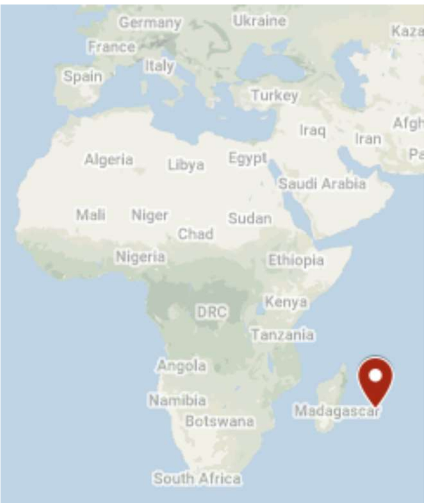
CASE STUDY 1-06: MOUFIA LECTURE THEATER | LA REUNION



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	15 Avenue René Cassin 97715 Sainte Clotilde, La Réunion, France
Latitude; Longitude	-20.902046923902343, 55.485358557421655
Climate zone (Köppen–Geiger classification)	Aw: Tropical savannah with dry winter

BUILDING INFORMATION	
Building Type	Educational Building – Lecture theatre
Project Type	New construction
Completion Date	2014
Number of buildings	1
Number of storeys	1
Total Floor Area (m²)	1193
Net Floor Area (m²)	1185
Thermally conditioned space area (m²)	36 m² conditioned space
Spaces with Natural Ventilation (with or without Ceiling Fans). Only (m²)	1149 m²
Total cost (€)	2 752 000
Cost /m² (€/m²)	2 306,7
Performance Standards or Certification	PREBAT (French National Research and Experimentation Programme on Building Energy)
Awards	

STAKEHOLDERS	
Building Owner/ Representative	University of La Réunion
Architect / Designer	Olivier BRABANT
Construction manager	SODIAC, Université de La Réunion
Environmental consultancy	Imageen
Structural Engineer, Civil Engineer	Intégrale Ingénierie, Laroche Joubert, AIEE Acoustique
Product Manufacturer	
Certification company	
Others	Jacques Gandemer. Aerodynamic and airflow design, specialist in architecture and urban planning

PROJECT DESCRIPTION [1] [2] [3] [4]

Figure 87: Northern facade

This 550-seat building, located in the French island of Reunion near Madagascar, is the first bioclimatic lecture theatre in the tropics. The building operates without air conditioning and with the use of natural ventilation only.

Thanks to its efficient airflow design, users feel comfortable throughout all year long. The lecture theatre is used as an auditorium but also for lectures and conferences.

It has a total area of 1200 m², as well as a car park of 420 places on 3 levels with PV panels at the top that acts a shading devices.

Figure 88: Eastern facade with air inlets and native vegetation

Figure 89 : Inside view of the lecture theatre

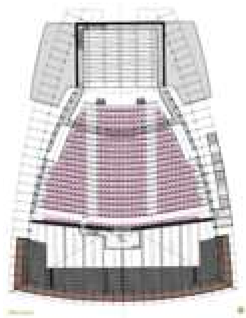


Figure 90 : Plan view of the lecture theatre

SITE INTEGRATION

Figure 91 : site integration of the lecture theater

The lecture theatre is located in the main campus of the capital city in the North of the island . It is connected by two bridges of the university campus and the rest of the city and is located in a complex of large buildings such as the building of the Regional council. There is dense vegetation around the building to cool the air and create a microclimate before entering the building.

ABC21 is funded by the
EU's H2020 programme

CLIMATE ANALYSIS

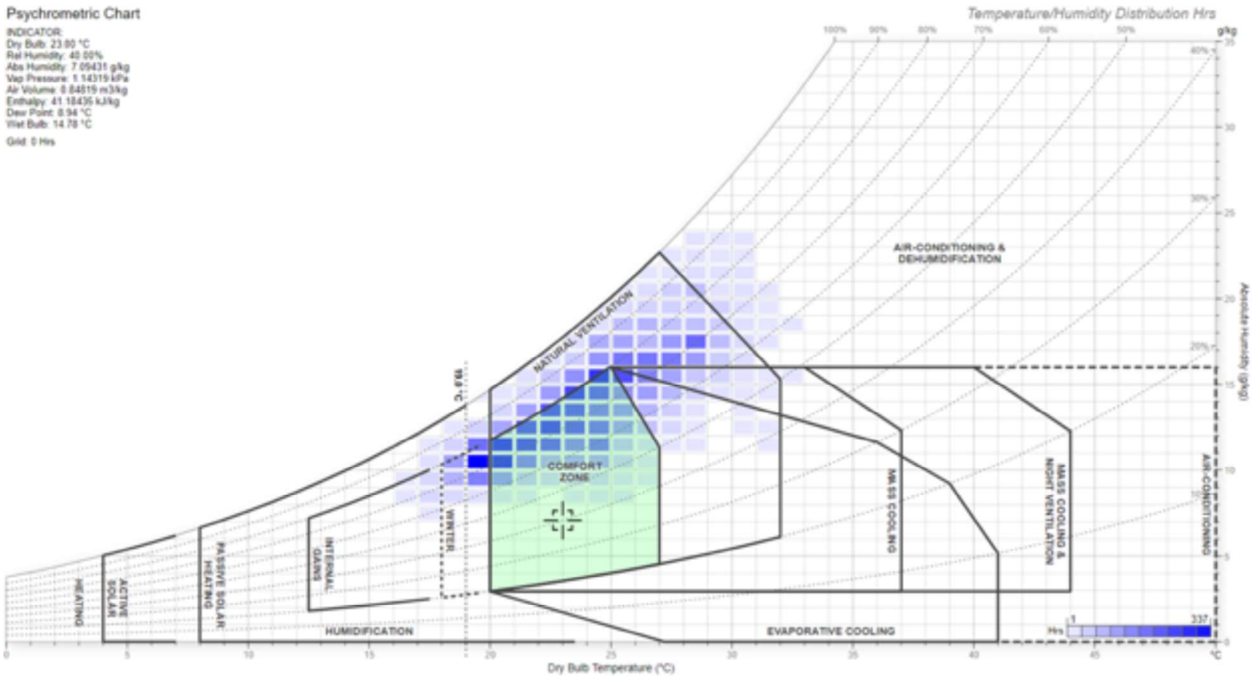


Figure 92 : Givoni Bioclimatic chart for the climate of Saint-Denis [5].

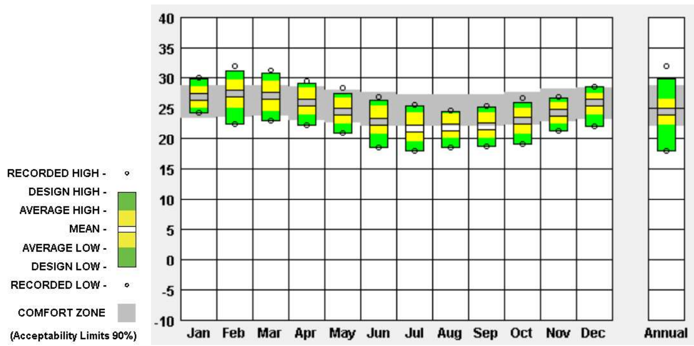


Figure 93 : Monthly temperature range for Saint-Denis. Source: Climate consultant - Adaptative Comfort model [6]

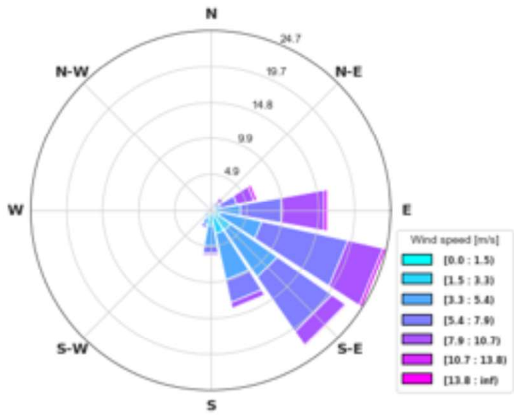


Figure 94 : Annual wind rose for Saint-Denis (Beaufort wind scale). [6]

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **4120** Wh/m² (June) Max: **6429** Wh/m² (January) Mean: **5355,67** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **1** CDD 10°C: **5059**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **99** CDD: **6**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **4** CDD 26º: **150**

KEY BIOCLIMATIC DESIGN PRINCIPLES [1] [2] [3] [4]	
Passive cooling strategy	**Comfort ventilation /** Natural cross-ventilation Low pressure shaft that acts like a natural pump: An opened U shaped-roof at the top accelerate the trade winds and create a natural low pressure thanks to the venturi effect. Glass louvers are installed on opposite facades. 4 differentiated air inlets (see Figure 7)
Passive heating strategy	None
Solar protection	Large overhangs protect the glass louvers and the main facades
Building orientation	The main facades of the building are North/South oriented
Insulation	**Roof insulation:** There is 10 cm of rockwool and 8 cm of air gap.
Vegetation	The surroundings were vegetated with native species, allowing the cooling of the air around the building.
Natural daylighting	Natural lighting is preferred thanks to the louvers and lateral louvers to limit artificial lighting
Use of local and embedded materials	Use of wood (structure et walls) and local volcanic stone (pavements)
Water saving and heat recovery on hot water drain	None
Waste management	Wood construction generates little waste
Others features	Densely planted soils better absorb water during heavy rains

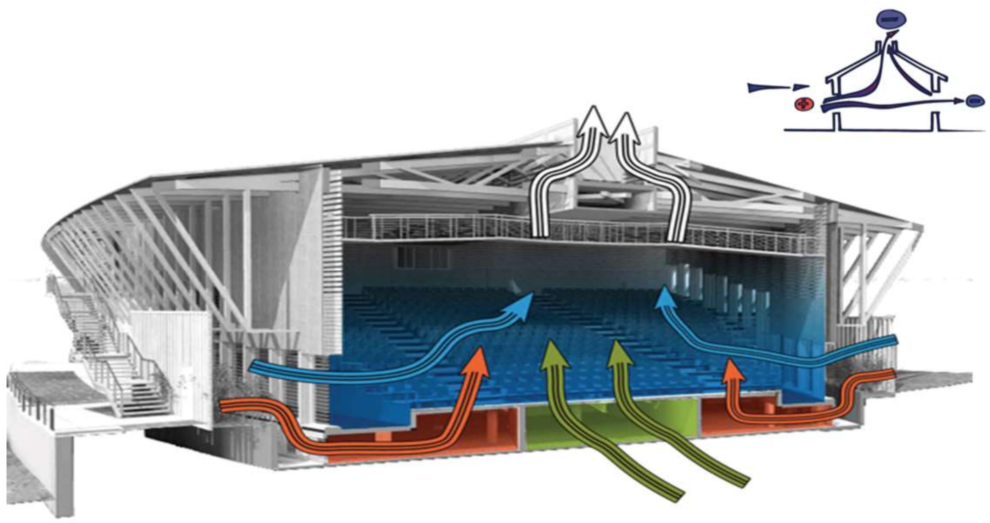


Figure 95 : Visualization of the air flow with the low-pressure shaft on top of the roof and the 4 air inlets located underneath the seats and at the side louvers.

INFRASTRUCTURES and REGULATIONS to enable SUFFICIENCY ACTION	
Dressing code	Informal dressing, adapted to the season, is welcome and promoted (e.g. short trousers and short leaves in hot periods): Yes
Protected bike parking and showers	Yes
Ceiling fans	In every room, even those conditioned: Yes (in offices only)
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: Yes.
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	In every room, even those conditioned: No
Book of instruction for correct use of the passive features (windows, solar protections, water savings) and active (lighting…) in order to promote sufficiency and efficiency actions	Available through leaflets and posters at relevant places, online, etc.: Yes

Figure 96 : Wind tunnel tests to validate the passive principles

Figure 97 : Posters explaining the airflow design and the environment objectives were installed closed to the main entrances of the lecture theatre.

BUILDING FABRIC AND MATERIALS [1] [2] [3] [4]	
Roof	External zinc skin/ 10 cm of rockwool / 8 cm of air gap/ceiling in wood
	Overall R-value : 3 m^2.K/W
Windows	Type of materials, thickness, etc. : Glass louvers and frame in Aluminium shaded by large overhangs
	Window-to-wall ratio (WWR) : N/A
	U-value: Unknown
	Visual transmittance: 0,87
Walls	Type of materials, thickness : Ext. Red cedar 2m / 8 cm air gap / Int. 2cm Wood (Meleze)
	Overall R-value : 0.63 m^2.K/W

Figure 98 : Side louvers

Figure 99 : Construction of the air compartments during the construction stage

Figure 100 : Low pressure shaft (top of the roof)

ENERGY EFFICIENT BUILDING SYSTEMS [1] [2] [3] [4]	
Low-energy cooling systems	The lecture theatre operates without any AC systems and uses only natural ventilation thanks to a difference of pressure from the different facades and the roof. The airflow design has been validated thanks to wind tunnel tests run in Laboratoire Eiffel in Paris.
Low-energy heating systems	None
Ceiling fans	Yes (offices only) Type: Hunter Industry II Power: 70W
Mechanical ventilation / air renewal	Only in the technical room where the video projector is installed
Domestic Hot Water	None
Artificial lighting	T5 Light bulbs Density=8.7 W/m2
Control and energy management	Yes (energy meters for each end uses)

Figure 101 : Solar shadings

Figure 102 : Ceiling fans are installed in every office space

Figure 103: T5 light bulbs (density: 8.7 W/m2)

Figure 104 : wooden superstructure

Figure 105 : low pressure shaft under construction

Figure 106 : The external walls are composed of wooden cladding

RENEWABLE ENERGY [1] [2] [3] [4]	
PV	A 145 kWp/1000 m^2 PV plant acts as a car shading system. The PV plant produces 10 times the low energy demand of the lecture theatre. The PV production is delivered on site.
Solar thermal	---
Wind	---
Geothermal	---
Biomass	---

The 145 kWp PV plant produces 183 kWh/m^2/year whereas the energy demand of the lecture theatre is only 23 kWh/m^2/year. The PV production is generated onsite only.

Figure 107: 145 kWp PV panels are installed as shading devices for the cars.

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS [1] [2]	
Thermal comfort indicators	1. Percentage of time outside an operative temperature range [Adaptive comfort method, Category II, EN16798-1, hot period (8th Feb. to 30th Apr. 2016)]: **0.6%**
	2. Percentage of time outside an operative temperature range (Fanger) : -
	3. Degree-hours [Adaptive comfort method, Category II, EN16798-1, hot period (8th Feb. to 30th Apr. 2016), occupation time: 8am to 6pm]: **1.1**
	4. Degree-hours (Fanger): -
	5. Percentage of time inside the Givoni comfort zone of 1m/s : hot period : **91%**
	6. Percentage of time inside the Givoni comfort zone of 0m/s: hot period: **5%**
	7. Number of hours within a certain temperature range:

Hot period (8th Feb. to 30th Apr. 2016) Occupation time: 8:00am to 6:00pm		
Range	Nb of Hours	Frequency
Ta≤26	**75**	8%
26<Ta≤28	**487**	54%
28<Ta≤30	**334**	37%
Ta>30	**12**	1%

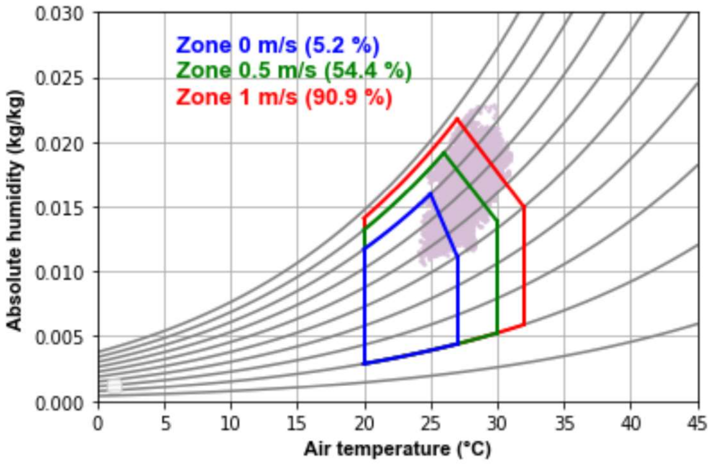


Figure 108 : Givoni bioclimatic chart – distribution of air temperature for the summer period (8th February to 30th April 2016) in the bioclimatic Amphitheatre during occupation time (8:00 – 18:00). Only 5% of the points are in the 0m/s comfort zone while approximately 91% are in the 1m/s comfort zone.

Energy performance indicators	1. Energy needs for heating: **-** [kWh/m²/year]
	2. Energy needs for cooling: **-** [kWh/m²/year]
	3. Energy use for lighting: **9** [kWh/m²/year]
	4. Energy needs for sanitary hot water: **0** [kWh/m²/year]
	5. Total primary energy use (kWh/y/m2) : **76** (total Primary Energy Factor (PEF) equal to **3.3** for electrical energy from the grid)
	6. Renewable Primary energy generated on-site: **183** [kWh/m²/year]
	7. Renewable Primary energy generated on-site and self-consumed: **183** [kWh/m²/year]
	8. Renewable Primary energy exported to the grid: **0** [kWh/m²/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): **241%**
	10. Delivered energy (from electricity bills) : **23** [kWh/m²/year]

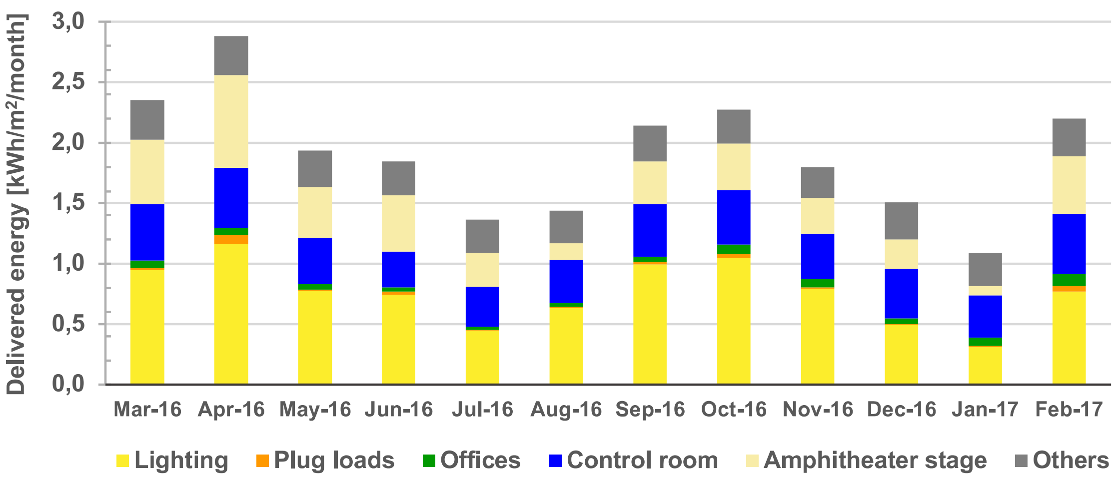


Figure 109 : Monthly delivered energy by end-uses for one year of occupancy (2016-2017).

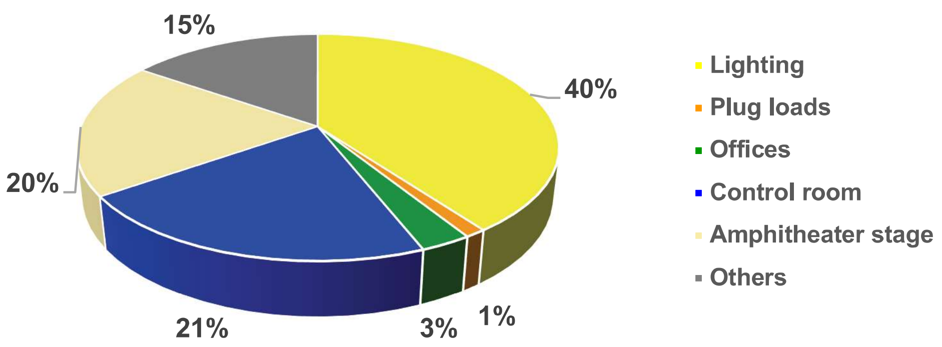


Figure 110 : Distribution of all end-uses of the building over one year (2016-2017). Lighting has the highest share in the building delivered energy.

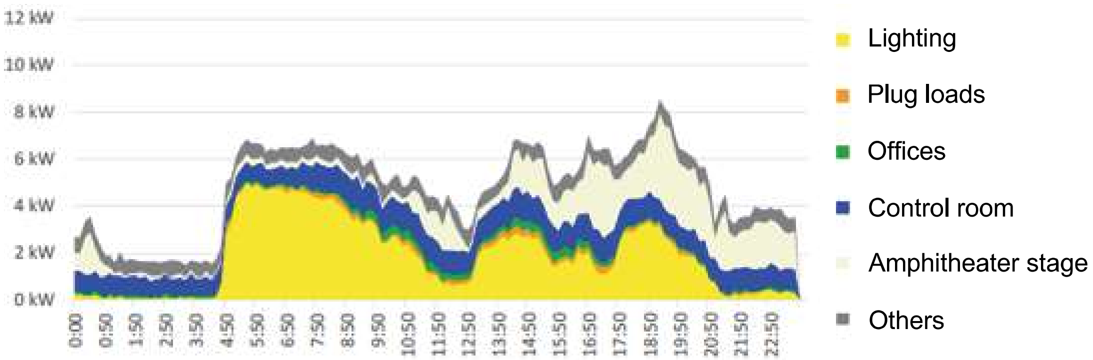


Figure 111: Load curves by end-use category for a typical working day in Feb. 2017

Acoustic comfort indicators	1. Airborne sound insulation : N/A
	2. Equivalent continuous sound Level : N/A
	3. HVAC noise level : N/A
	4. Reverberation time : N/A
	5. Masking/barriers : N/A
Visual comfort indicators	1. Light level (illuminance) : N/A
	2. Useful Daylight Illuminance (UDI) : N/A
	3. Glare control : N/A
	4. Quality view : N/A
	5. Zoning control : N/A
Indoor Air Quality indicators	1. Organic compound : N/A
	2. VOCs : N/A
	3. Inorganic gases : N/A
	4. Particulates (filtration) : N/A
	5. Minimum outdoor air provision : N/A
	6. Moisture (humidity, leaks) : N/A
	7. Hazard material

ABC21 is funded by the EU's H2020 programme

Users' feedback	A Post Occupancy Evaluation has been conducted during the hottest days in February 2016. People were asked about their thermal sensation on a 7-point scale: from 'cold' (−3) to 'hot (+3). The majority of the votes was neutral **(70%). Only 8%** of the votes are higher than 0.5 (see Figure 112). Besides, despite the lack of ceiling fans in the main space**, 94%** of the people find the space **comfortable** (80%) or slightly uncomfortable (14%). Figure 114 shows that **50%** of the people would **prefer to have more air velocity**. Overall, people are satisfied with the indoor thermal comfort.

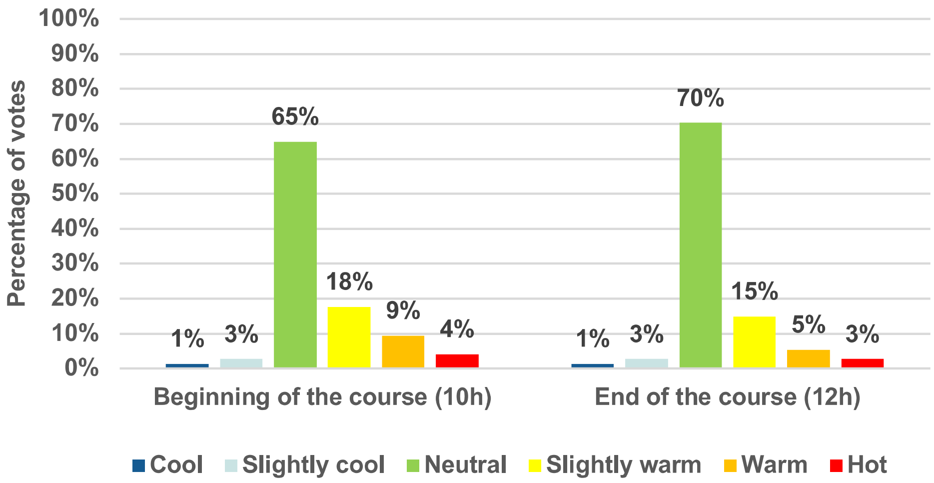


Figure 112: Frequency distribution of thermal sensation votes obtained on a summer day (3rd February 2016). The total number of votes was 74.

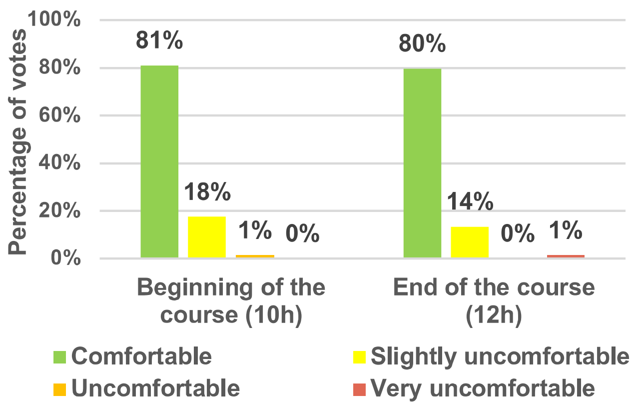


Figure 113: Frequency distribution of thermal comfort votes on the3rd February 2016.

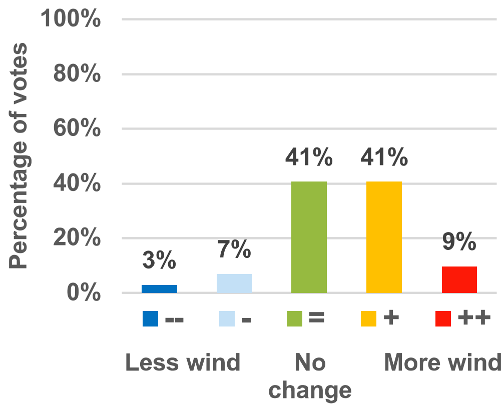


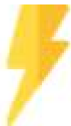
Figure 114 : Frequency distribution of questionnaire responses on air movement preference on the3rd February 2016.

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	This project shows that it is possible to feel comfortable in big spaces like a lecture theatre with an adapted airflow design in the tropics. Air conditioning and mechanical ventilation can thus be avoided. Moreover, the lecture theatre consumes 5 times less energy than a classical auditorium and produces 28 times more than its low consumption. The lecture theatre is the first positive energy and bioclimatic lecture theatre in the world.
Recommendations	"Architecture is above all an act of resistance. Architecture, for a sustainable society, is a great opportunity to implement new or also forgotten technologies and materials, […]. It is crucial to be aware of everything that composes the act of building, the environment, the

landscape, the existing climate, the different seasons. For decades, building technology and architectural design have promoted energy-intensive climatic reasoning. We can no longer afford this approach, we must go back to basics and work with the climate, not against it." Said the architect of the project.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

		
Passive Design	**Energy Efficiency**	**Renewable Energy**

Weaknesses

1. The lack of ceiling fans in the main space of the building. Not enough air velocity during the hot days with no wind outside. People complain about the lack of air movement during the hottest days.
2. The initial objective of dense vegetation for the creation of "cool island effect" near the amphitheatre and around the car park is not really achieved.
3. The thermal comfort and the living environment could be further improved.

REFERENCES

[1] Garde, Francois & Maareva, Payet. (2015). Ventilation naturelle sous les tropiques. Amphithéâtre du Moufia à Saint-Denis de La Réunion.. Ecologik. 47.

[2]https://www.researchgate.net/publication/282607717_Ventilation_naturelle_sous_les_tropiques_Amphitheatre_du_Moufia_a_Saint-Denis_de_La_Reunion

[3] http://www.cpu.fr/actualite/developpement-durable-luniversite-de-la-reunion-invente-le-premier-amphitheatre-bioclimatique/

[4] http://www.archi.re/amphitheatre-bioclimatique/

[5] PD: Psychrometric Chart n.d. https://drajmarsh.bitbucket.io/psychro-chart2d.html(accessed May 7, 2021).

[6] Milne (UCLA) M. Climate Consultant 6.0. n.d. http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php.