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Design methodology and evaluation of wind harvesting devices Integrated to buildings

Conference on Advanced Building Skins

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ABSTRACT

Architects and designers are encouraged to use energy harvesting devices as a strategy to balance energy consumptions of buildings, aiming to minimize the maintenance cost of buildings and meet the criteria of net-zero energy. This research aims to provide simple and straightforward design methodology to architects to integrate wind harvesting energy devices to their project.

The proposed design method considers orientation and scale of buildings, contextual conditions, as well as on-site wind speed data to optimize building-integrated devices (BID) performance and financial efficiency of the energy produced. It will achieve a more efficient resource utilization by better integration of devices to buildings and by repartition of cluster of devices over large surfaces. Building envelopes are becoming smarter; Building's façade or rooftops are available for new function of building-integrated device (BID), such as photovoltaic panels and wind turbines to produce clean energy.

Following an in-depth analysis on the performance and behavior of existing building that integrates BID devices, we further studied the relationship between building design and BID. The goal is to developed strategies to compensate the unstable performance of BID caused by air flow turbulences and to optimize the wind amplification effect of buildings.

Combining wind analysis in an open circuit wind tunnel as well as computational fluid dynamic (CFD) software ANSYS

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Fluent, we simulated the reaction between wind and several building typologies to predict potential extracted energy by measuring wind speed enhancement (the extracted energy depends on the cube of the wind speed). The geometry of buildings makes contributions to wind speed enhancement.

KEY WORDS:

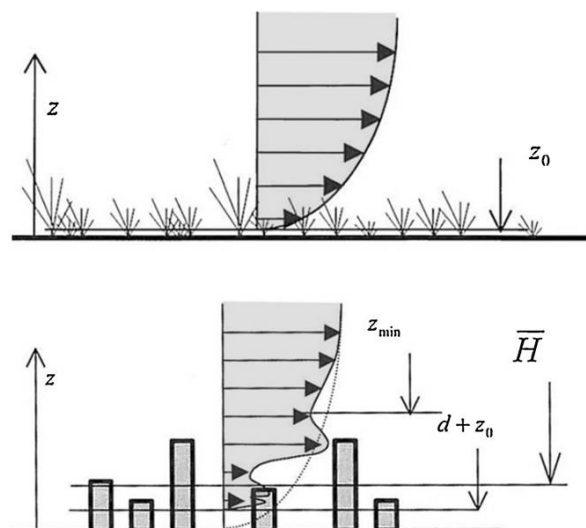
- 1 Wind Energy Harvesting Devices
- 2 Net-Zero Energy Building
- 3 Urban wind behavior Simulation
- 4 Internet of Energy
- 5 Advanced building skin design methodology
- 6 Building Integration Strategy

BULLET POINTS (3)

1. Wind and well-designed integrated micro-turbine have a strong potential to efficiently reduce building energy consumption.
2. Buildings make contribution to wind speed enhancement which can be precisely calculated and mastered by energy harvesting devices
3. This research aims to propose a simple design methodology for architects to efficient design building integrated devices to building.

1. Wind and buildings, localization of maximum wind speed

Wind is the air motion relative to the earth that is created by difference in atmospheric pressure caused by difference in temperature due to the intensity of solar radiation reaching the earth's surface^[1]. Main wind characteristics such as surface drag, scales and intensity of turbulence, wind speed, and the wind profile in urban areas are greatly affected by roughness properties of the urban areas^[2]. The surface roughness that results to a high turbulence zone as shown in Fig. 1 greatly influences the wind speed and direction, hence its extractable power^[3].



When air hits buildings and other obstacles in the urban environment, a resultant complex air whirls or waves are formed as shown in Fig. 2. A combination of building shape, height and distance between buildings affects the direction and intensity of wind flow and can potentially affect its extraction for energy in urban environment.

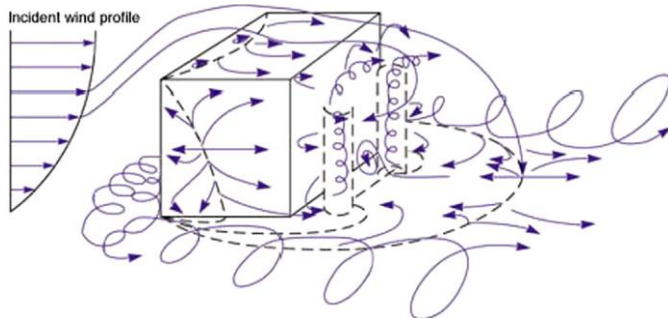


Fig 2: Different typologies of wind turbulence

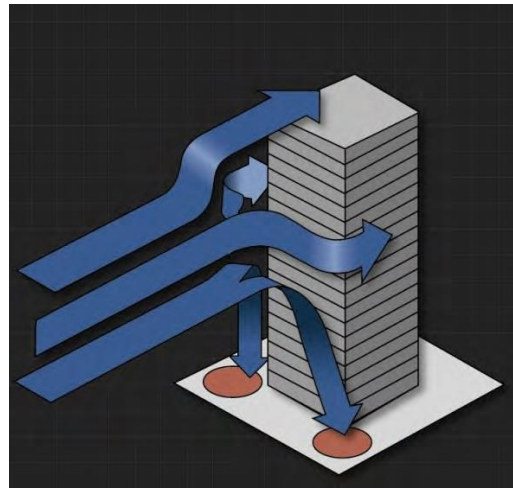


Fig 3 : Effect of wind on tall buildings^[4]

1.1 Wind flow characteristics in the urban canopy layer:

In the urban canopy layer, the flow is almost completely governed by street or canyons' geometry (aspect ratio and length-to-depth ratios) and building height distribution especially in urban sections where buildings are closely spaced and a skimming flow pattern takes place^[5, 6].

1.2 Wind flow characteristics along rivers, seaside and open areas:

Within the urban environment, wind speed is generally greatest when the wind flows parallel to the river. However, lower relative wind speeds can be found when the approach airflow is perpendicular to the river due to change in aerodynamic drag. The air flowing over the river generally becomes less turbulent after passing through the building^[7].

1.3 Turbulence intensity

Turbulence can be thought of as fluctuations in air flow, Turbulence Intensity is a scale characterizing turbulence expressed as a percentage. The turbulence intensity, I , is defined as the ratio of the root-mean-square of the velocity fluctuations, u' , to the mean free stream velocity, u .

$$I = \frac{u'}{u}$$

1.4 Assessment Of Urban Wind Turbulence

Since wind profiles in urban areas tend to be more turbulent due to the presence of buildings, trees along the streets, and other obstacles^[8], computational wind engineering (CWE) has been developed recently to evaluate the interaction between wind and buildings. A number of different techniques have been employed in CFD simulations including: Direct Numerical Simulation (DNS) ^[9]; Large Eddy Simulation (LES) ^[10], or the Reynolds-Averaged Naviere Stokes (RANS) method with various turbulence models. The choice is generally made based

on the details of the flow to be obtained and the computing resources available^[11]. CFD modeling is used in our research to determine the effects of the building at points where a turbine might be integrated.

2. Wind power density calculation

The energy produced by a BID is an important information for the development of the research. The wind extractable power is estimated by the following equation:

$$\text{Power} = \frac{1}{2} \times \rho \times A \times V^3 \times C_p$$

$$C_p \text{ max} = 0.59,$$

$$\rho \text{ (air density)} = 1.23 \text{ kg/m}^3$$

$$A = \pi r^2 = 1/4 \pi D^2$$

Based on the wind extractable power equation for horizontal-axis wind turbine, which integrated with the Betz Limit already, we learned the following:

$$\text{Power} = 0.12 \times D^2 \times V^3$$

Given the identical wind harvesting device (consistent turbine diameter), the wind extractable power is only determined by the inlet wind velocity.

The study in fluid dynamics simulation of a section of a building shows that its localization and profile have an immediate impact on wind speed around the building. An animation showing wind speed behavior in time, demonstrates that hotspots where wind speed can be 2 to 3 times higher than air inlet velocity are fluctuating to specific zones around the building edge and skin. How could we as architects take advantage of this situation to propose specific harvesting devices and building usage?

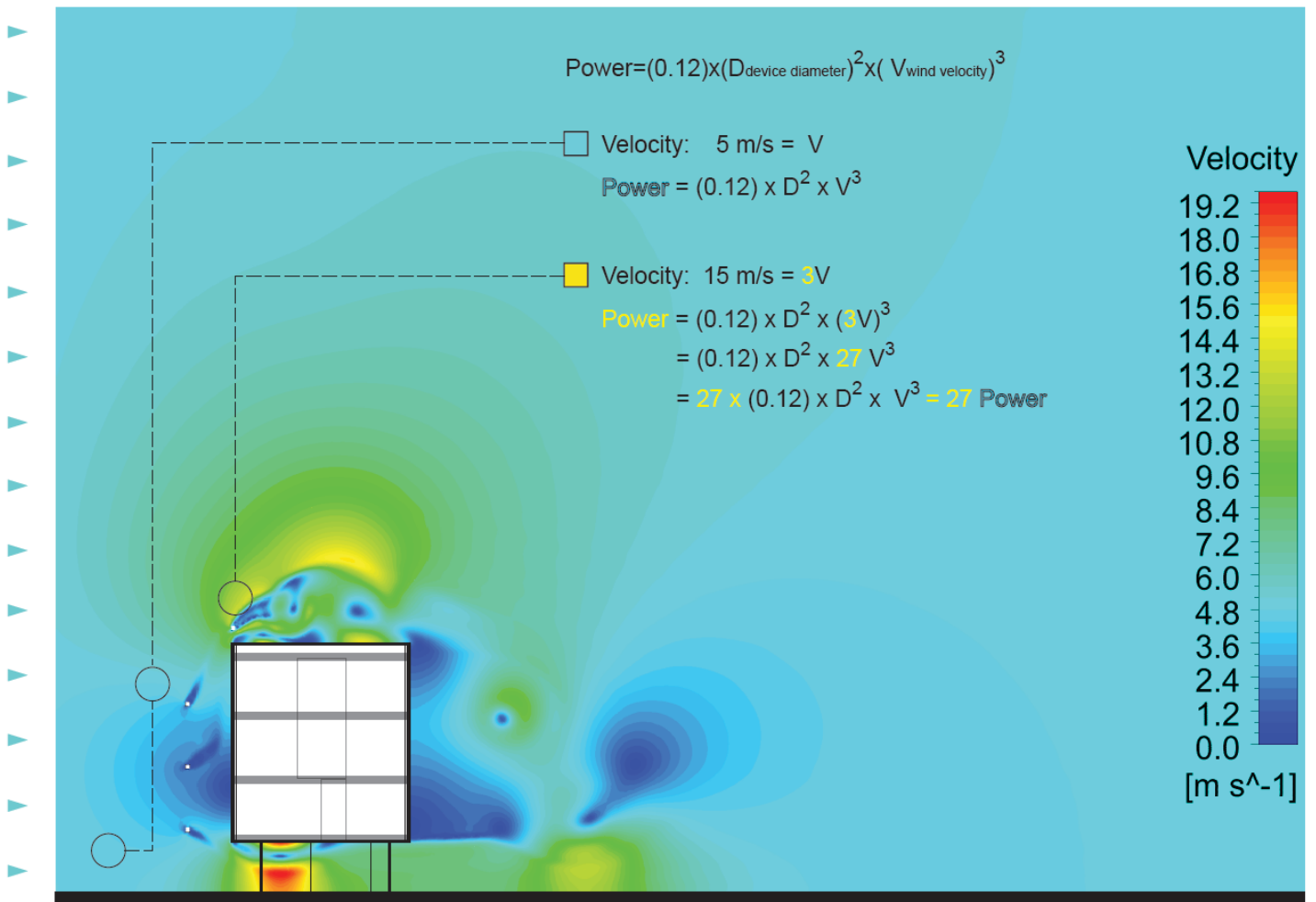


Fig 4: Wind simulation on the section of a surelevated building, SERERO Architects

3. Maximizing performance of building integrated devices in urban environment

3.1 Micro-turbine and micro-generation

Urban energy generation, such as, what is produced by small scale wind turbines or photovoltaic systems installed on or around buildings can be defined as micro generation^[12]. This requires the use of different design approaches to assess the most suitable generator types, develop building forms that will enhance their efficiency, and predict expected power outputs^[13, 14]. Micro-wind turbines are classified in terms of their swept areas (<25 m²) and therefore, have rated powers of up to 6 kW^[15].

It is found that the concentration effect of buildings and the height of buildings could enhance wind power utilization by increasing the wind speed by 1.5–2X and wind power density by 3–8X under the given simulation conditions^[16].

3.2 Generic Techniques and Options for the Integration of Wind Turbines

a. Stand-alone wind turbines

This is the traditional wind energy producing type. The installation and localization of the device, because of its autonomy, is simplified as well as its maintenance.

b. Retrofitting wind turbines onto existing buildings

The overall performance of the retrofitted wind turbine varies depending on the roof position, roughness of the upwind area, size of the building, upward edge rounding and the yaw of the free stream wind^[17,18]. The structural stability of the building as well as vibration dissipation is an important issue and often increase the complexity of this type of installation.

c. Full integration of wind turbines together with architectural form

Based on this turbulent effect, wind turbines needs to be placed high enough to capture strong winds and be above any turbulent air^[19]. Due to the turbulent nature of wind in urban environment, the power output stability significantly depends on the type of the wind turbine installed as well as the location within the turbulence region.

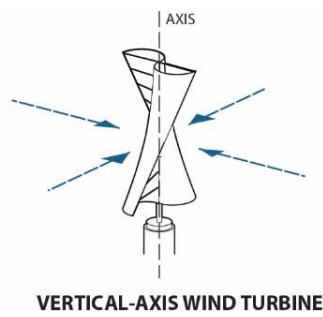
4. Classification of BID integration strategy

Here is a model of classification of BID integration types to a building. BID can be organized along two criteria:

The type of device [Fig 5], the type of integration [Fig 6,7]

We consider two typologies of integration:

- a. Stand-alone turbine
- b. Full-integrated



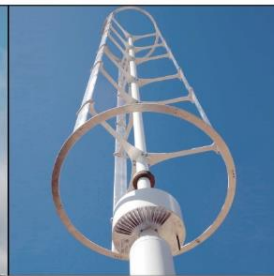
VERTICAL-AXIS WIND TURBINE



WIND TREE



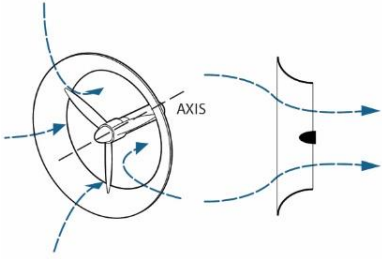
QUIET REVOLUTION QR-5



WINDSPIRE



EOLIE 500



HORIZONTAL-AXIS WIND TURBINE
COMPACT WIND ACCELERATION TURBINE



WIND LENS TURBINE



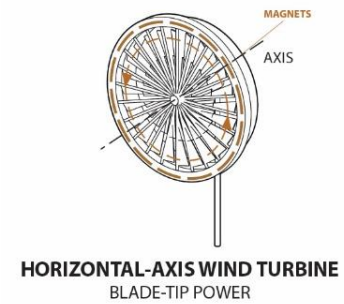
TAMER



CROCK SCREW WIND TOWER



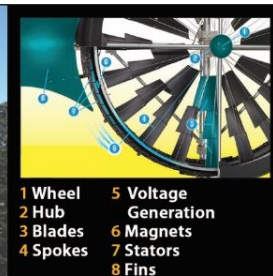
FLODESIGN



HORIZONTAL-AXIS WIND TURBINE
BLADE-TIP POWER



TAM POWER HONEY WELL



- 1 Wheel
- 2 Hub
- 3 Blades
- 4 Spokes
- 5 Voltage Generation
- 6 Magnets
- 7 Stators
- 8 Fins



AE-5

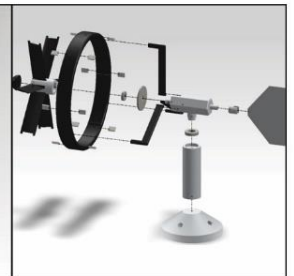


Fig 5: Different typologies of wind turbines

Collage of images and text related to vertical-axis wind turbines in buildings. It includes a photograph of a building facade with wind turbines, a diagram of a wind turbine, and a table of statistics.

VERTICAL CITY	54,000
Power Production (Renewable Energy)	45
Wind turbines in the top of the building will power the lighting on the building.	15 Turbines x 3 Turbines High
Wind speed at 15m height	4

DAVID SERREDO - DISPOSITIVO'S EOLIENS INTERIORS

Collage of images and text related to existing building integrated wind harvesting devices. It includes a photograph of a building facade with wind turbines, a diagram of a wind turbine, and a table of statistics.

EXISTING BUILDING INTEGRATED WIND HARVESTING DEVICES - VERTICAL AXIS WIND TURBINE	54,000
Power Production (Renewable Energy)	45
Wind turbines in the top of the building will power the lighting on the building.	15 Turbines x 3 Turbines High
Wind speed at 15m height	4

DAVID SERREDO - DISPOSITIVO'S EOLIENS INTERIORS

Fig 6 and 7 : Different integration typologies of wind turbines

5. Wind turbine building integration design methodology

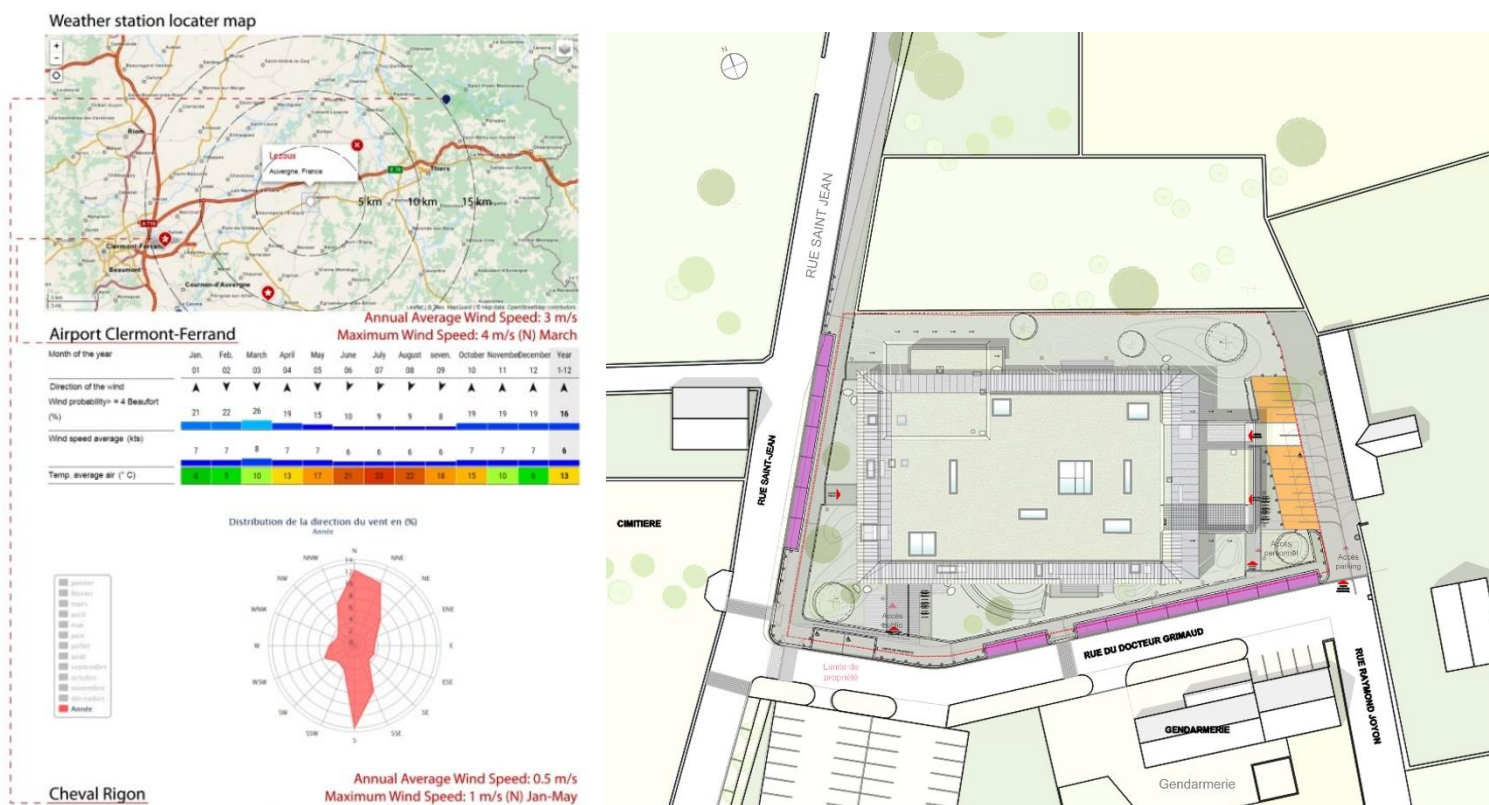


Fig 8: On site wind speed and direction from an online resource. (Windfinder)

5.1 Contextual information

a. Site (Weather Data)

The directionality as well as the velocity of the wind are important factors to affect the extractable wind power. A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are distributed at a particular location. This research mainly took information of annual wind speed average and local wind rose image from *Windfinder* online resource^[20]. To identify local weather data, this research usually compares and triangulates data from 2 to 3 weather stations on a website, on real time basis.

b. Building information

A combination of building geometry and distance between buildings affects the direction and intensity of wind flow and could potentially affect its extractable power. This research considered building plan layout, building height, orientation, envelope and roof geometry as factors to classify different type of boundary condition for integrating wind harvesting devices.

c. Proper selection of device and installing location/ Wind harvesting methodology diagram

The dendrogram [Fig. 9] guides designers through a straightforward design methodology for choosing proper wind harvesting device and suitable integration strategy. The process starts with classifying on-site wind roses (wind data) into bi-directional, omni-directional, and uni-directional conditions. Secondly, these

conditions are compared with 2 types of building plan layout – elongated building and concentrated building. Ten types of building and local wind relationships are defined, such as “elongated building receives perpendicular prevailing wind” and “concentrated building receives omni-directional wind”, which is also a common situation in urban area. Thirdly, the methodology involved the effect of wind speed gradient at different heights of building. As the buildings are constructed higher, they could receive higher wind speed at top. Finally, different device installing locations on a building are concluded, from rooftop, corner of building, façade, sides of building.

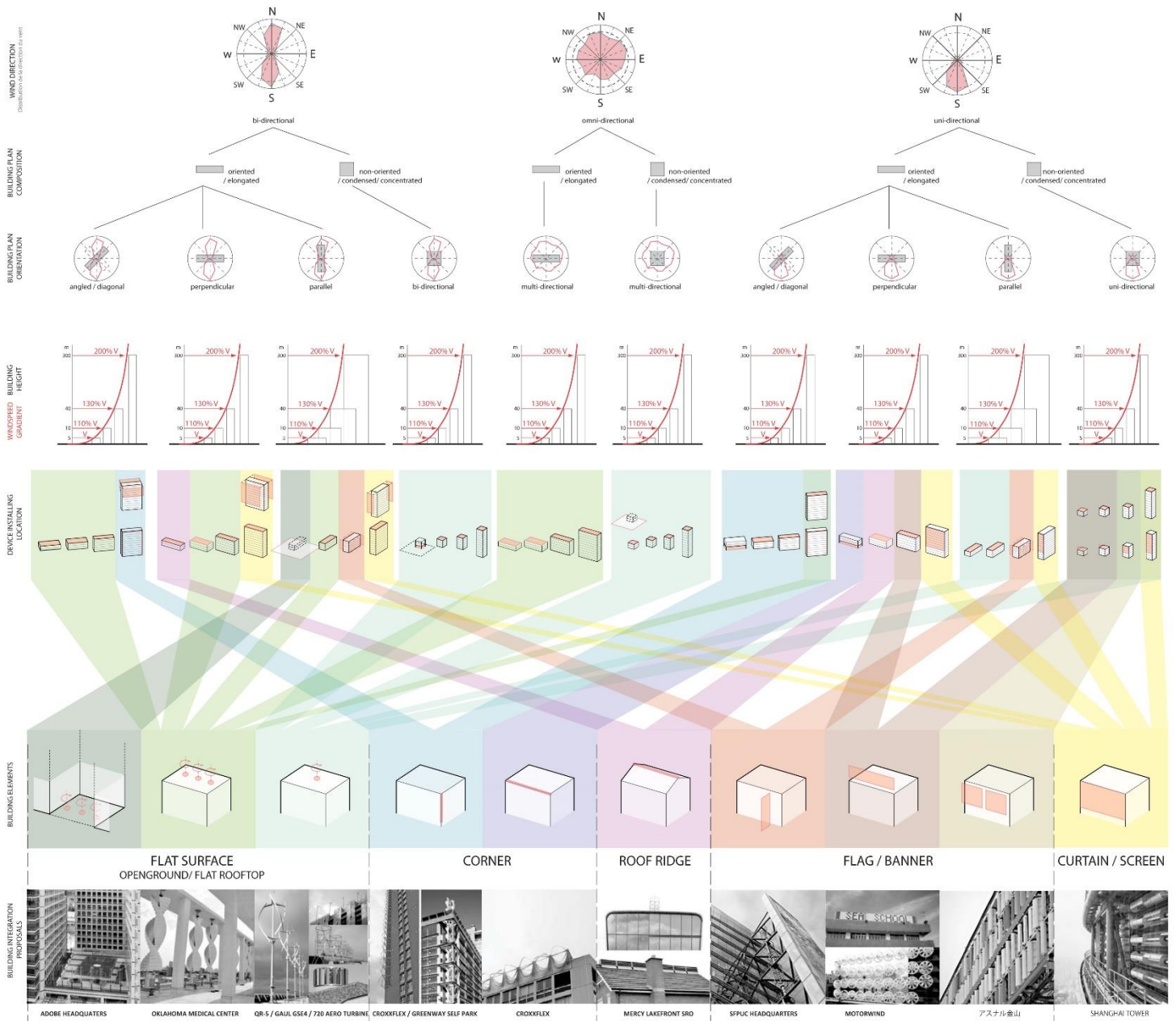


Fig 9: Building integration methodology dendrogram.

d. Typology of devices

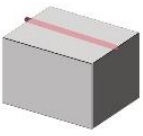
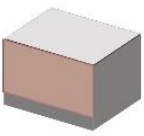

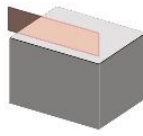
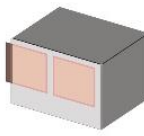
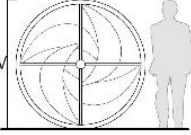
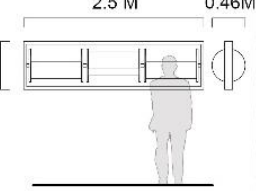
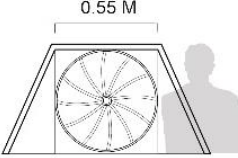
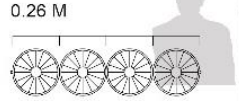
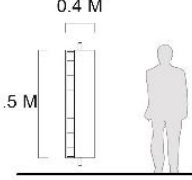





	MERCY LAKEFRONT SRO AEROTURBINE	SHANGHAI TOWER WINDPODS	RIDGEBLADE	MOTORWIND	アスナル金山 ECO-CURTAIN
INTEGRATING LOCATION					
	ROOFTOP / TOITURE	CURTAIN WALL / MUR-RIDEAU	ROOF RIDGE / FAÎTAGE	ROOFTOP BANNER / RIVE DE TOITURE	FACADE BANNER / ECRAN DE FACADE
DEVICE SCALE					
PHOTOGRAPHY					

Fig 10: Devices integrated to buildings

2- Calculation and performance evaluation

We considered 2 types of performative analysis of the devices that we are describing here: Computer simulation (CFD simulation) and wind speed measure on a building scaled model in a wind tunnel (Eiffel type soufflerie).

a. Wind tunnel: Physical Simulation for the phenomenon observation.

We built an open circuit wind tunnel [Fig. 11] to simulate the physical reactions between wind and different building and roof shapes. Based on our experimentation, we further assess the best option for applying wind harvesting devices to architectural structure.

The geometry of buildings makes contributions to wind speed enhancement. [Fig. 13]

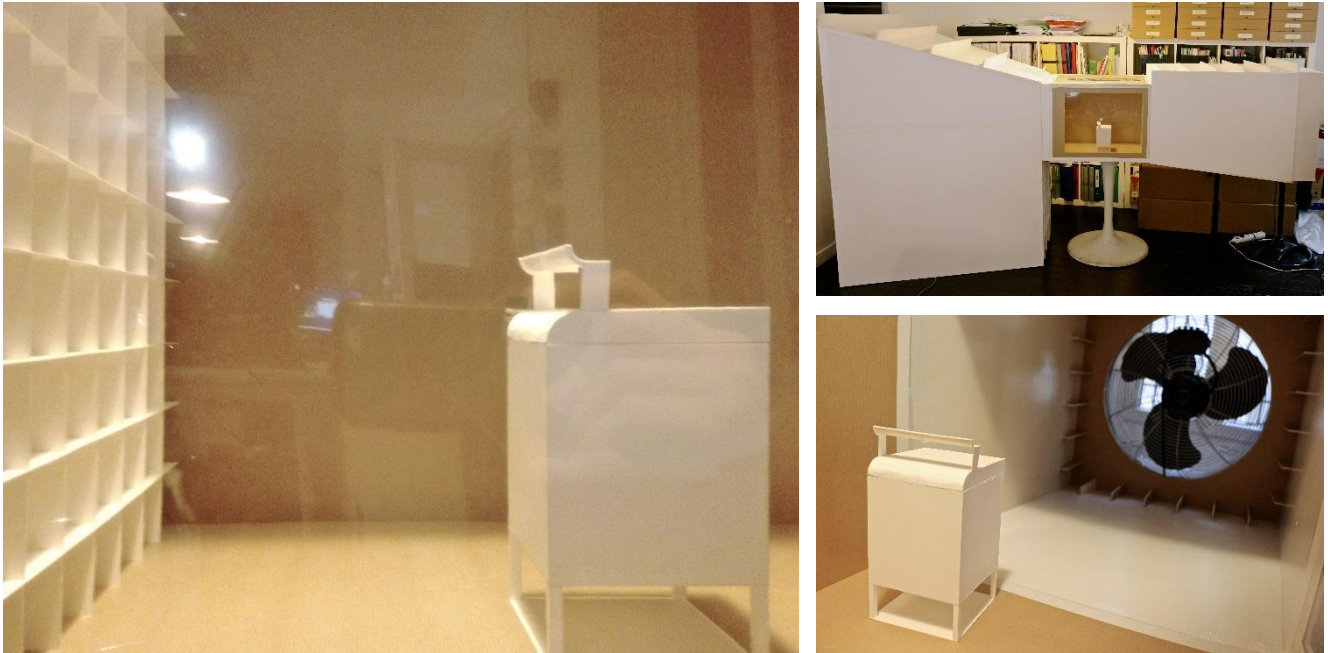


Fig 11: Open circuit wind tunnel in SERERO Architectes

b. Digital Simulation for vertex localization and wind acceleration evaluation (ANSYS Fluent)

Computational fluid dynamic (CFD) software ANSYS Fluent allowed us to predict potential extracted energy by measuring wind speed enhancement (the extracted energy depends on the cube of the wind speed). [Fig. 12]

The two analysis (CFD and wind tunnel) are precisely correlated and the data converge precisely. This experimentation confirms the devices evaluation precision virtually and at scaled model.

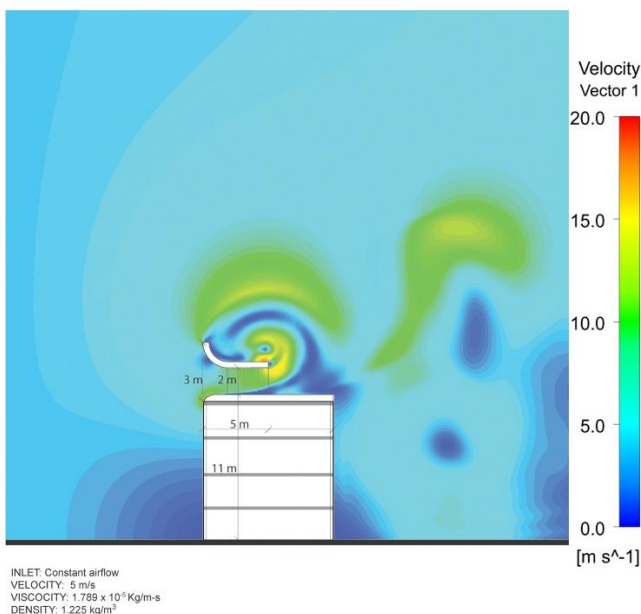


Fig 12: Wind speed enhancement results. (Unit: m/s)

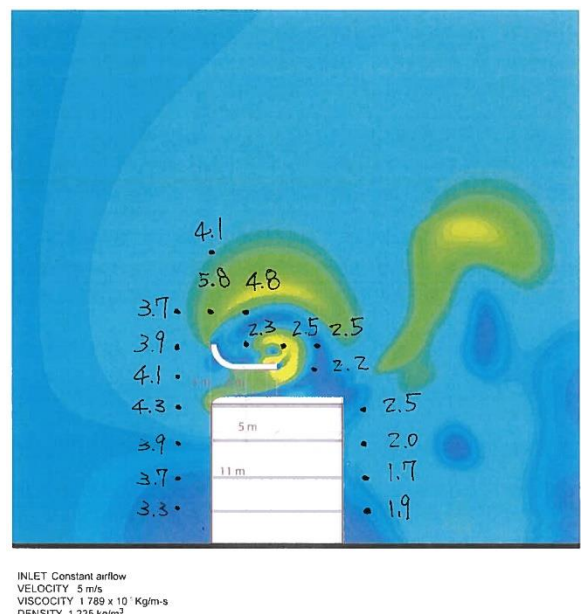


Fig 13: Wind speed enhancement results. (Unit: m/s)

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