 2 windows (1.4 m^2 + 1 m^2) Doors: opened	105 Vol/h	15 Vol/h
North: 3 windows South: 2 windows (1.4 m^2 + 2 m^2)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

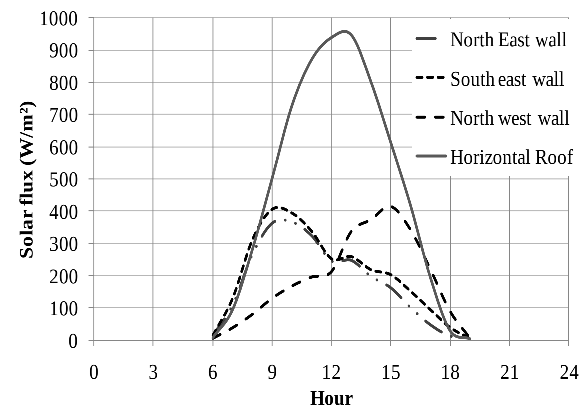
Case Study: an urban block on La Reunion Island

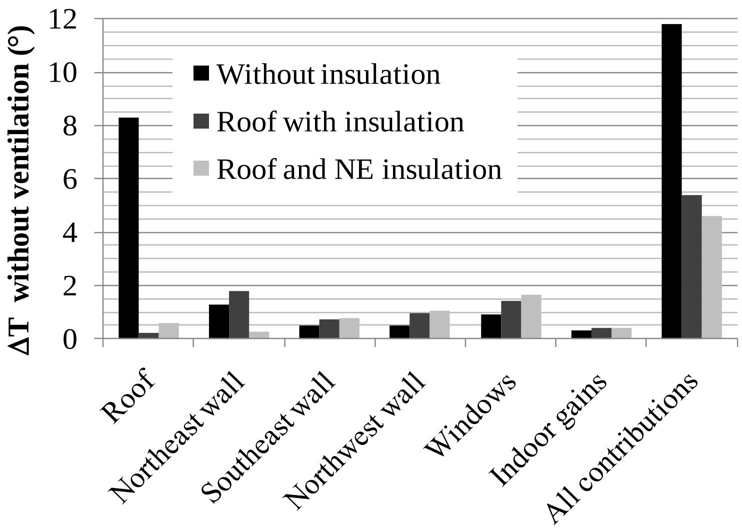
<u>Fourth step</u>: Thermal approach: how to reduce the overheating of indoor air? Insulation and Ventilation

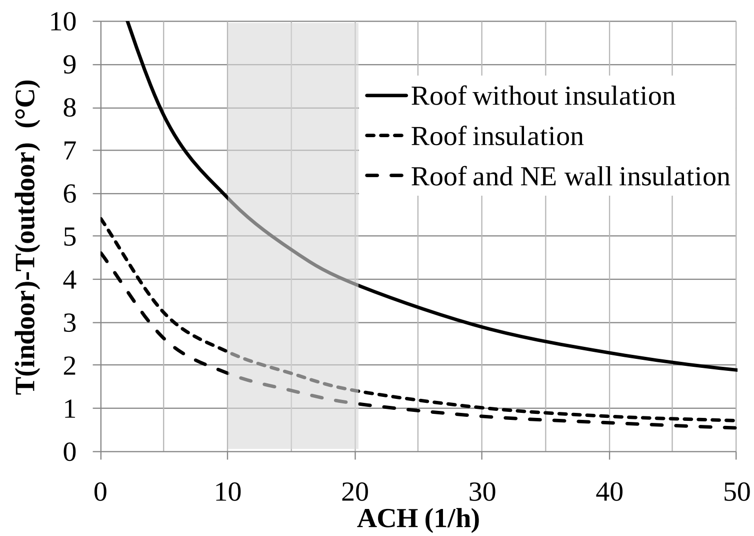
Climatic input data:
T<32°C => ΔTs<2°C

Who 's responsible?









Conclusions

A simple method was developed to assess the comfort of buildings in urban area in warm tropical climate:

✓A method was developed for designers who want to understand which elements of the building are responsible for overheating.

✓A CFD-Network tool was combined with a thermal tool

✓Computation of the mass flow rates through the openings according to the local climatology

✓Computation of the mean overheating temperature as comfort criteria

Contact information

Guillaume Dupont
General Manager
Meteodyn America Inc.

Guillaume.dupont@meteodyn.com
T: (1) 215 545 1687
M: (1) 267 475 4278
F: (1) 215 279 8702