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Housing vulnerability in the Caribbean region:

A socio-cultural and technological approach

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Abstract— **San Andres is a Caribbean island, with an extreme aggressive atmosphere, an annual average air temperature of 27.6°C. High Resolution Meteorological models forecast the following for 2100: Changes in rainfall (+2.5 ÷-10.3%), sea level rise (+23÷32cm), temperature (T_{av}=+1.4°C) and possibility of storm force winds.**

Polychrome wood houses typology is losing ground in favor of concrete/brick buildings, indifferent to the Caribbean culture. Psychologically, such trend represents modernization; technically speaking, it poses a setback in terms of natural resources use and comfort; aesthetically, an antinomy related both to local identity and the richness of the natural environment.

The San Andres Climate-house project proposes three climate-sensitive housing typologies, adapted to the climate change and respecting the material culture, the aesthetics and the island's life model.

Principles implemented:

- **Appropriate configuration and low-impact materiality, compatible with the local labels;**
- **Constant use of the stack effect, cross ventilation and floor inertia;**
- **Structural reinforcements, shutters and concrete stilts to reduce vulnerability to strong winds and floods;**
- **Design and orientation to reduce thermal gains;**
- **Reuse of rainwater.**

Regarding energy and materials, the island is absolutely dependent but due to its cost (16.105€), social housing cannot implement solutions such as ventilated enclosures or the building integrated photovoltaic (TeCd) on roofs. The additional costs to adapt housing to climate change are justified with a reduction in vulnerability, environmental impact and costs in the life cycle.

The thermal simulations with ventilated envelopes secure better comfort with regards to brick/concrete of 7.3÷10.5°C without air-conditioning. CFD simulations lead to compact forms that reduce the resistance to strong winds yet maintaining generous eaves to reduce the thermal gains by direct radiation. The materials are free from chemical pollutants and largely recyclable or reusable.

A social housing prototype will be carried out in 2012.This electronic document is a "live" template. The various components of the paper [title, text, heads, etc.] are already defined on the style sheet, as illustrated by the portions given in this document.

Keywords : Climate house, San Andres Island, Climate Adaptive housing, Raizal culture, Housing adapted to the climate change, ventilated facade, ventilated roof, climate sensitive architecture, vulnerability in caribbean

I. INTRODUCTION

San Andres is a Caribbean island, with an average annual temperature of the air of 27.6°C and an extreme aggressive atmosphere. The High Resolution meteorological models [1] developed by IDEAM [2] provide sensitive changes in the regime of the rains, a rise both in temperature and sea level (+23÷32cm and the possibility of hurricanes.

The draft Climatehouse - Sanandres has been developed to counteract these risks in the framework of the INAP project. Successively, at Universidad Piloto in Colombia, the *Ecoenvolventes* group has developed simulations completed to further on thermal aspects raised with housing models adapted to the Climate Change.

The project proposes three types of housing adapted to the climate change respecting the material culture, aesthetics and the lifestyle of the island. To understand the scope of this project it is important to understand both the physical aspects, as well as the cultural and economic context, which are illustrated as follows.

II. SAN ANDRES ISLAND

The Archipelago of San Andres, Providencia and Santa Catalina with a total land area of 57 km^2 , is located in the south-west of the Caribbean Sea with a marine extension of 300,000 (three hundred thousand) km^2, equivalent to about 10% of the extension of the Caribbean sea.

The archipelago is notorious for two outstanding characteristics: the richness of the ecosystem and its cultural roots.

The Island of San Andres, with its 26 km^2, is the largest of the homonymous archipelago. Its remoteness from the other Caribbean islands and the extent and variety of the coral formation connote one of richest coastal and marine extensive ecosystems in the tropical region. The cultural traditions of the native Raizal population are generated by the mixture of traditions of afro descendants and English colonists. Such blend manifests itself in the language, religion, uses and customs, and of course the architecture. For these reasons, the territory of the archipelago was declared by UNESCO as "Seaflower Biosphere Reserve" [3] in 2000.

Notwithstanding this seemingly idyllic landscape that characterizes the island, there are two risk factors capable of irreparably compromising the balance and the above mentioned conditions: changes in weather conditions and the gradual impoverishment of the cultural expressions of the island.

III. CLIMATIC CHARACTERISTICS OF THE ISLAND

A. *Physical and geological features of the island*

The geological formation of the territory is volcanic and the rocks are mainly functional type of coral; the conformation of waterproof clay type predominates in the island territory and makes the groundwater level high.

The hydrographic system is mainly characterized by the presence of intermittent surface tides (*Guilles*) that are activated in the rainy season representing the irrigation system of the central areas of the island.

B. *Weather*

Due to its location in the intertropical zone, the Island of San Andres presents minimal thermal variations throughout the year, being the annual average temperature of the air 27.6 °C, the difference in average monthly maximum temperature (31.3°C) and minimum- (23.5°C) is hardly 7.8°C.

Rainfall corresponds to the unimodal model, where a dry season (December to May) is alternated with a wet period (June to November) in which 47% of the rainfall occurs at night. The average relative humidity is 83%; the high load of salinity in suspension makes the atmosphere extremely aggressive toward the materials of construction. San Andres can count on entry 2686 hours of sunshine per year, with 224 hours of sunshine per month (7.4 hours/day ± 20%), an interesting value to consider for further development.

The prevailing winds are from the trade Northeast (40%) and East (40%), having the character of weak or moderate breeze.

C. *Risk Factors*

The position of the archipelago makes it especially vulnerable to the effects of climate change. Climate forecasting models have been applied especially in the island of San Andres. These high resolution meteorological models [4] remain particularly significant and forecast for 2100 the rise in temperature (T_{av}= +1.4°C), fluctuations in speed of the rains (+2.5÷-10,3%), sea level rise (+23÷32cm), and the possibility of hurricanes. The increase of the temperature, in addition to the possible effects on the biological heritage, increase the levels of discomfort and demand a greater amount of energy to provide pleasant conditions inside the buildings.

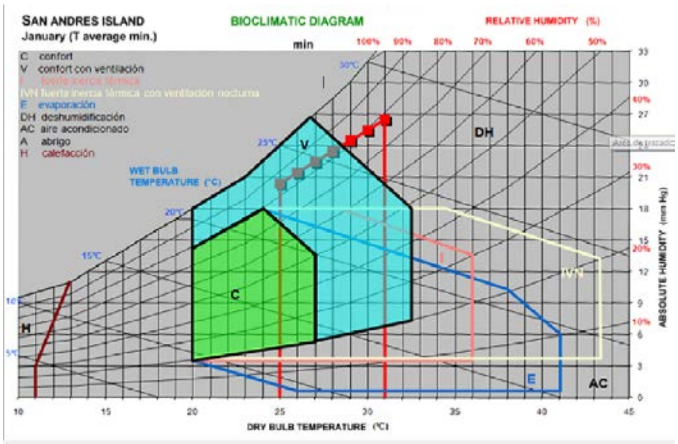

Image 1. San Andres Bioclimatic Diagram

The change of regime of rains is a concern in the presence of long dry seasons, as the water supply comes from the collection of rainfall and groundwater wells; especially delicate is the position of the inhabited center, with a strong presence of tourism, where the water consumption per capita is approximately twice as much as the housing use.

The effects of sea-level rise are more significant regarding expected values, representing a significant loss of the surface of the island compromising both human settlements and natural resources. "With the sea-level rising one meter, a flood could occur, affecting more than 10% of the island of San Andres, represented in areas of marshes, coastal belts, fillers and artificial low coral terraces covered by mangrove. In these sites, urban, residential and commercial areas would be affected, as well as the harbor of the island." [5]

The risk that the island be hit by hurricanes is of considerable impact due to the light materials and the construction techniques of the island, which have the presence of pronounced eaves likely to be removed by hurricanes

Comparing such risks, governmental, intergovernmental and non-governmental organizations have promoted and carried out the Integrated National Adaptation Project (INAP) [6] enabled to define and implement specific pilot measures of adaptation to confront the current impacts of climate change.

Amongst such measures, the transfer of local knowledge to increase awareness allowing the generation of management strategies that improve the capacity for adaptation in vulnerable communities is a key issue.

These dynamics, which have been a concern for the understanding of the most vulnerable realities in Colombia, have also aimed at the protection of biodiversity, society and material culture as primal components that constitute the economic basis of the inhabitants of the island.

In this context, studies have been developed for the adaptation of housing to the climate change "Integrated National Pilot of adaptation", seeking to mitigating the adverse effects of climate change through specific measures, specifically referred to high mountain ecosystems and insular areas of the Colombian Caribbean region.

IV. CULTURAL ASPECTS

A. *Character and cultural autonomy island*

Raizal culture is characterized by the cultural blend (linguistic, religious, social, architectural and musical) between afro and euro descendents populations, emphasized by the distance from the mainland, the dimensions of the territory and the availability of primary and secondary resources.

The small size of the territory and its isolation lead to a behavior of conservation and careful management of resources; however, the cultural autonomy and social conservationist spirit of the raizales have been strongly affected by the opening of the airport and the consequent massive influx of tourists. This dynamic has resulted in the rapid acceleration of trade, which has altered the relations and the consolidated balances by introducing novel myths such as concrete-durable and glass-modern which have connoted urban and rural building development. [7]

This constructive model has enabled greater densification, less vulnerability to the effects of hurricane winds and the possibility of integrating installations of a certain complexity and management of spaces of greater size and complexity. Technically however, it represents a decline in the management of natural resources because the design and physical characteristics of the material favor heat gains.

Moreover, from an aesthetic approach it is an antinomy compared to traditional construction image and concept.

The massive presence of tourists on the island (an average of almost 1000/day), allows the appreciation of the heritage landscape of the island but on the other hand, reproduces non native life styles being detrimental to the raizal culture, as tourists practices, heavily dependent on stereotypes, do not allow for proper cultural exchanges nor a thorough understanding of the very own lifestyle of the island

B. *Material Culture: housing*

The most evident manifestation of the island´s culture material is formed by the polychrome wooden constructions that adapt labels actually owned by the Anglo-Saxon homes, suitably adapted to climatic conditions and those typical of the the Caribbean tropics.

It is simple geometry on stilts with wooden balconies, with a two or four gabled roofs and a maximum height of two floors.

The "spontaneous" character of the constructions is easily recognizable, especially in the change of inclination of the roof shape determined by the use of the mezzanines. The traditional island housing has vertical windows and hinged shutters in wood.

Image 2. Typical San Andres house. Auth. Per Y. Lidvall/AspectusForma

However, urban rules aimed at quality, durability, and reducing the environmental impact of its use have not issued application norms [7]. This political-regulatory delay has implicitly allowed the replacement of local constructive models for foreign ones climatically inappropriate, with high environmental impact. Therefore the typology of houses in polychrome wood is losing in favor of concrete-brick and air-conditioning- dependent buildings, which are indifferent to the Caribbean culture. Psychologically, such represents a modernization; technically, it is a setback in terms of natural resource use and comfort; aesthetically, poses a fracture with respect to the antinomy concerned with identity and the richness of the natural environment of the island.

V. Energy and Natural Resources

1) Water. - The most important source of water supply is rainfall; it is estimated that rainwater recovered corresponds to 12-18% of the demand for residents [8].

Water for human use comes from wells whose watersheds are generated primarily by the cycle of rainfall being susceptible to fluctuations in their sensitive levels; water supply depends on the rainfall regime by which five dry months alternate with seven months of rain (from June to December), allowing the recharge of aquifers.

The two large consumers of water around the island are the residents and tourists: with an estimated consumption per capita of 150 l/day and 289 l/day respectively [9]. A third source is the sea water, previously desalinated by reverse osmosis.

2) Electrical energy. - Electrical energy comes from office of non-renewable source, the use of three plants with diesel engines.

VI. Climate adaptive housing

The project Climatehouse-Sanandres proposes three climate-sensitive typologies for housing adapted to climate change in the respect of the material culture and aesthetics and the model of life islanders. Contrary to what the name may suggest, the factors that are considered herein and how to deal with them are quite different from those that characterize European households. One first reason is economic: Being the island dependant of the continent in terms of energy and materials, the costs are greater. Considering that social housing has a set cost less than or equals to 16.106 €, it is not such a financially viable solution, as the use of more efficient and ventilated envelopes or the use of photovoltaic roofs.

The major costs to adapt housing to climate change are justified with the reduction of vulnerability and environmental impact and with the increase of thermal comfort, which in turn enables reducing costs in the life cycle.

The second reason is cultural, given the material culture of the raizal ethnic group characterized by constructive typologies in wood, utilization of attics, with balconies that constitute a quintessential social area and highly permeable to the flow of air, which is not exactly coincident with the adiabatic concept that characterizes the *Climahaus*.

Climatic conditions in the island, the salty atmosphere associated with high temperatures and relative humidity, generate stress conditions that reduce the life of any type of surface. Regarding the conceptual development of the project design activities are oriented to:

1) *Reduction of vulnerability to climate change*:

a) *Construction on stilts*, to reduce vulnerability to high winds and flooding,

b) *Utilizing shutters* to reduce vulnerability to hurricanes and the effects of solar radiation,

c) *Reusing of rain water for sanitary use,*

d) *Implementing the use of low consumption faucets, toilets and electrical lamps and appliances*.

2) *Integration of specific functions of thermal control and energy generation in the architectural envelopes*;

a) *Constant use of the stack effect, cross ventilation and inertia of the night floors to reduce energy demand and maintain the internal climate control*.

b) *Using facades and ventilated roofs* (only ventilated roofs for social housing).

c) *Reduction of the energy dependence of non-renewable sources* through the use of building integrated photovoltaic roofs with surfaces of catchment in TeCd (except for social housing).

3) *Development of a constructive system that integrates design, materials and technologies* (based on analysis of the traditional housing island) depending on the reduction of cultural, environmental and energy impacts;

a) *Use of materials and finishes of low impact* (long life, resistant to the saline aggression, with a minimal quantity of chemical solvents, recyclable and/or reusable);

Image 3. Natural Air Flows in the apartament block

4) *Recognition of the spatial and functional qualities of the traditional housing as well as the materiality of the aesthetics of the shelter island as a starting point for the development of low impact model;*

a) Incorporation of forms, chromatic hues and typical spaces of the native architecture.

b) Compact design and orientation on how to reduce thermal gains.

The thermal simulations with ventilated envelopes carry a greater comfort with regard to brick/concrete 7.3÷10.5^{o}C without air-conditioning; the CFD lead to compact forms that reduce the resistance to strong winds yet maintaining generous overhangs to reduce the thermal gains by direct radiation.

VII. RAIZAL CULTURE AND HOUSING ADAPTED TO THE CLIMATE CHANGE

The island's unbalanced economy which relies largely on revenue coming from tourism amounts to the fact that almost all of its consuming resources come from the continent, making it highly dependent on outside funds. The island however may reduce its energy dependence, or even become autonomous by exploiting renewable sources.

The cost of photovoltaic in San Andres, for example, which would be prohibitive without the government contribution, can make the values of solar radiation more advantageous because transport costs have an impact on them.

Relatively complex is the possibility of utilization of wind energy, nowadays already affordable compared to the energy generated by non-renewable sources, which depends on types of high efficiency rotors that can operate with relatively low air speed.

The raizal architectures have evolved according to the resources and the climatic conditions of the places to get to constructive solutions which are generally made of used local materials and construction techniques at the same time simple and ingenious.

The adaptive intelligence of the spontaneous architecture has been taken as a starting point to harmoniously integrate new knowledge and technologies to the homes. Such has been conceived to successfully address the effects of climate change, particularly in the face of hurricanes and tropical storms, as they require less maintenance in the period of life, offering greater comfort, reducing the environmental impact in the life cycle and enabling energy self-sufficiency.

It is expected that the present housing model proposal, unlike many other projects, be carried out, tested and susceptible to replication.

Today we can have knowledge and technologies (ranging from state-of-the-art to not so advanced) that allow for developing timely and effective responses in terms of performance and useful life, factors which are important in determining a context climate-environmental and aggressive in a territory that must sustain high costs to import construction materials.

With regards to the conceptual development of the project design activities are oriented to:

1) Integration of specific functions of thermal control and energy generation in the architectural envelopes

2) Development of a constructive system that integrates design, materials and technologies (consequential to the analysis of the traditional island housing and to the "imported" models) that will make it possible to reduce the impacts of cultural, environmental and energy;

3) Recognition of the spatial and functional qualities of the traditional housing as well as the materiality of the aesthetics of the shelter island as a starting point for the development of of low impact models;

4) Formulation and development of models specifically designed for the urban and rural San Andres contexts.

VIII. DESIGN OF THERMAL ENVELOPE AND SIMULATIONS

The design of different types of housing has been associated to strictly functional and formal principles and typical spaces of the island culture.

In the second instance ventilated envelopes have been designed (roof only in the social housing) to minimize the transmission of heat to interior spaces. The ventilation in the envelopes has a dual role: to avoid thermal bridges and to activate flows of dissipation of excess thermal gains generated by solar radiation.

All of the designs incorporate the characteristics of the island housing, with stilts construction, compact forms, two-gabled ventilated roofs with broken shape to use the attic; for the protection of the solar radiation extensive eaves and shutters are used. Given the pivotal role of social life, a balcony is included in the profile of the construction.

In the social housing the ventilated roof, working like a big umbrella, is the element that reduces, thanks to the air flow that is generated by stack effect, a good part of the overheating that solar radiation generates because the facades with simple wooden tables or bedroom with air are not very effective in the control of the radiant temperature in the warmest hours of the day. Another prop comes from the shutters that prevent the permeation of heat through the glass.

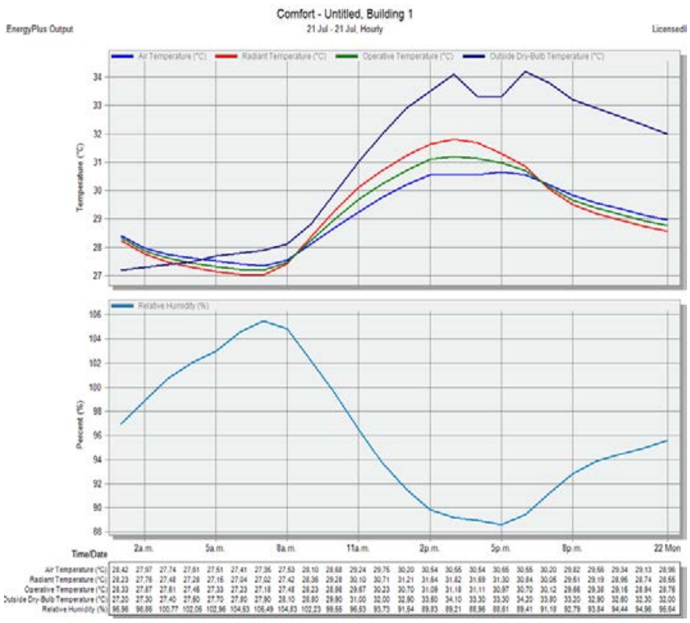

Image 4. CFD San Andres in the hottest day (21 of July)

The use of wood as a structural and facade material does not generate heat bridges, while the solution with stilts allows the generation of constant flows of relatively fresh air that reduces the thermal gains.

Special attention has been given special to form, dimension, materials and solar protection of the transparent surfaces: the mark of the windows, supplemented with movable shutters in function of both the orientation and the hour of the day, are configured to not interrupt the continuity of the ascending flows. The deployed solutions, in addition to allowing the visual permeability, generate from modest laminar flows functional to the change of air, to large volumes depending on requirements.

Compared to the results the thermal simulations and fluid dynamics, yielded modest data regarding internal temperatures:

1) 1.9°C (+0.3°C with the single panel and -2.0°C with sandwich panel, such as maximum value) *in the warmest day* and

2) -1.5°C (+1.1°C with the single panel and -1.7°C with sandwich panel, such as maximum value) *in 75% of the days on average in the 24 hours*, being the household fresher in regards to the external temperature in the hours of the night and in the morning.

In the evening hours, with facades in simple wooden panels or OSB, internal temperatures get to have the same value of the external temperature in the warmest day, while keeping about 2°C below in 75% of the days yielding equally high temperatures. For this reason, the design enables the ventilation of the internal surfaces that accumulate heat, like the floors, in tandem with the ventilation of the ceilings that evacuates the less dense air.

Although permeability to the air does not allow obtaining ideal temperatures during the day, it favors quick freshening in the night hours in which the family meets and remains indoors.

In this sense, the generation of permeable stripes with a specific microclimate characterized by latticework having dual function is proposed. They will allow for the passing of air in horizontal, open with bulkheads, and will reflect daylight so that it enters indirectly reducing the demand of electrical light.

The principal social area is maintained as external space to take advantage of the effects of the breezes.

In the apartment block, where the budget limitation is not so severe, it is possible to take advantage of the stack effect both in the ventilated facades and perimeter the suction which is generated by associating the pile-dwelling structure with a central courtyard. In this case the results of thermal simulations are much better:

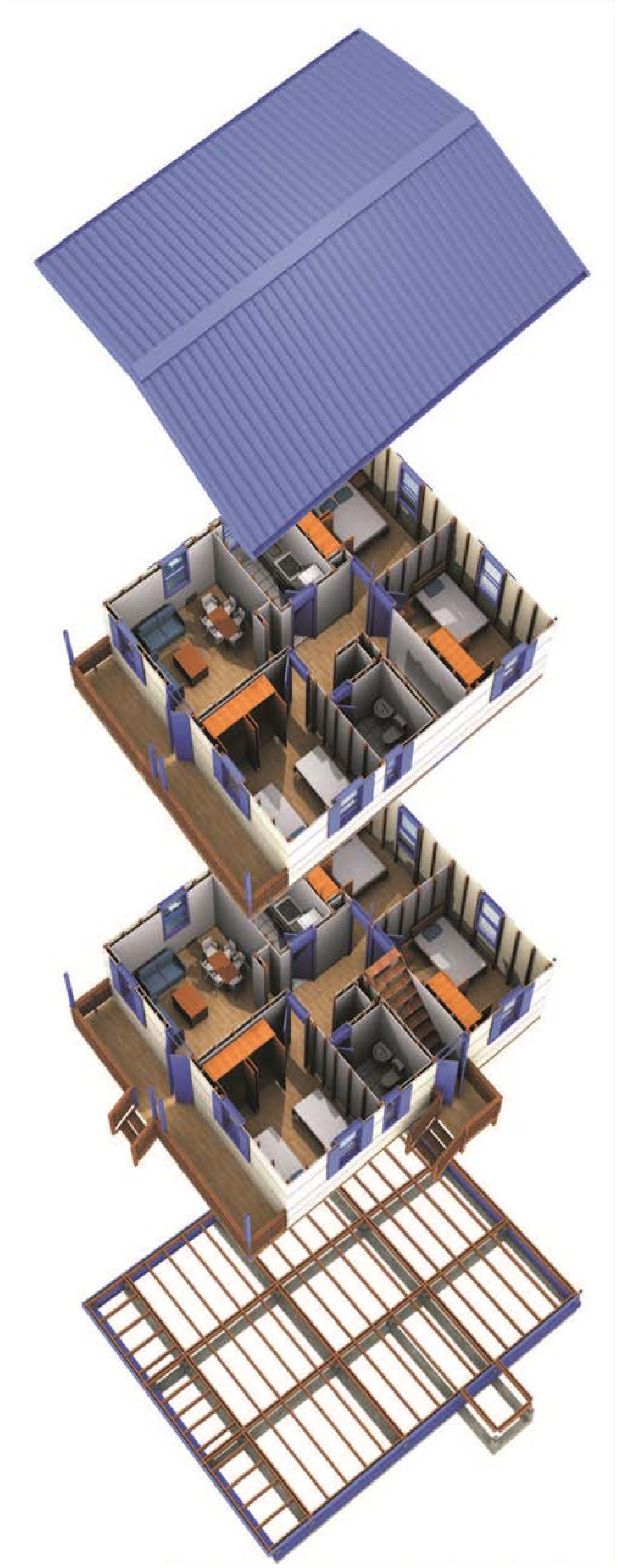

Image 5. Social housing design

1) *-4.5°C* (-9.7°C as maximum value) in the warmest day and

2) *-2.5°C* (-5.8°C as maximum value) *in 75% of the days on the average in the 24 hours.*

The inertia that is possible by associating the coating surface on wood to a brick and plaster envelope makes the internal temperatures to be generated after sunset. In these conditions is advantageous to accelerate heat dispersion by cross ventilation of the ceiling, floor and the internal space in general safe for the exceptionally warm days where the outside temperature is maintained for more than 2°C above the interior, yielding useless the effects of ventilation until the early hours of the day.

IX. TECHNOLOGY

The technological results have been oriented toward dry built envelopes allowing the reduction of the impact at the end of life and obtaining thermally certain behaviors when using certified products. Much attention has also been given to the search of equilibrium conditions between the functions of isolation and inertia, in order to determine the most favorable conditions of limitation of thermal gain and appropriate phase angle so that the thermal wave is attenuated while its effects correspond with external thermal conditions that favor fast dissipation.

In order to allow the change of air and nocturnal thermal dissipation, it intervenes on the designed openings to ventilate the people and/or to refresh the floor and ceiling surfaces.

Another aspect that is currently being worked on is the access of light that affects differently whether it comes by direct solar radiation or by indirect means: The intention is to minimize access to the interior of the direct solar radiation, implying thermal gain, without sacrificing the natural lighting through shielding that allows entry of indirect light.

X. CDTE/CDS PHOTOVOLTAIC

The solution raised for housing solutions is one of Building Integrated Photovoltaics of recent marketing and which has characteristics that are especially suitable for San Andres. The panels are composed of a thin film of cadmium tellurium, which has a bandwidth of catchment very close to the optimum value for the calculated theoretical solar cells (1.44 eV) and a high absorption coefficient.

Approximately 99% of the incident light is absorbed by a thickness of the layer of only 1 micron (with respect to 10μm for the Si). Due to its characteristics, is a solution of a good efficiency and low cost as it allows a broad absorption of the sun's spectrum. With panels of CdTe, cadmium sulphide is used as a conductor, whose transparency permits the passage of sunlight through the layer of CdTe.

The good performance of the panels of CdTe is neither in the cost or efficiency but in the presence of cadmium which is a highly toxic material; it is the precision that the cadmium content in a photovoltaic module is less than 0.1 % by weight;

in the panels of CdTe cadmium is present in a very stable way. It is precisely the encapsulation that allows its attachment to the course of the life of the cell (25 years) and also readily recyclable. The tests conducted at the University of Parma, show that the cells of CdTe are also very stable in terms of efficiency: their performance can exceed the value of crystalline silicon panels for greater sensitivity with diffuse light and better shade tolerance, being also lower their loss of sensitivity with the increase in the temperatures (to 70^{o}C: -9% against -23% of crystalline silicon).

It is also competitive in terms of cost per kWh of energy produced (2.4 € /W compared to € 5/W of SiC) [10].

XI. Conclusions

After modeling climate change scenarios for the island of San Andres, housing models adapted to the climate change as well as further simulations have been developed to quantify the thermal effects of the proposed solutions.

The different risks (sea-level rise, hurricanes, the increase in temperature and changes in rain regime) have shifted the conception of the house, as a response to the climate change trying to keep as much as possible the connotations of the material culture that characterizes the island housing.

The studies, which seek to preserve the cultural and environmental heritage of the archipelago, have provided low-impact solutions that take advantages of the air for the thermal control, the rain water to avoid the dry periods, the phyto-purification to reduce the loads on the sewerage or replace it. For the generation of energy roof tile BIPV with thin films of CdTe/CdS will be preferred: less expensive and more efficient in terms of cloudy sky with respect to the crystalline silicon panels.

The economic limits provided by the social housing oblige to the deployment of less envelope-efficient solutions, whereas in the homes of free market performance envelope generated by the fully ventilated envelopes provide significant values of thermal comfort while minimizing the demand for air conditioning.

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