Passive design in tropical climates: Key strategies implemented in a French certified sustainable neighbourhood

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Key strategies implemented in a French certified sustainable neighbourhood

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ABSTRACT: Sustainability has become an increasingly important element to be considered at all levels, from the building to the urban planning development of communities and cities. It is expected that 60% of the world population will live in the tropical belt by 2030 with a huge increase of CO_2 emissions in those areas. Passive design approaches thus play an important role in the development of sustainable and resilient neighbourhoods and buildings, especially to reduce the cooling needs and to improve thermal comfort conditions. This paper presents two residential buildings, a newly built apartment building and a retrofitted one that are located in the neighbourhood of 'Ravine Blanche', in the city of Saint-Pierre, in Reunion Island in the Indian Ocean. Ravine Blanche has been awarded the French sustainable neighbourhood certification in the tropics. This existing neighbourhood is part of an urban renewal program that includes the retrofitting of existing buildings as well as the development of new building projects with regard to the different and complex climate sensitive design in the tropics. The paper will present the awarded neighbourhood and the two buildings. Then the different passive strategies that have been implemented so as to cool the buildings and to minimize the solar radiation will be presented. Different design tools have been used in order to choose the optimal passive features for each case study towards a common main goal, which is to favour natural ventilation and reduce solar heat gain. A large-scale field study is going to be conducted this year in order to assess the thermal comfort conditions linking both inside and outside areas.
Keywords: thermal comfort, passive features, retrofitting, urban greening potential, tropical climate

INTRODUCTION
Reunion Island is a small French tropical island located in the Indian Ocean (21° of latitude South and 55,5° of longitude East). Like many tropical islands, Reunion has to face a significant increase in its population. The construction of new buildings is thus necessary as well as the renovation of old buildings built in the 60ie. The rapid growing of the population has led to the construction of new neighbourhoods and buildings not necessarily built according to the local tropical climate conditions, creating a heat island effect and of course, discomfort issues inside and outside the buildings.
Moreover, due to its remote and insular conditions, the island is mainly dependent on imported fossil fuels. This strong dependence on fossil fuels leads to electricity supply risks and increasing greenhouse gas emissions while the island aims to achieve self-sufficiency in its electricity production by 2030. One solution to overcome this challenge is to encourage the construction of 'green' buildings and sustainable neighbourhoods, as well as promoting the development of renewable energies.

THE STUDY CONTEXT
The Ministry of Ecology, Sustainable Development, Transport of Housing of France launched in 2008 a national call for proposals focusing on ecodistricts [1], named in French 'EcoQuartier', which mainly aims at promoting sustainable urban development in projects, improving the quality of life of its citizens, reducing carbon footprint and conserving natural resources. To take their involvement one-step further in this program, the national sustainable neighbourhood certification was created in December 2012 [2], which recognizes and rewards exemplary development projects that successfully perform in maintaining social quality of life and supporting their economic development while preserving the environment. Assessment criteria are categorized into twenty commitments and each project is then evaluated using a grid of indicators. A first scientific campaign of evaluation based on three of the twenty commitments related to water, energy and waste management, has been launched in order to assess the real performance of the district and the efficiency of the policies set up. A transverse evaluation of all the others commitments will be done afterwards.

CLIMATE AND BUILDING CODE IN LA REUNION
Reunion Island is located into the tropical zone. The local climate is thus tropical, with hot and humid weather conditions along the coastline and temperate in high altitudes, as the highest peak is 3000 m high. The specificity of this Island is directly linked to its landscape. As a result, behind the general qualification of hot and humid, a multitude of microclimates can be

observed in Reunion. Many works have been done in order to clearly identify and delimit these climate zones, such as the Thermal, Acoustic and Ventilation Regulation in the overseas department (in French: Réglementation Thermique, Acoustique et Aération) [3] and the PERENE local green buildings guideline [4]. These building codes defined different zones depending on the altitude of the studied region and the wind influence. According to the zone studied, different levels of performance to reach for the construction elements of the buildings are required.

The case study is located at 'la Ravine Blanche' in the city of Saint-Pierre. The city is located in the coastal area (i.e. for an altitude below 400 m). The temperature is hot in summer and cool in winter. The solar radiation is significant all year round, with a daily mean value of 5,6 kWh/m^2.day. During the winter period, South Easterly trade winds are particularly strong in winter and have an impact on the optimal orientation of new constructions. Figure 1 gives the main climatic features of the city of Saint-Pierre.

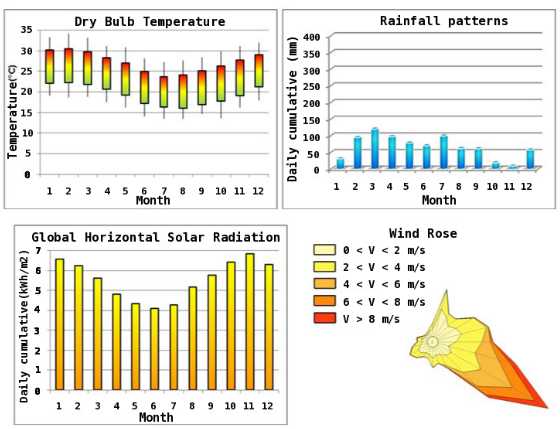


Figure 1: Weather conditions in Saint-Pierre, Reunion Island. Source: PERENE 2009 [5].

PRESENTATION OF THE NEIGHBOURHOOD OF RAVINE BLANCHE

The neighbourhood of 'Ravine Blanche' is located in Saint-Pierre, Reunion Island. It is an old neighbourhood that started to develop in the 1960's and 1970's and totally disconnected to the city centre. The existing neighbourhood is under an urban renewal program, which covers an area of 148 acres with a population of 6000 inhabitants. Before the renewal project started, the district was recognised as a stigmatised neighbourhood composed of 75% of social housing and identified as a monofunctional entity, with a low rate of shops and public services. In addition to poor physical conditions of the housing, the concentration of disadvantaged social housing tenants was also recognised as a key concern, since 89% of unemployed people were under the age of 20, 25% were sole parents and 30% had very low annual incomes.

The study area is illustrated in Figure 2 below.

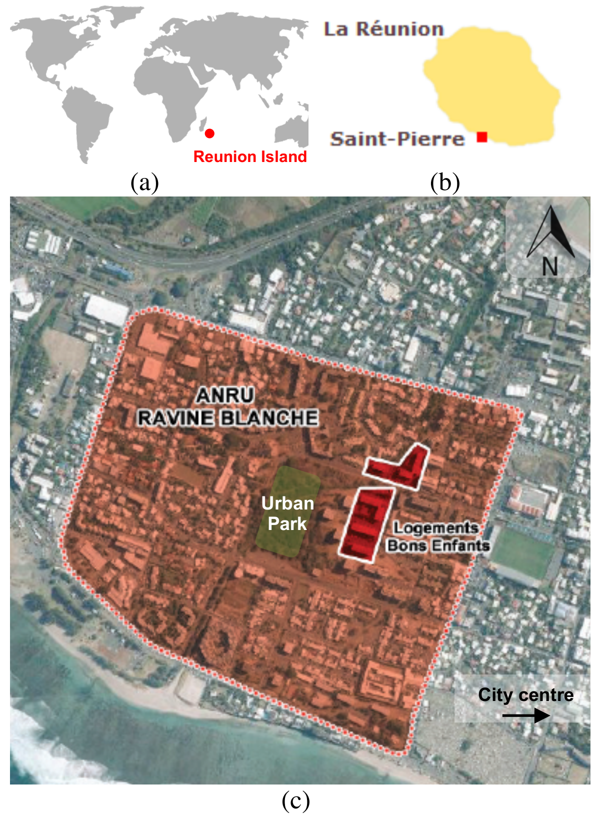


Figure 2: Study area - location of (a) Reunion Island on the world map, (b) the city of Saint-Pierre and (c) the sustainable neighbourhood of Ravine Blanche (the area is approximately 1km x 1 km) (source: Google map)

The urban renewal project was launched in Ravine Blanche in 2008-2009 for a total project cost of $165 million. It encompassed the refurbishment of 842 social housing units, the construction of 558 new housing units and the 'résidentialisation' of 1340 units. Indeed, housing diversity can be achieved by what is in France called the 'résidentialisation', meaning small, self-contained residential units with limited access via enclosures, which are intended to enhance security, social control and appropriation. The program also aimed to renew and develop facilities so as to develop a mixed district, with the creation of 6000 m^2 of shops, offices and public services, the renovation of three schools and the construction of two new schools as well. Major improvements were done in terms of urban infrastructure. An urban park of 4,94 acres with a series of landscaped ditches and basins for management of rainwater was created.

Ravine Blanche is the only overseas neighbourhood that was awarded the EcoQuartier certification in the tropics among 32 other French projects in 2013. A qualitative and quantitative campaign of measurements is currently conducted in order to measure the real performance of the ecodistrict.

DESIGN AND RENOVATION OF AN EXISTING BUILDING: "LES BONS ENFANTS"

'Ravine Blanche' is composed of different buildings that were built in the seventies, with mass housing blocks often in the form of tower blocks, on the purpose to house people at low-level income. Most traditional buildings of this period were not originally designed to incorporate energy efficient systems or passive features.

The 'Bons Enfants' cluster of buildings was built in 1975 and needed a considerable refurbishment. The seven existing buildings of the operation have been retrofitted according to passive bioclimatic principles so as to provide 168 comfortable units of different typologies. The different buildings of 'Bons Enfants' are at an average altitude of 20 metres above sea level and at a distance of 200 metres from the seafront. The buildings are located in close proximity to the city centre on the East side as well as to a new urban park on the West side. All the buildings present a parallelepiped shape with a terrace roof. The main facades of the buildings are North and South oriented except for two buildings. Table 1 below lists the main features of the retrofitting project.

Table 1: Building features of the 'Bons Enfants' project.

Building owner	SHLMR (social housing company)
Programming	Retrofitted social building
Total Net Floor Area	12 180 m^2
Total Cost	8.5 M€
Cost per m2	697.9€ /m^2 net floor area
Total Number of buildings	7 (C, D, G, H, I, J, K)
Number of storeys per building	3 or 4 storeys
Total number of units	168
Total area of solar thermal panels	294 m^2

As shown in Figure 3, the regeneration project includes the creation of exterior verandas, replacement of existing harmful materials, installation of solar thermal panels for domestic hot water supply, improvement of thermal comfort conditions and creation of green areas and gardens. Domestic hot water for all the buildings is produced thanks to 294m^2 of solar thermal flat plate collectors with an estimated annual energy production superior to 700 kWh/m^2.yr.

(a) (b) (c) (d)

Figure 3: Retrofitting of an existing large tower block 'Bons Enfants Building C' and passive solutions set up: (a) South façade of the old existing building, (b) same façade for the retrofitted one, (c) louvered shutters and (d) exterior covered veranda. Photo Credits: T. Giraud.

In the case of refurbishment, achieving optimal thermal comfort conditions is complex since the orientation, the form and the site location of the buildings cannot be changed. Nevertheless, this project focused on how to improve thermal comfort within this context. The main retrofitting strategies focused on structural work by renovating the entire exterior envelope of the structure, as well as interior modification.

A combination of two main tools was used so as to achieve this goal: the aerodynamic tool URBAWIND that estimates the air exchange and a thermal tool called 'BATIPEI' that computes the indoor temperature [6].

URBAWIND is based on a computational fluid dynamics code, especially developed to model the wind in urban areas and for green buildings projects [7]**.** It has been used so as to quantify the natural ventilation potential around and within the block studied and assess the mass flow rates entering the flats.
For this case study, the natural ventilation module was used. In order to evaluate the velocity fields around the building, the layout of the block geometry with the surrounding buildings has been defined in URBAWIND. Indeed, the surrounding exiting buildings can have a non-negligible impact on the retrofitted ones. Figure 4 shows an example of the mean speed coefficient for the trade wind direction (wind direction of 120°) and their direction in this area.

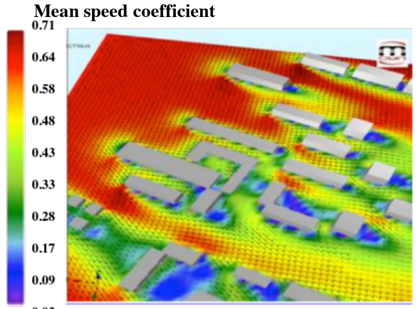


Figure 4: Mean speed coefficient for the different buildings of 'Bons Enfants' (for a wind direction of 120°) (Source: SOCETEM study)

In addition to the velocity fields, another significant indicator of natural ventilation potential is the pressure coefficient. The pressure coefficient shows the positive and negative pressures with respect to the wind direction on the studied surface. The mean pressure coefficient has been calculated for the different buildings studied on the outside walls. The results obtained indicate a strong impact of the surrounding buildings on the different blocks of buildings studied, as well as an impact of the buildings' blocks between themselves.

Air Change Rates per Hour - ACH were then evaluated for different types of apartment, different orientations, different floor levels and different positions (under the roof, gable wall, etc.) for each building. The overall flow rate inside an apartment depends on the size and position of the openings, the wind speed and the pressure coefficient. It is necessary to consider the wind speed levels inside the buildings and the flow-rates through the openings, which depend on the orientation of the building studied. The results obtained highlighted that the flow rate associated with thermal breezes was always lower than the flow rate that takes into account all wind directions. The results obtained from URBAWIND allow determining the air change rate to apply in 'BATIPEI'.

BATIPEI is a design tool developed for renovated projects under tropical climate by the engineering practice Solener and the French energy agency (ADEME). BATIPEI aims at evaluating the indoor thermal comfort by taking into account the external climatic parameters, the internal heat gains and the air change rate of a room. It is a simple assessment tool used for existing building that allows identifying the main sources of heat transfer and evaluating the impact of different strategies. The mean overheating inside the building, expressed in °C, is calculated. For this project, a threshold of 2°C of mean overheating was applied. A comparison between the mean overheating obtained before and after retrofitting for an apartment located on the last floor is presented in Figure 5.

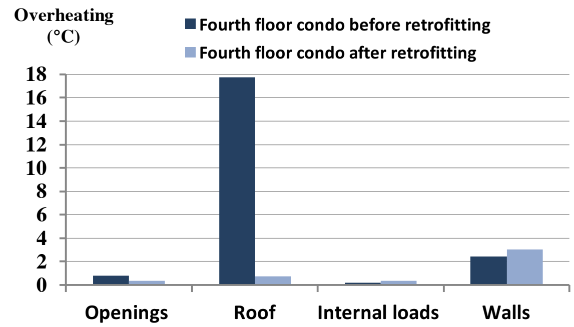


Figure 5: Mean overheating comparison for an apartment on the last floor before and after the retrofit, without any air change. One can notice that the roof insulation is the priority of the renovation project.

The first retrofitting scenario consisted in roof insulation with 5cm of expanded polystyrene, maximal building porosity (i.e. openings in the building structure that allow air exchange) with the use of full-height louvered windows so as to enhance natural cross ventilation, protection against solar heat gain with exterior louvered shutters and covered verandas.

The results obtained highlighted that the lack of roof insulation and the air change rate were the main factors influencing the overheating. Indeed, it can be observed that before retrofitting, the main part of the heat transfer is associated to the roof (84%) but that the insulation significantly reduces its impact.

However, despite the retrofitting scenario chosen, the walls remained a source of overheating. The insulation of the most solar exposed facades, i.e. the building gables, thanks to a fibber-cement exterior siding was added to the strategies.

The Figure 6 below presents the average overheating temperature for different floor levels. The results are given for three cases, without ventilation, with an air change rate of 10 ACH and with the air change rate calculated in URBAWIND. It can be observed that the cooling potential is far more important for the highest floor levels. This is particularly due to the high ventilation potential for high apartments. Finally, the overheating is lower than 2°C for the range of ACH expected to be reach in these buildings.

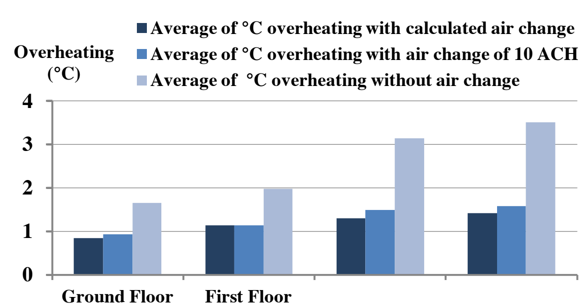


Figure 6: Mean overheating temperature according to the floor level for different air change rate per hour

The main passive features applied to this project are described in Figure 7.

Figure 7: Plan view of a representative unit before (left) and after (right) retrofitting so as to enhance natural ventilation by (1) creating covered exterior verandas, (2) enlarging the openings, (3) removing non-loadbearing elements and (4) adding louvered shutters on solar exposed windows. Design: Endémik.

DESIGN AND CONSTRUCTION OF A NEW RESIDENTIAL BUILDING: THE NIAMA PROJECT

In addition to the refurbishment of existing buildings, 'Ravine Blanche' also consists of the construction of new buildings that include several bioclimatic principles so as to enhance occupants and users' quality of life.

Located in the neighbourhood of 'Ravine Blanche', in Saint-Pierre, 'Niama' is a new social housing operation that was completed in the end of the year 2014. Niama is compliant with the Thermal, Acoustic and Ventilation French Regulation for the overseas territories (in French: Réglementation Thermique, Acoustique et Aération or RTAA DOM). RTAADOM is applied to the design of new residential buildings only and requires mandatory rules concerning thermal, acoustic and ventilation performances.

The project's main characteristics are given in Table 2 below.

Table 2: Main features of the 'Niama' project.

Building owner	SIDR (social landlord)
Programming	New social building
Total Net Floor Area	1 695 m²
Total Cost	3.22 M€
Cost per m2	1899,7€ /m² net floor area
Number of storeys	4
Total number of units	19
Total area of solar thermal panels	40 m²

The French Thermal Regulation for overseas territories focuses on the design of passive principles such as cross natural ventilation, sun protection and solar energy for water heating. Different levels of requirements exist for the performance of the building envelope according to the altitude of the project, the presence or not of air conditioning. To fulfil these requirements, the buildings have to be designed with mandatory cross natural ventilation and a minimum opening percentage of 20% of each facade and a limited solar factor for opaque surfaces and windows. The solar factor represents the proportion of energy, which is transmitted through the structure.

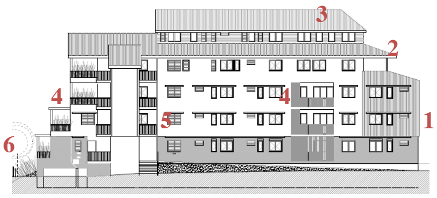
The RTAADOM also set out technical requirements concerning energy efficiency. It stipulates that all new dwellings shall be fitted with a solar hot water system that can meet at least 50% of the dwelling's hot water demand. Besides, ceiling fans are mandatory in rooms without satisfactory ventilation rate (i.e. only one façade with openings to the outside). For utility spaces (kitchen, toilets and bathroom) without any openings and where mechanical ventilation is required, a minimum air extraction rate is specified. The different technical requirements for the 'Niama' project are listed in Table 3.

Table 3: Technical requirements applied to the project of Niama, according to the RTAADOM regulation.

Objective	Building element	Requirements
To reduce solar heat gain	Opaque horizontal solar exposed structure	Solar factor Smax ≤ 0,03
	Opaque vertical solar exposed structure	Solar factor Smax ≤ 0,09
	Transparent structures adjacent to an un-conditioned space	Solar factor Smax ≤ 0,65
To enhance natural ventilation	Openings	Openings in at least two opposite facades
		Minimum opening-to-wall ratio of 20%

Niama uses many passive design strategies in order to reduce its energy consumption while maintaining satisfactory thermal comfort conditions inside the building. An elevation plan of the south façade presenting the structural elements is given in Figure 8.

(a)



(b)

1. Metal cladding
2. Roof overhang
3. Insulated roof
4. Exterior veranda with wooden vertical strips
5. Solar shading devices on exposed windows
6. Greenings of the surroundings
7. Solar thermal panels

Figure 8: (a) South Façade and (b) North Façade of 'Niama', Saint-Pierre, Reunion Island. Design: Co-architectes. Photo credits: N. Peyrebonne.

The building is cross naturally ventilated thanks to its optimal orientation and the use of full-height glass louvers located on opposite facades. The main facades and windows are sunshaded thanks to fixed vertical or horizontal solar protection depending on the orientation and the type of openings. Passive approaches include fixed vertical solar shading on the East side so as to protect from the morning sunlight and the trade winds, covered veranda and louvered shutter on the West side. The main facades (North and South) are protected thanks to a combination of simple roof overhangs, fixed horizontal solar shadings and exterior verandas. The exterior facades of the lowest storey are made in light painted materials. The two last storeys of the building, which are more solar exposed, are made with wood siding. Solar absorptivity is low and prevents overheating of exposed parts.

Besides, domestic hot water for all the building is produced thanks to 40 m² of solar thermal flat plate collectors with an estimated annual energy production superior to 622 kWh/m².yr and a minimum solar coverage rate of 63%. The installation of efficient ceiling fans in addition of natural ventilation allows avoiding the use of mechanical cooling systems. Finally, the building is surrounded by native plants and benefits from its proximity to the new urban park.

Figure 9 below illustrates the floor plan of the first floor of Niama, with the position and type of openings.

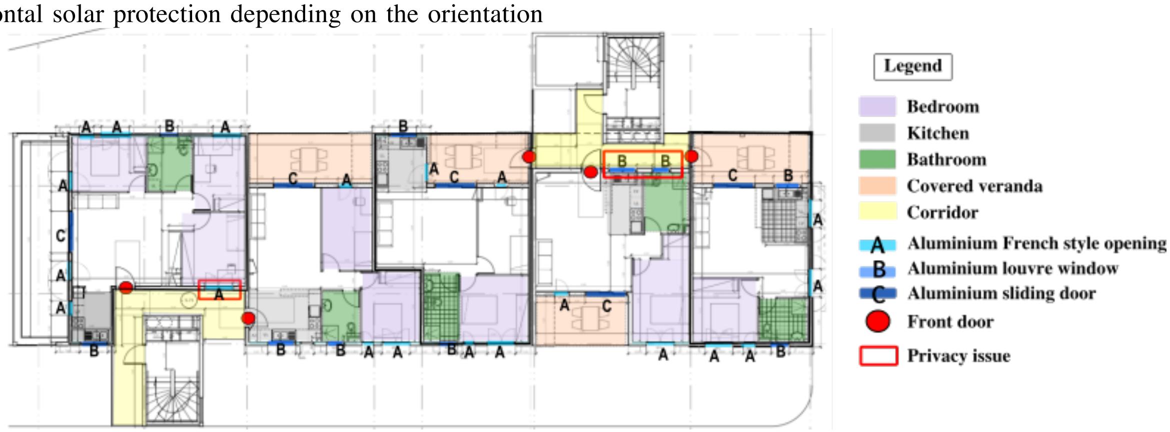


Figure 9: Floor plan of the first floor of the Niama building. Design: Co-architectes.

FUTURE WORK

A large-scale measurement campaign, which is intended to last for one year, will be carried out from September 2016 in the sustainable neighbourhood of Ravine Blanche in order to acquire data of the microclimatic conditions and investigate thermal comfort perception and thermal preference of people inside the buildings as well as in outdoor urban spaces for the tropical climate of Reunion Island.

A post-occupancy evaluation of occupants' thermal comfort of six residential operations, including the two building presented in the previous sections, and three institutional buildings of the study area will be carried out simultaneously. Interior comfort can be studied using Givoni's comfort diagram [8]. The study will focus on a comparison between new built housing, retrofitted buildings and old existing buildings built without any energy or thermal comfort considerations, linking more specifically interior and exterior environments.

For the outdoor thermal conditions, the applicability of different thermal indices, including PET [9] and UTCI [10] will be studied. The investigation will include on-site monitoring of the physical conditions and subjective assessment with field questionnaire surveys. The physical measurements will consist to collect the microclimatic parameters such as ambient air temperature, relative humidity, wind speed, globe temperature, mean radiant temperature and global radiation at different locations in Ravine Blanche.

CONCLUSION

This paper has presented an awarded Ecodistrict in the tropical climate of Reunion Island and two building projects (one renovated project and one new project) designed with specific tools adapted to each type of project. The passive strategies implemented either for retrofitting the existing building or designing the new one have also been presented with a climate-sensitive design approach which is crucial for human health and comfort [11]. In both cases, the different passive strategies have been set up in order to enhance the living conditions inside the buildings. Satisfactory thermal comfort conditions can be ensured even in harsh tropical conditions by implementing structural and architectural passive solutions such as a high level of porosity of the facades combined with optimized solar shading devices, as well as by greening the buildings' immediate surroundings.

ACKNOWLEDGEMENTS

The authors would like to thank the Municipality of Saint-Pierre for their financial support and for the data provision. Also the authors thank the different architects for permission to publish their pictures and plans: Endémik and Co-architects. The authors thank also the consultancy practices Solener, SOCETEM and Meteodyn for their valuable contribution to this project.

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