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Towards a Wind Urbanism in Tropical Environments

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Abstract

One of the conditions for the proper functioning of passive comfort in humid tropical environments is successful implementation of natural ventilation in buildings and more specifically, how to achieve a 1m/s wind velocity within a building. In reviewing a rich literature, we asked ourselves how to ensure the sustainability of effective natural ventilation for a built complex in a humid tropical environment? This question led us to investigate the contextual aspects of sustainable natural ventilation through various dimensions: the chain of natural ventilation, the programmatic context, the climatic and geographical context, and the regulatory context. We applied these dimensions to a case study, the eco-district of Cœur de ville city of La Possession, on the island of La Réunion, Indian Ocean, France, in developing a new conceptual approach that integrates urban planning and aeraulic engineering from the beginning of the design process for maximum ventilation efficiency. To this end, we initiated a new approach based on co-design, the use of physical wind tunnel simulation at different scales and the integration of envir onmental, architectural, and landscape recommendations at the scale of the district and of the buildings making up this district, in an enforceable urban planning regulation. This has enabled us, within the framework of the eco-district study area, to consider comfortable natural ventilation under a new urban concept: the windy city (as compared to the sunny city) and how to guarantee the preservation of such natural comfort without adding air conditionning in any building of this new city. This approach has the potential to be applied in other eco-neighbourhoods in a tropical environment and could even be extended to other climatic zones, in the context of current global warming.

Keywords

wind urbanism; tropical environment; natural ventilation; ecodistrict; urban design

1. Introduction

A rich literature, (Fry & Drew, 1974; Garde et al., 2004; Hyde et al., 2016), has shown the influence and importance of context in tropical bioclimatic architecture. More specifically, the use of natural ventilation involves interactions with the external environment, including topography, surface roughness, and other buildings mask effects. The nature, quality, climate, and typology of tropical environments can therefore degrade or improve the performance of building ventilation (Yassine & Elgendy, 2011). With this in mind, it seems essential to take into account the context, and in particular the external variables and spatial scale, that may influence ventiliation under the purview of urban planning. The need to broaden the scope and to change the scale of the project appears to be essential to preserve the qualities of a building operating with natural ventilation for comfort, which is the only operational passive design method in a humid tropical environment. This dimension was very quickly integrated by the first settlers when they began to organise the trading posts and towns where they planned to develop their settlement. In his book Chang (2016) quotes Simpson's report "the sanitary conditions of Singapore, 1907" : "In his manual, Principle of Tropical Sanitation, Simpson noted that the streets should be wide, straight, and cut at right angles, with the main avenues oriented in the direction of the prevailing and healthy winds". The same hygienic concern, expressed here in the need to favour good urban ventilation, can be found in the design of buildings at the time. This approach has also been developed in relation to the influence of sunlight on urban comfort (Harzallah, 2007) and its possible impact on the design of cities. G. H. Pingusson, a French architect, summarises the climate-architecture issue in (Architecture d'Aujourd'hui n°3, 1945), as follows: "living and working conditions can be greatly improved by a constant renewal of the ambient air, which can be obtained either by a very thorough air conditioning (engineer's solution), or by a happy arrangement of the buildings on the ground (town planner's solution) or the design of the dwelling (architect's solution), the last two making use of the light winds prevailing permanently in the colony". He defines a new name for this work: "wind architecture".

To what extent could a 'wind urbanism' also be conceived and what impact would it have on the resulting design methods and urban organisation? We therefore asked ourselves, how can an appropriate urban design in a tropical environment promote or optimise the natural ventilation potential of the buildings that make up this ensemble and how can this potential be preserved over time?

We will analyse a project in progress, the eco-district of Cœur de ville Possession.

Figure1 Birds eye view eco district Cœur de ville © City of La Possession.

We will see how this notion of wind urbanism has been taken into account, from the conception of the project to the regulatory transcription and with what results. In the first part (section 3) we will explain the context, (programme, climate, regulation), in the second part (section 4) we will show how we superimposed aeroclimatic strategy and urban thinking and the experience feedback (different steps used in the design concept).

2. Context

a. The natural ventilation chain

One of the difficulties in correctly understanding natural ventilation, beyond its different dimensions, is to take all the required parameters into account. It would be pointless to try to optimise the final dimension which interests us here in particular, i.e. the internal air velocity (m/s), or its corollary the internal flow rate or air renewal rate (Vol/h), as the source of the occupant's comfort, without taking into account in one way or another all the parameters having a direct influence on it, i.e: the natural ventilation chain (See figure 2):

Regional climatology

- The signal and its characteristics,
- The topography of the site and its immediate surroundings,
- The site and urban planning surrounding the building,
- The architectural form,
- The organisation of the air flow in the living area.

Neglecting one of these parameters fundamentally undermines the success of any natural ventilation strategy, while taking them into account will determine the comfort potential of the site.

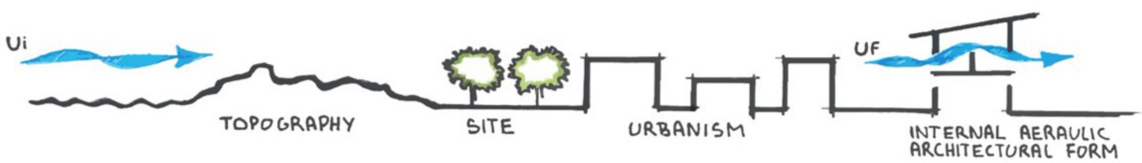

Figure 2 the « Natural ventilation chain » illustrated– © author.

This notion began to emerge in 1945. The architect Henri Pingusson summarised the climate-architecture issue as follows: “living and working conditions can be greatly improved by a constant renewal of the ambient air, which can be obtained either by a very thorough air conditioning (engineer's solution), or by a good arrangement of the buildings on the ground (town planner's solution) or the design of the dwelling (architect's solution), the last two using the light winds prevailing permanently in the colony”. He defined a new name for this concept: “wind architecture” (Architecture d'Aujourd'hui n°3, 1945) and highlighted the origin of air movements created by the potential difference between the high pressure zones in front of the building and a low pressure zone on the opposite façade. This approach was subsequently refined, but it was not until the 1960s that the scientific explanation of natural ventilation began, per Tristan (1997): “The engineer's conclusion is identical to that of the man in the field, but it is supported by modelling which is based on fluid mechanics”.

b. Programmatic context

The project is part of a commission from the town of La Possession, Reunion Island, which has published a set of specifications summarised below:

The "Cœur de Ville" operation is a large-scale development plan for the Commune of La Possession which constitutes a real opportunity for immediate development of the existing town centre.

The objectives of this plan are :

- To create a shopping centre and a range of services that meet the legitimate expectations of the population;
- To make the city centre more dynamic while maintaining the idea of a "garden city";
- To densify the town centre within the framework of an enhanced diversity of housing.

c. Climate and geographic context

i. Climate context (see Figure 3) :

The data below show that current climatic conditions are not so favourable to human comfort and the challenge is real. It is worth remembering that, given its mountainous relief in the centre, with a peak at 3000 m, Reunion is marked by meteorological disparities, reflected in numerous microclimates and in particular in terms of wind direction and intensity.

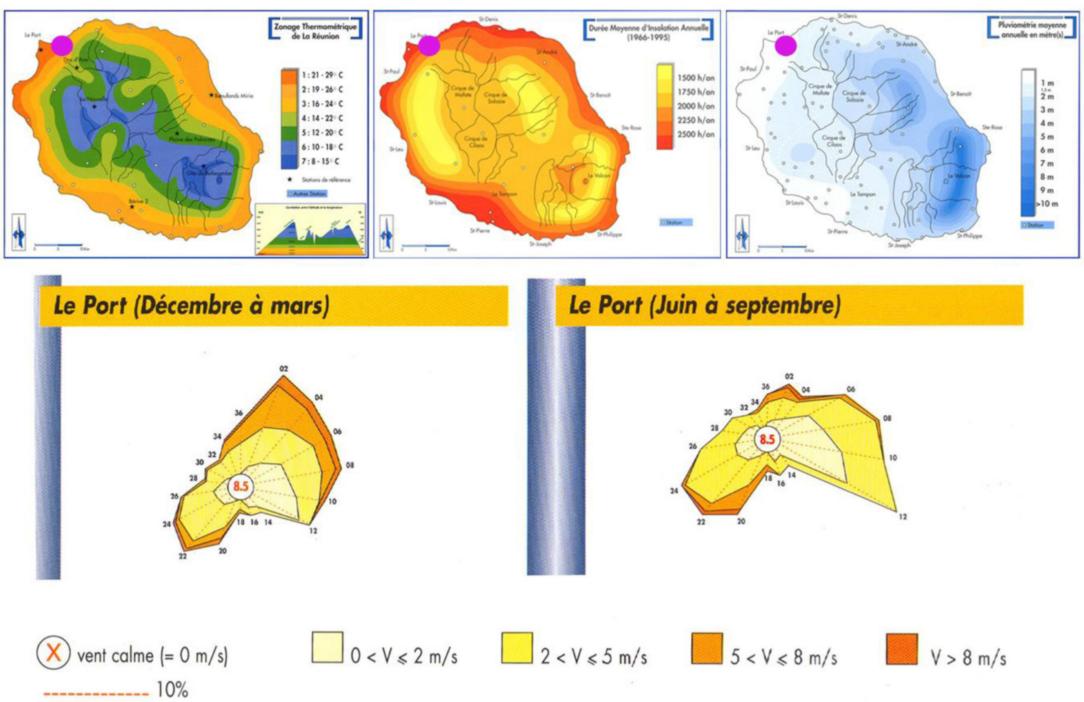

Figure 3 Extract of weather map and wind rose, (© Météo France) "Atlas climatique de la Réunion".

Temperature: Annual averages between 19 and 26°C, with a maximum temperature in the hot season of 36.9°C and a minimum temperature in the cold season of 14.9°C, a maximum monthly average of 31.8°C in February and a minimum monthly average of 18.9°C in July.

Rainfall:, Annual average below 1.5m, rainy season from January to March

Insolation: high, average annual duration 2500 h/year, average global radiation (i.e. the combinaton of direct solar radiation and reflected or scattered solar radiation reaching a ground level, horizontal surface, of unit area) in January is 2900J/m^2 and 1400J/m^2 in July.

Wind: low, breezes prevailing. Study site protected from the winds in relation to the town of Le Port (wind rose presented), exposure to the north-east trade winds is less marked than in Le Port.

ii. Geographic context

Figure 4 shows the mountainous environment of the site, with the cliff of the coastal road to the north, the mountain to the east and the ocean to the northwest. It is also marked by two ravines, the main one being the Ravine à Marquet.

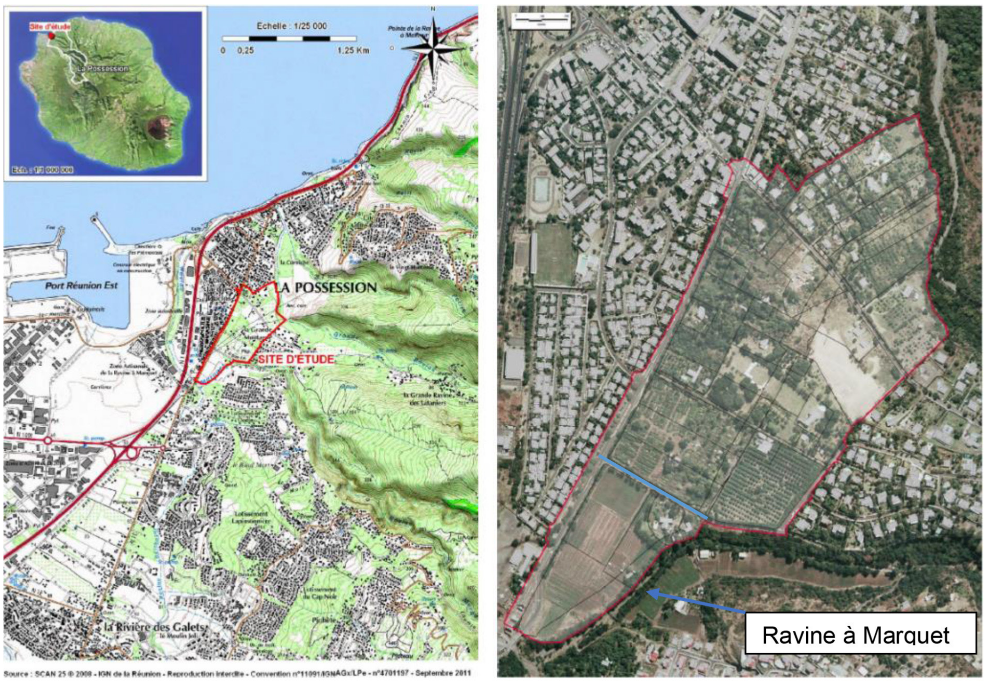

Figure 4 study area localisation (left) – map extract (© IGN) – (© Google Earth) right.

At the methodological level, we see the first pitfall encountered in any bioclimatic project, whether urban or architectural: the reliability of data sources. Unfortunately, there is no weather station in immediate proximity to the project area. From our knowledge of the site and its context, we believe that the data closest to the project area in the city of Le Port, a few kilometres away (see figure 5), need to be considered with caution. Indeed, the town of Le Port is located at the foot of a major cliff to the north-east. However, by analysing the weather data, it can be noted that in the hot season, which is the one we are most interested in with regard to summer comfort, the prevailing winds come from the North East. As such, the prevailaing winds will be disturbed by this relief (the cliff of the coastal road), thus reducing the ventilation potential of the site in a significant way.

iii.Aéroclimatic context :

In order to compensate for this uncertainty, we proceeded with a qualitative climatic recalibration, based on weather data and the analysis of J Gandemer, a consulting engineer in aeraulics.

We therefore worked with an approach based on a transposition of the data from the Port station by taking into account the relief and roughness of the site from a purely qualitative point of view (Gandemer, 2011) in order to evaluate the direction of the prevailing winds:

Figure 5 Position of the project in relation to the Port weather station Google Earth).

"The site wind irrigation is based on :

- The mountainous bypass winds (cirque of Mafate) South-West and North-East.
- Trade winds from the East / South-East;
- The existence of thermal breezes coming perpendicularly to the sea and roughly from the West / North-West for the fresh marine flows (morning) and from the East / South-East for the fresh terrestrial flows coming down from the heights (evening and night);

These thermal breezes have relatively low velocities (average of about 2 to 4 m/s) but are constant and must be used to the maximum of their cooling potential given the interest in comfort ventilation (sea breeze in cooling the built masses and play of their inertia).

The environment is relatively urbanised on the seaward side which induces a global masking effect on the site for the marine flows and reduces the wind speed and its penetration in the lower layers. It is therefore necessary to find an urban design that is free of this constraint. (See Figure 6)

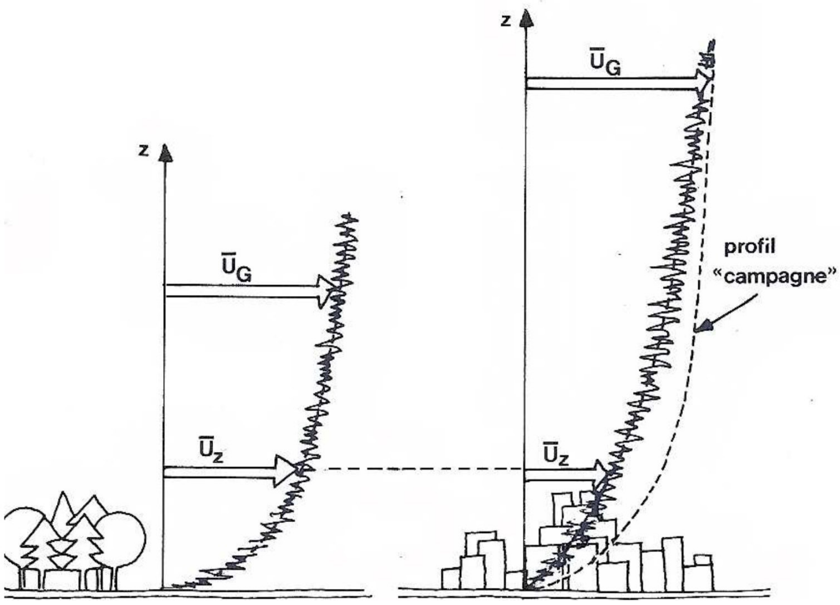

Figure 6 Comparative wind profile sketch countryside/city – (© J Gandemer).

The topography of the site gives a difference in level of approximately 25 m between the RN1 and the "Grande Montagne" plateau with a rather north-west: south-east axis. The proposed urbanisation must take advantage of this "elevation effect". Moreover, the slopes on the plateau are too gentle and will be "roughened" by the urbanisation for there to be an acceleration at the "top" of the plateau. On the other hand, the favourable effect of height has a positive effect on wind dynamics (see Figure 6). In conjunction with the topography, the existence of a large gully to the north (Lataniers gully) and a small one to the south has the consequence of developing the concentration and guidance of fresh currents (heavier density, cooler air) coming down from the heights. Climatic urbanisation must seek to use these cool veins.

On the other hand, in maritime thermal breezes, given the overall rise in topography (rise towards the plateau), no significant concentration can be considered and the marine flow sweeps over the entire site relatively homogeneously. (See Figure 7)

In order to overcome this approximation, a wind vane was finally installed on site in May 2019 and the data are currently being analysed and will be used for the current phase 2.

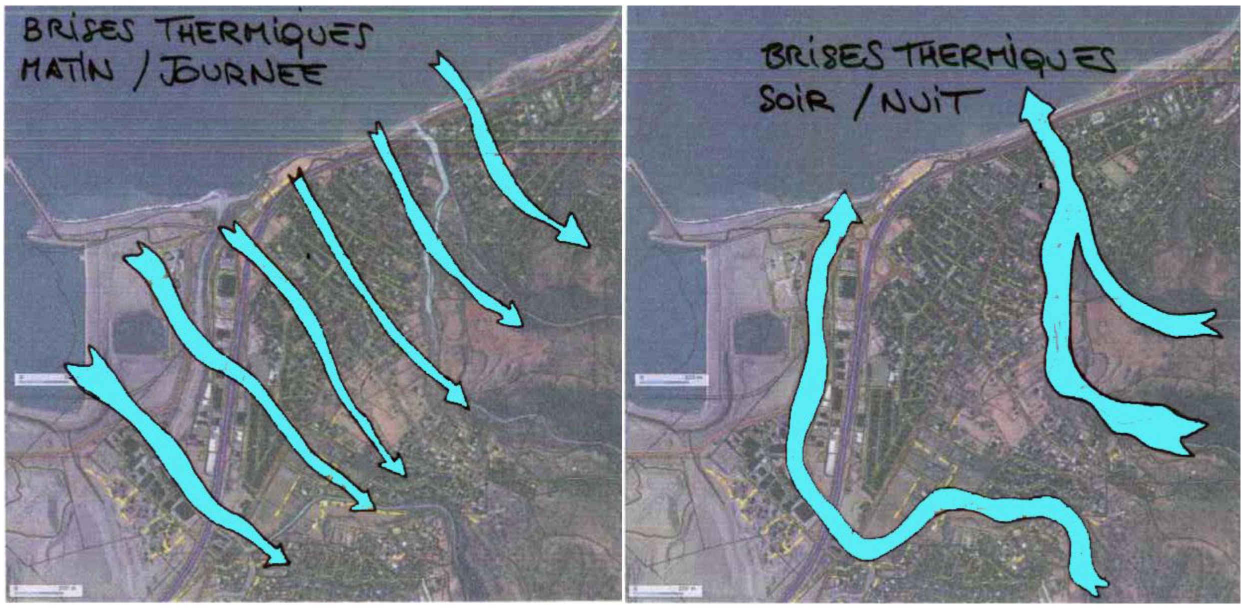

Figure 7 Representation of day and night thermal breezes on La Possession (© LEU / Gandemer).

iv. Build context

The project is positioned in a mixed urban environment, consisting of villas and small buildings (Ground+3, Ground +4) relatively homogeneous, constituting a roughness of medium-dense urban type, or low suburban (see Figure 8 and Figure 9). In particular, this context should be considered upwind of the project, i.e. West, North/West.

d. Regulatory context: the Urbanism Local Plan (ULP)

In addition to the results of our reflection described above, it is necessary to transcribe them into a body of rules, guidelines or other means likely to be followed by the architectural designers of the various blocks in order to maintain the overall coherence for natural ventilation. Indeed, it has all too often been noted that the simple description of ambitions does not guarantee a result that matches them. This point was recently underscored by Nicolas Michelin, an architect and town planner of numerous urban plans (Michelin, 2016) :

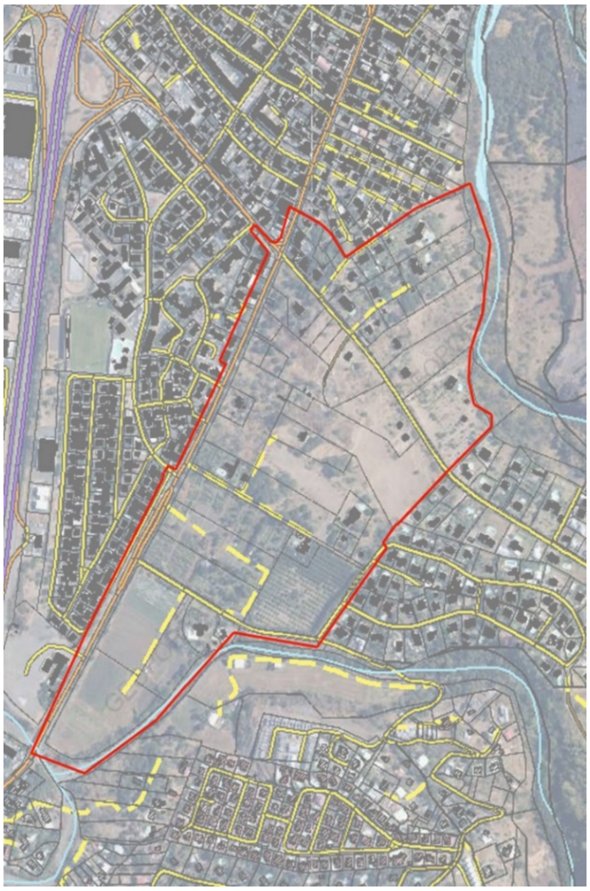

Figure 8 Plan view, context of the buildings surrounding the study area – (© LEU Réunion).

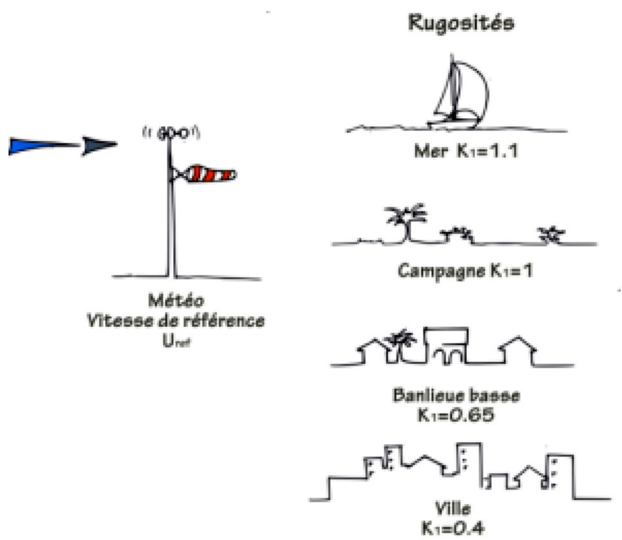

Figure 9 Illustration of different roughnesses © J Gandemer.

After consultations with the team's lawyers, a point confirmed in Morgane Colombert's thesis (Colombert, 2008), it emerged that a transcription of certain rules in the DLGs (Development and Landscape Guidelines) resulting from the urban-air study, into the ULP would offer minimal guarantees, necessary to ensure the success of the project. Indeed, the ULP remains the reference document opposable to third parties and therefore less easily "circumvented" in an urban planning project.

It is this approach and this work that we will explore hereafter and which makes it possible to leave the example heart of city and to consider a method of regulatory transcription of a wind urbanism.

An example of wind urbanism in a tropical environment: Superimposing aeroclimatic strategy and urban thinking

The originality of the approach and our contribution consists of the upstream assistance of an air conditioning consultant and the integration into the LUP (Local Urban Planning Scheme) of the DLGs (Development and Landscape Guidelines) containing recommendations relating to the air conditioning operation of the complex.

3. The urban study was carried out in six stages:

- Step 1: Definition of initial urban scenarios;
- Step 2: Definition of an aeroclimatic strategy at the scale of the urban plan;
- Step 3: Definition of an aeroclimatic strategy at the block level.
- Step 4: Definition of an aeroclimatic strategy at the building level;
- Step 5: Finalization of the urban plan's ground plan;
- Step 6: Revision of the LUP with the integration of the aeraulic DLGs among others

3.1 Step 1: Definition of initial urban scenarios July 2011 : Figure 10

These initial scenarios (see provide a visualisation of the major urban intentions, including road layout, positioning of buildings and public spaces, distribution of the built programme, and gardens.

This initial "visualisation" of the programme was drawn up at the very beginning of the study and proposed two functional variants. This document was used as the basis for dialogue with the ventilation engineer.

Figure 10 shows on the two lower plans the position of the commercial area in blue and the position of the future tropical mall in green. They are distinct in scenario 1 (commercial area is along the main road) and connected (commercial area is superimposed on the tropical mall) in scenario 2.

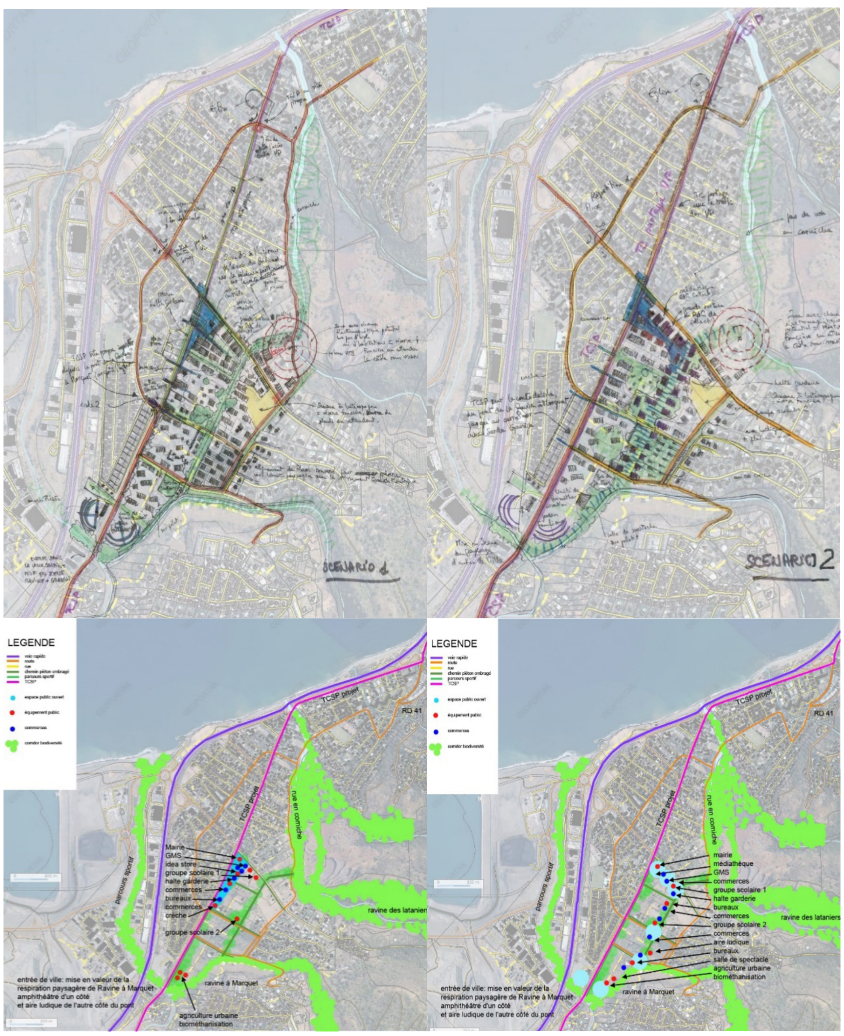

Figure 10 Scenario 1 top and bottom right, scenario two top and bottom left

3.2 Step 2: Definition of an aero-climatic strategy, September 2011

In this second step, a general principle of building organisation based on the sole consideration of the optimisation of the aeraulic potential is outlined. It shows a non-continuous distribution of built volumes perpendicular to the day and night breezes (see Figure 12), taking into account the principles of inter-distance D between buildings, in relation to their height H (see Figure 11), with D>5H for the buildings in the lower part. A buildings herringbone layout is represented in the middle section and villas in the upper section.

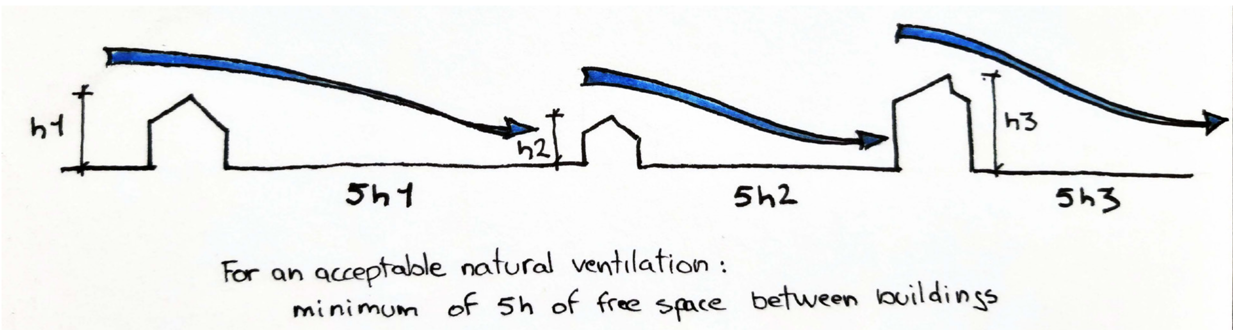

Figure 11 minimum distance between buildings for a natural ventilation (J. Gandemer).

Figure 12 Initial design scheme (© J Gandemer).

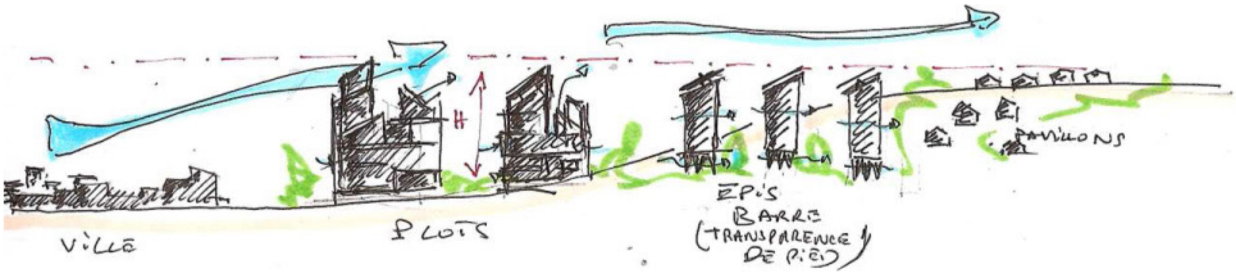

Figure 13 Cross-sectional organisation with an epannelage taking into account topographical effects (© J Gandemer).

The concept was then refined (see Figure 13) by reducing the spacing between blocks using the roof depression (depression wells). This allows us to propose a final principle (see Figure 13) with inter-distances lower as the height of the buildings decreases on the slope.

These first elements of the aero-climatic strategy formalize consideration of the topography, the surrounding roughness, the organization of the built granulometry and the outline of the built form (in particular the proposal of a mono-sloped roof with its back to the dominant diurnal winds, optimizing the potential for depression and therefore for cross ventilation) (Gandemer, 2011) This is a work on the macro scale of the city,.

Limitations on the basic rules of urban organisation

The above approach has shown the limits of the basic concepts (see Figure 14).

Indeed, studying an architectural object as such and improving its natural ventilation efficiency and thus reducing or even eliminating the need for air-conditioning is one thing, applying it to a group of buildings with the consideration of their interactions is another. This approach, which has already been theorised and described in the main principles of interaction between buildings, summarised in (Gandemer & Picgirard, 2012) and in the other studies mentioned above, does not, a priori, allow the design of a city or a district of reasonable density. If we stick to the simple principles defining the minimum distance between two buildings allowing the initial ventilation potential to be regained upwind of the first building, the gaps between buildings are incompatible with the density expected in this type of urban plan (see Figure 15) due to the scarcity and high cost of land.

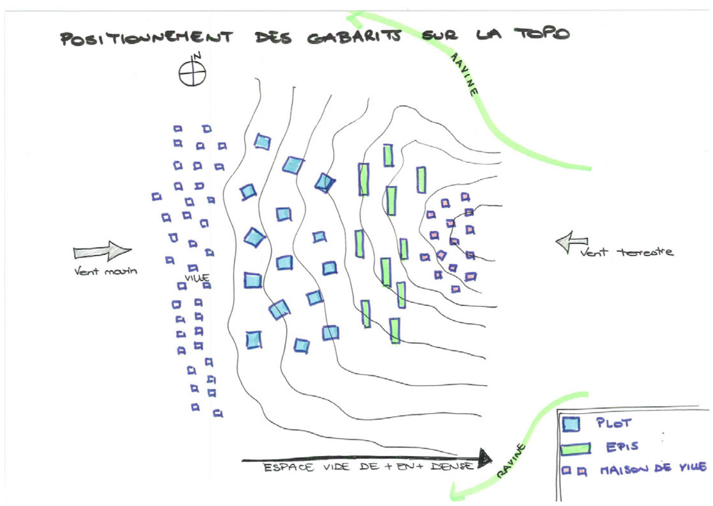

Figure 14 Principle transcription, in plan of the proposed typologies (© J Gandemer).

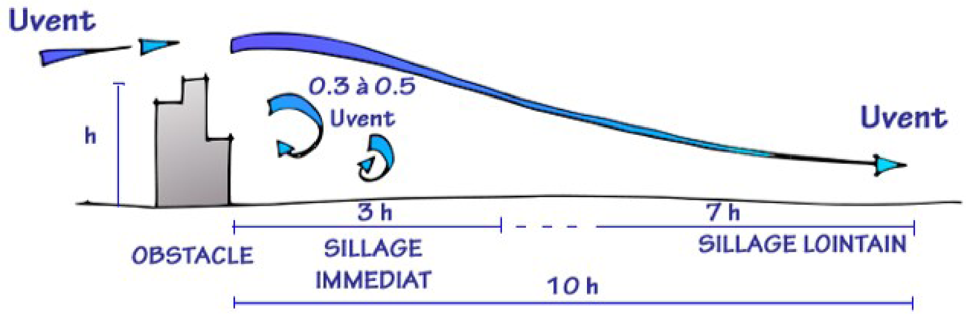

Figure 15 Sketch of the trajectory of a built obstacle - (© F. Picgirard, J. Gandemer, 2012).

Our objective was therefore to go further and propose operational solutions, i.e. solutions viable in terms of urban image, densification, and therefore, economy. We had to "tightenbring closer" the blocks at the bottom and therefore validate new concepts. It therefore appeared necessary to deepen our knowledge of the interactions between built forms and the optimisation of these built forms themselves, in order to define functions at the scale of the block, preserving and optimising the ventilation potential for all.

A study was commissioned from the Eiffel Laboratory associated with Jacques Gandemer Conseil (Gandemer, 2011). Its aim was to provide us with elements of response at the following scales:

- At the block scale, the organisation of the built volumes between them was assessed, taking into account the interactions (masking effect, arrangement of buildings in relation to each other, buildings in line, staggered buildings, etc.). (See Figure 16)

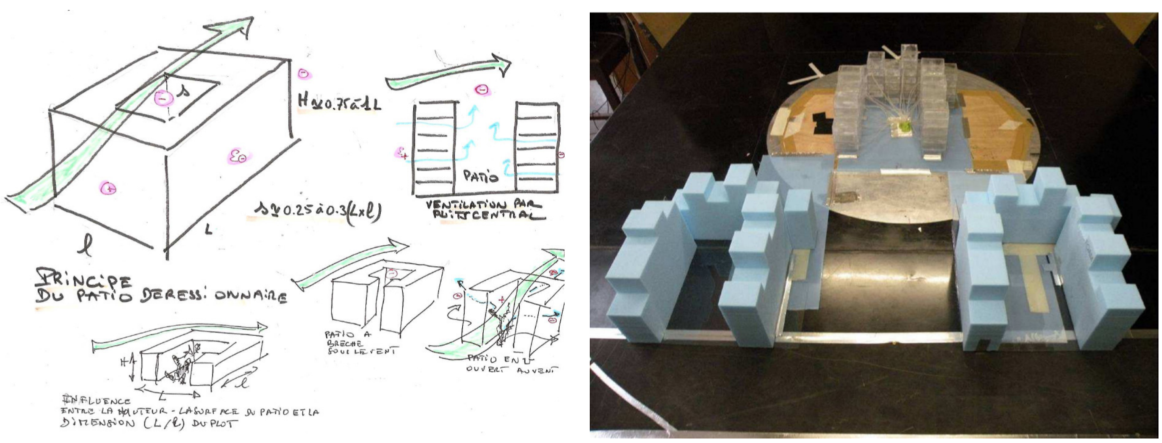

Figure 16 Conceptual sketch at building scale (right) - J Gandemer - wind tunnel study model interactions between buildings at block scale (©J Gandemer) - (© Laboratoire Eiffel) (left).

- At the building scale, the architectural typology best adapted to the context (plot, plots with closed patios, U shape building, building on piles or not, variability of heights) was determined (See Figure 17)

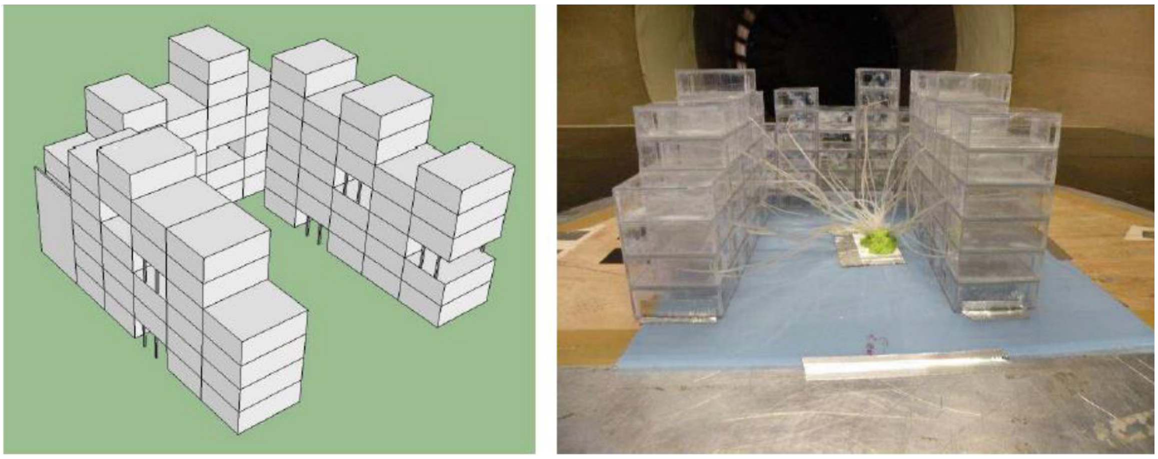

Figure 17 Wind tunnel study model for building scale simulation - (©J Gandemer)- (© Laboratoire Eiffel).

- At the scale of the cells in a building the air velocities and ultimately the potential comfort provided by this natural ventilation were assessed.

The results of this study were pressure coefficients, Cp, and air velocities at the facade of the housing cells to assess their comfort potential.

This led to the following steps:

3.3 Step 3, definition of an aeroclimatic strategy at the island level and definition of the interactions between islands and built form, December 2011

Different building forms (depression patio, open U-shape...) were tested (Gandemer, 2011) in combination with each other (see Figure 16) in order to determine which ones are the most effective in supporting natural ventilation and under which distance conditions.

The patio plot architecture or in open U-shape in the studied proportions and transparency were shown to promote natural ventilation most effectively. We also make the following recommendations:

- In "isolated" patio plots (with a distance between two plots greater than 60 m) and if we want to achieve natural ventilation for 100% of the dwellings, we must favour the implantation of the two stilted facades towards the direction of the prevailing winds (or of the wind that we essentially want to use for natural ventilation) at more or less 30° around the direction of the average wind

- For the "isolated" open U-shaped plot, if 100% natural ventilation of the flats is to be achieved, the opening of the U will have to be oriented towards the direction of the prevailing winds (at + or - 45° around the average direction).

- In an urbanisation with blocks and in order not to compromise the cross ventilation mechanisms, we recommend minimum spaces of 30 m, and the same recommendations for orientation with respect to the dominant winds as above;

- Generally speaking, it will be necessary to favour a staggered arrangement (and not in line) of the blocks on the one hand, and always adopt slightly oblique orientations of the mass plan in relation to the prevailing winds (the precise incidences on the facades are difficult to "adjust" given the variability of the wind);

- The architectural goal was to produce a relatively compact urbanisation with efficient natural ventilation for all flats. However, for certain configurations and wind directions, it has been shown that only 70% and even 50% of the flats in a plot function completely in natural ventilation. Nonetheless, the results and the unsteady nature of the mechanisms (siphoning, etc.) and whatever the configurations retained and recommended (porosity and spacing in particular) assure us that all the flats will have air renewal rates of at least 10 vol/hour respected.

Subsequently, and considering the practical and climatic constraints of the site and of the urbanization of Cœur de ville La Possession, there will be flats which will not have an efficient natural ventilation, even if the recommended aerodynamic conditions have been met. Also and keeping in mind that the thermal loads are well evacuated in all the flats, the “defective” units will be equipped with air fans.

3.4 Step 4, definition of an aero-climatic strategy at the building level

The work then turned to the building form itself in order to optimise it. With the open U shape retained, we tested different distributions of openings and with or without pilotis (see Figure 15).

In parallel to this work, we tried to visualise the architectural transcription of this principled form (see Figure 18). We note the desire for non-uniform heights on the U-shape, with the thin through grid and the main dimensions being 18 m wide at the U-shape opening and 30 m wide for the buildings. It is a question here of moving from a theoretical volumetry to a work on the functional and viable architectural form. This transposition work is therefore essential.

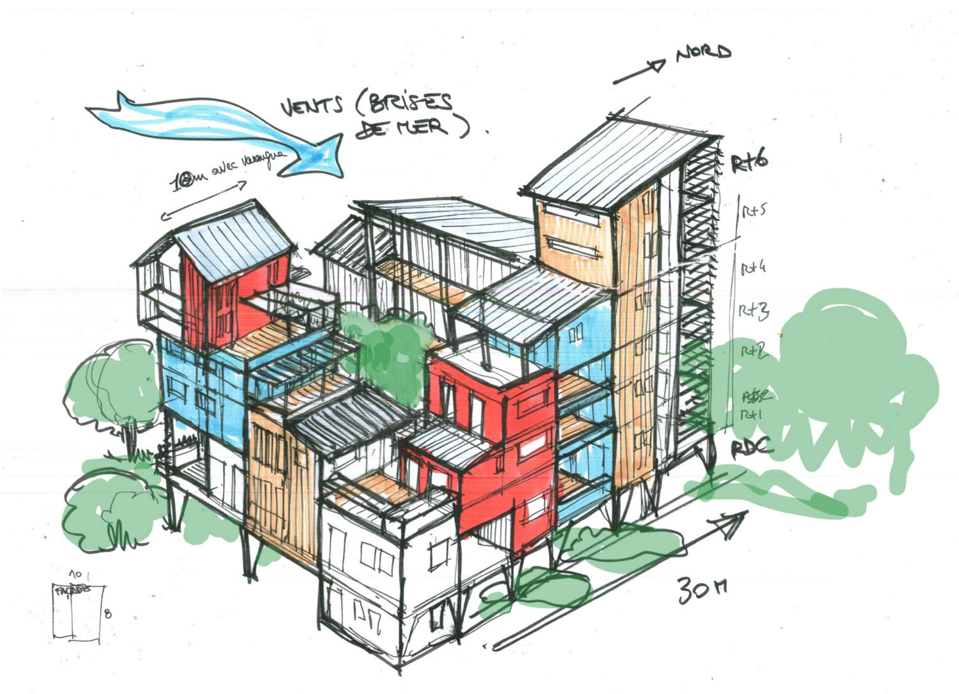

Figure 18 Architectural concept sketch (© LEU Réunion).

We can summ up the points mentioned above:

- The importance of a good knowledge of the wind conditions, in order to reduce the uncertainties on the initial wind potential and thus the final wind potential (we can underline here the lack of precision of the wind data on the site which leads to a greater uncertainty due to the recalculation approach used and the need mentioned for a complementary study)

- The reminder of the three dimensions of natural ventilation and in case of impossibility to fully use the natural ventilation of comfort with air renewal rates higher than 50 vol/hour, to “fall back” on the natural ventilation of evacuation of thermal overload and to obtain the air velocity of 1m/s by means of air mixers (e.g. fans). What is recommended in some cases for this project:
- The adoption of a non-homogeneous velum (average built height). A constant velum, such as a maximum height of Ground+4, which results in a homogeneous “sheet”, is less favourable to the efficiency of natural ventilation and should be avoided (see Figure 19);
- These recommendations do not constitute the urban project, of course, but they do specify certain constraints to be respected in order to achieve the objective of designing a sustainable tropical garden city, a tropical eco-city.

3.5 Step 5, finalisation of the ground plan

The urban design principles, combined with the conclusions of the wind tunnel study, have led us to propose the final mass plan below.

This is a far cry from Haussmannian urbanism, closed blocks aligned to the street, or zoning urbanism with street alignment. We find the distribution of the typologies of blocks, bars and individuals, with the formalisation of the concept of U-shaped areas open to the dominant diurnal winds and we perceive the importance of vegetation on the periphery of the buildings as a complement to the aeraulic strategy (See Figure 19). The inter-distances of the blocks here are clearly smaller than those initially proposed, as a result of the wind tunnel work.

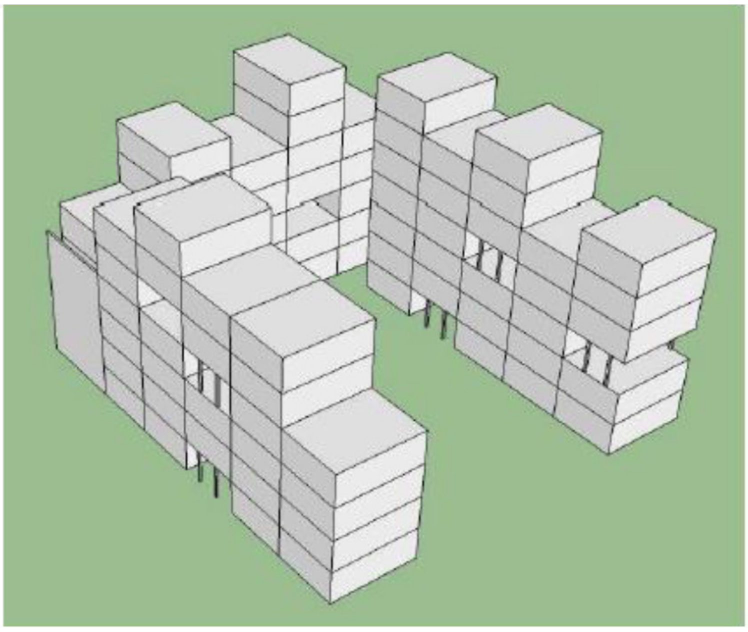

Figure 19 Illustration of a U-shaped building with non-homogeneous height. (© J Gandemer).

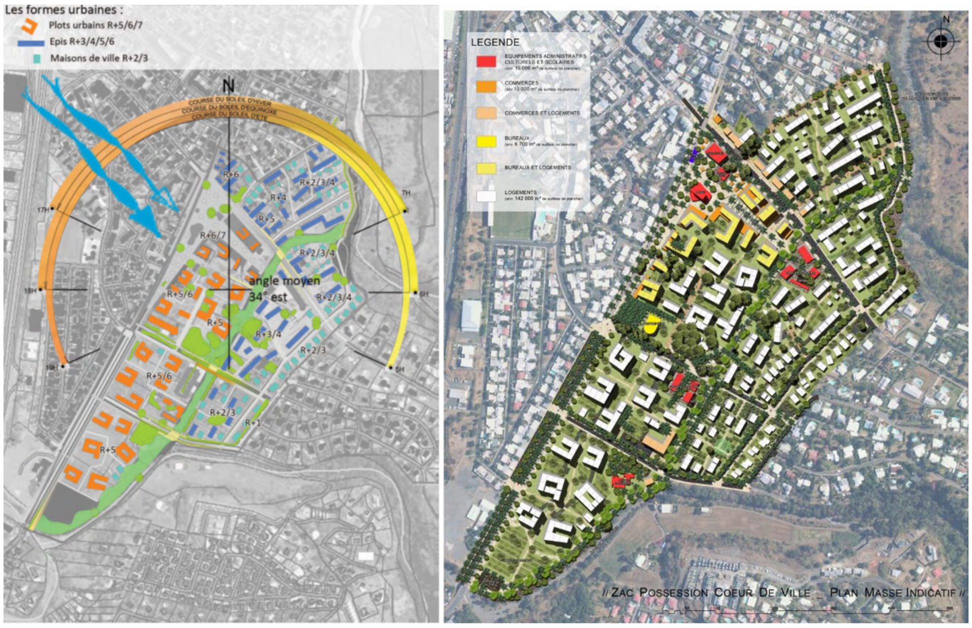

Figure 20 Final mass plan , epannelage (left) developments (right) - (© LEU Réunion).

We also find the typological distribution taking into account the topography, U-shaped buildings at the foot of the site, staggered bars in the intermediate part, and individual houses in the upper part.

It thus appears that the aeraulic hypotheses and the programmatic, architectural, and urban wills make it possible to organise a theoretical wind urbanism plan with an average density of 76 dwellings/ha, i.e. a ground to floor ratio of approximately 0.6, corresponding to a common density for a collective housing complex and meeting the profitability objectives set out by Steffen Lehmann (2010), achieved with a density of more than 70 units/ha.

3.6 Step six, regulatory transcription, revision of the ULP and the DLG

The definition of an aero-climatic organisation seen above must be translated to the regulatory scale in order to be transposed and used by the architects and project managers, while being “controlled” by the project owner and its AMO (Assistant Project Manager). This should make it possible to avoid the pitfalls mentioned above and thus ensure that these intentions are reflected in the projects. Within the framework of Cœur de ville La Possession, the regulatory tool used was the revision of the ULP and more precisely the DLG. In parallel and in addition to the ULP and its DLGs, an SD reference framework, including recommendations (educational aspect + design aid tool) and prescriptions (regulatory aspect) was established in collaboration with the TRIBU consultancy firm, Alain Bornarel, one of the creator ofat the origin of the HQE© (Environmental High Quality) in France. It is not enforceable but has served as an educational tool for the architects in charge of various projects.

4. Experience feedback

At this stage of the project, we can already draw some operational conclusions:

i. Importance of governance: A project of this type unfolds over time; it will take between 10 and 20 years for the whole area to have its final appearance. Given the stakes and the political and technical changes, the role of the chief town planner is fundamental. Indeed, it is the chief town plannner who must ensure that the objectives and overall project coherence are maintained. The chief town planner's role and authority, based on a global vision of the project, are essential for the success of the operation.

ii. Compliance with initial objectives: The projects currently underway generally comply with the urban planning requirements, but the lack of governance has led to some drift, despite the advice and warnings of the chief urban planner, LEU Réunion. In general, however, the system put in place seems resilient and adaptible in its implementation phase.

iii.It remains to organise a follow-up to evaluate the performance achieved both in terms of comfort and predicted electrical consumption. It is only after these observations that more definitive conclusions can be drawn. The feedback from a number of eco-neighbourhoods in France has sometimes been disappointing (L. Blanchard, 2017):

Monitoring throughout the study period, and then during the occupied phase for at least a full year, appears fundamental to give this type of innovative project the maximum chance of success. The timeframe of our component of the project unfortunately did not allow us to collect post-occupational data. Nevertheless, a follow-up is planned, which will be implemented as part of the eco-neighbourhood certification process and which will be interesting to integrate into the rest of this study as part of a concluding 'lessons learned'.

As a result of our findings, corrective measures have been taken in the project monitoring methodology to improve compliance with the initial objectives, particularly in terms of airflow:

- Integration of sustainable development concepts of the project into the ULP, making it enforceable;
- Establishment of mandatory aeraulic engineering advice as part of the sketch phase in the architects' projects;
- Assent of the chief town planner at the sketch stage, including a compulsory airflow notice. Intégration These new measures will be evaluated at the end of phase 2 of the work (around 2025).

5. Conclusions

The literature and examples analysed have shown us the interest and limits of taking into account natural ventilation at the urban scale. With the exception of the new town of Sidi Sayeh (B. Blanchard et al., 2010) none of the cases discussed herein truly reflectthe "windy city" concept of natural ventilation potential at the town or district scale. An essential link in the "natural ventilation chain" is therefore missing to ensure the comfort of the inhabitants.

We showed in this specific tropical context, through this new methodology using wind engeenering, that it was possible to provide and ensure comfortable natural ventilation in the long term for any inhabitant of any building by considering specific position of the buildings (interdistances), specific shape (low pressure patio and U shape), and introducing these rules in an appropriate urban regulation with project supervising.

On the basis of these observations, we can propose a methodology for the elaboration and respect of an aero-climatic urban project from the urban scale to the construction rules at the scale of the buildings on the island:

Preliminary data

- Programmatic data;
- Collection and use of climatic data;
- Precise climatic recalibration of the wind data.

Development of the project

- Definition of an aero-climatic strategy in parallel with the urban project;
- Finalisation of the urban project;
- Aerodynamic work at the urban island level;
- Aerodynamic work at the building level.

Regulatory transcript

- Definition of a general organization in a mass plan;
- Regulatory transcription in the general data of the ULP;
- Creation of DLGs at the urban island level.

Project supervision

- Establishment of a sustainable development reference framework;
- Support for project owners and project managers;
- Monitoring of projects at all stages of study and until their completion;

Monitoring in occupied mode

- Informing the occupants of good practices;
- Monitoring of electrical consumption;
- Analysis of behaviour;
- Corrective measures (if any).

Our specific contributions and practices within the framework of this study process were decisive and innovative at two levels: the design method with the air expertise; and the regulatory transcription of this air study in the ULP, through the DLGs (Design and Landscape Guidelines).

It is important to stress that each of these phases is essential to the success of the project, not to mention all the other technical, regulatory and consultation aspects that are also necessary. This succession of phases can be compared to the “natural ventilation chain”, where each link is essential to the final success of a project.

These objectives must be shared by the entire decision-making chain and in particular the project owner, who can or should delegate it to their chief planner. Otherwise, the initial intentions, however good they may be, run the risk of being diverted to the altar of immediate profitability, which is incompatible with the very notion of sustainable development.

Feedback through surveys and instrumentation is planned in the near future to assess the efficiency of the systems, the dysfunctions, their origins, and the corrective measures to be envisaged. This work could be the subject of an extension of this study.

The tropical wind city of tomorrow is not a chimera, it will have to propose its own ideal, shaped by an original context, in which, undoubtedly, natural ventilation will have an essential role to play, but it will not be done without the collaboration and the adhesion of all the actors.

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Author Contributions

Conceptualization, methodology, analysis, and writing, A. P.. The author has read and agreed to the published version of the manuscript.

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