

CASE STUDY 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)	Af: Equatorial rainforest, fully humid

BUILDING INFORMATION

Building Type	Educational Building – Lecture theater
Project Type	New construction
Completion Date	2014
Number of buildings	1
Number of storeys	1
Total Floor Area (m ²)	1193
Net Floor Area (m ²)	1149
Thermally conditioned space area (m ²)	36 m ² conditioned space
Spaces with Natural Ventilation (with or without Ceiling Fans). Only (m ²)	1185 m ²
Total cost (€)	2 752 000
Cost /m ² (€/m ²)	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 81: 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 theater 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 82: Eastern facade with air inlets and native vegetation



Figure 83 : Low pressure shaft

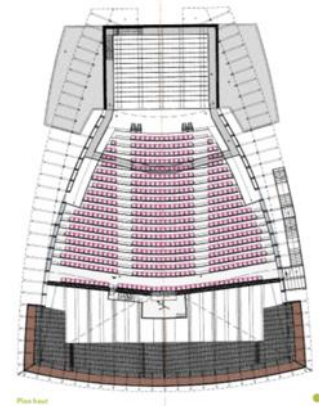


Figure 84 : Plan view of the lecture theater

SITE INTEGRATION



Figure 85 : 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.

CLIMATE ANALYSIS

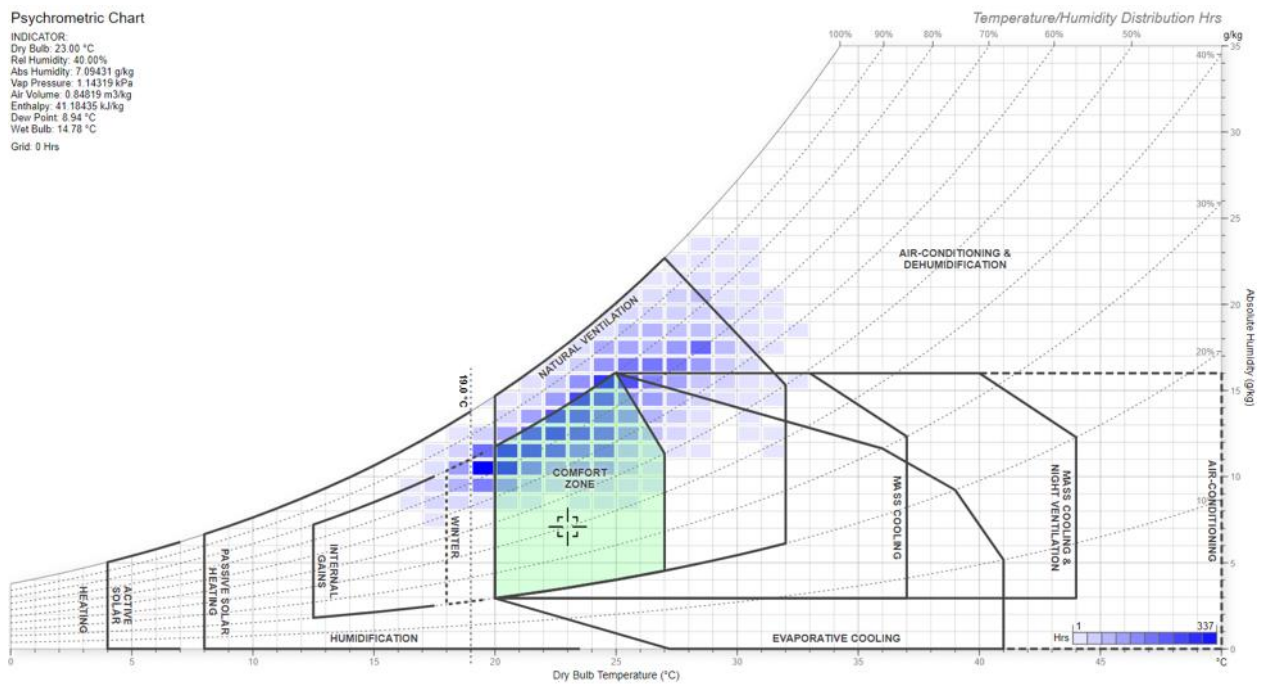


Figure 86 : Givoni Bioclimatic chart for the climate of Saint-Denis [5].

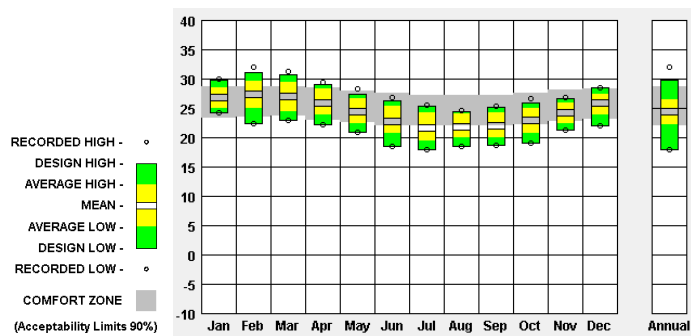


Figure 87 : Monthly temperature range for Saint-Denis.
 Source: Climate consultant - Adaptive Comfort model [6]

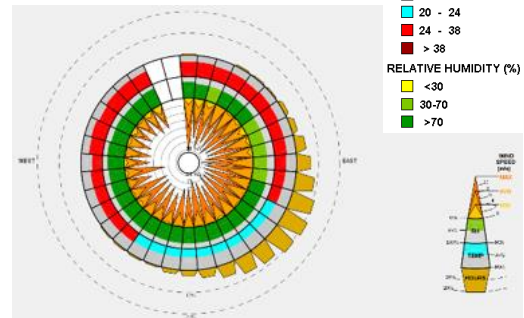


Figure 88 : Wind rose for Saint-Denis [6]

Global horizontal radiation (Avg daily total) Min: **4120** Wh/m² (June)
 (month) / Max (month) 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 18.6°C: **4**
 CDD 26°: **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 89 : Solar shadings

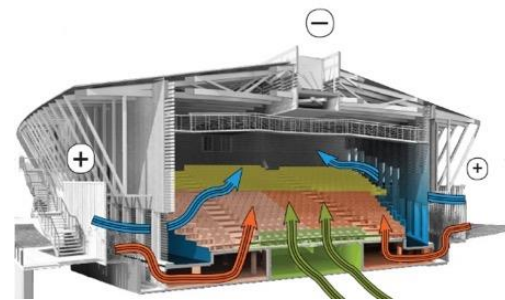


Figure 90 : low pressure shaft on top of the roof and visualization of the 4 air inlets



Figure 91 : Side louvers



Figure 92 : Construction of the air compartments during the construction stage



Figure 93 : Low pressure shaft (top of the roof)

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 94 : 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 95 : wooden superstructure



Figure 96 : low pressure shaft under construction



Figure 97 : The external walls are composed with wooden cladding

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/m ²
Control and energy management	Yes (energy meters for each end uses)



Figure 98 : Wind tunnel tests to validate the passive principles



Figure 99 : Ceiling fans are installed in every office space



Figure 100: T5 light bulbs (density: 8.7 W/m²)

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 183kWh/y/m² whereas the energy demand of the lecture theatre is only 23 kWh/y/ m².
The PV production is generated onsite only.

Figure 101: 145 kWp PV panels are installed as shading devices for the cars.

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS [1] [2]

Thermal comfort indicators	<ol style="list-style-type: none"> 1. Percentage of time outside an operative temperature range (Adaptive) 2. Percentage of time outside an operative temperature range (Fanger) : 3. Degree-hours (Adaptive) 4. Degree-hours (Fanger) 5. Percentage of time inside the Givoni comfort zone of 1m/s : 90% 6. Percentage of time inside the Givoni comfort zone of 0m/s 7. Number of hours within a certain temperature range
Energy performance indicators	<ol style="list-style-type: none"> 1. Energy needs for heating (kWh/y/m2) 2. Energy needs for cooling (kWh/y/m2) : 3. Energy use for lighting (kWh/y/m2) : 9 4. Energy needs for Sanitary Hot water (kWh/y/m2) 5. Total Primary energy use (kWh/y/m2) : 69 (total Primary Energy Factor (PEF) equal to 3.00 for electrical energy from the grid) 6. Renewable Primary energy generated on-site (kWh/y/m2) : 549 7. Renewable Primary energy generated on-site and self-consumed (kWh/y/m²) : 549 8. Renewable Primary energy exported to the grid (kWh/y/m²) : 0 9. Ratio of renewable primary energy over the total primary energy use (with and without compensation) (%) 10. Delivered energy (kWh/y/m2) (from electricity bills) : 23
Acoustic comfort indicators	<ol style="list-style-type: none"> 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
	<ol style="list-style-type: none"> 1. Light level (illuminance) : N/A 2. Useful Daylight Illuminance (UDI) : N/A

Visual comfort indicators	3. Glare control : N/A
	4. Quality view : N/A
	5. Zoning control : N/A
Indoor Quality indicators	Air
	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	

Users' feedback A Post Occupancy Evaluation has been conducted during the hottest days in February. Despite the lack of ceiling fans in the main space, **94%** of the people find the space **comfortable** (80%) or slightly uncomfortable (14%). **50%** of the people would **prefer to have more air velocity**. Overall, people are satisfied with the indoor thermal comfort.

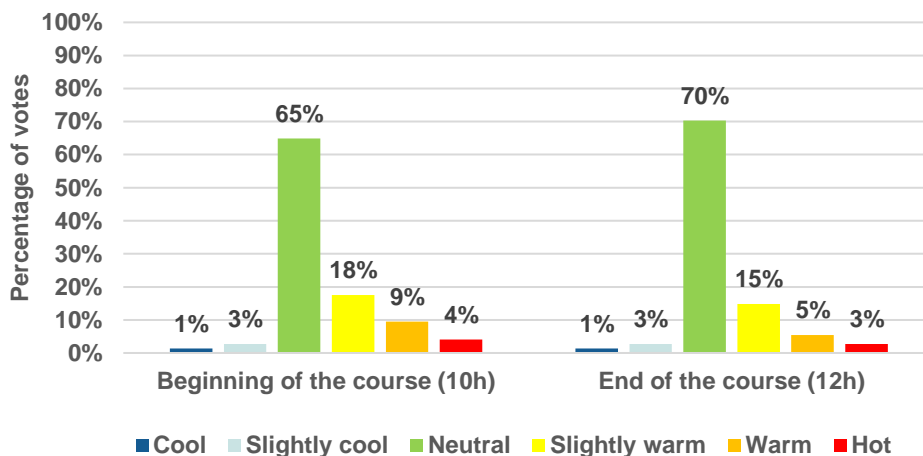


Figure 102: Frequency distribution of thermal sensation votes obtained on a summer day (3rd February 2016). The total number of votes was 74.

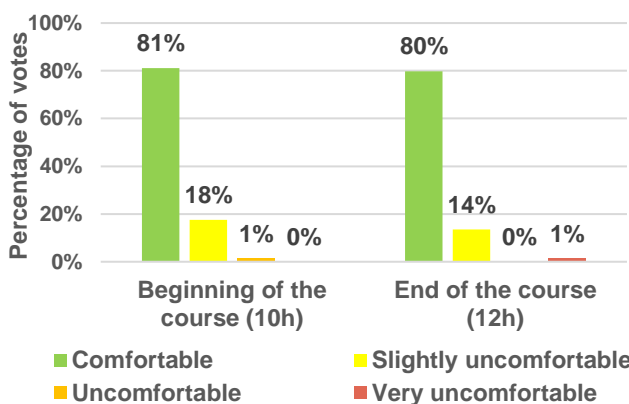


Figure 103: Frequency distribution of thermal comfort votes on the 3rd February 2016.

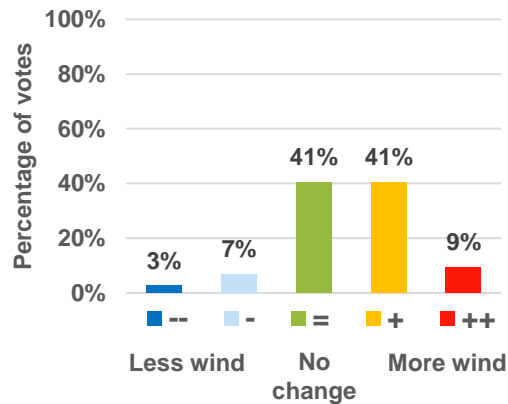


Figure 104: Frequency distribution of questionnaire responses on air movement preference on the 3rd February 2016.

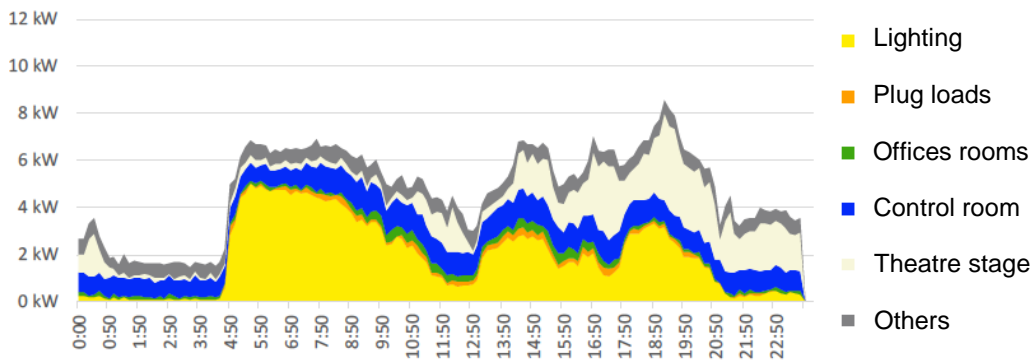


Figure 105: Load curves by end use category for a typical working day in Feb. 2017

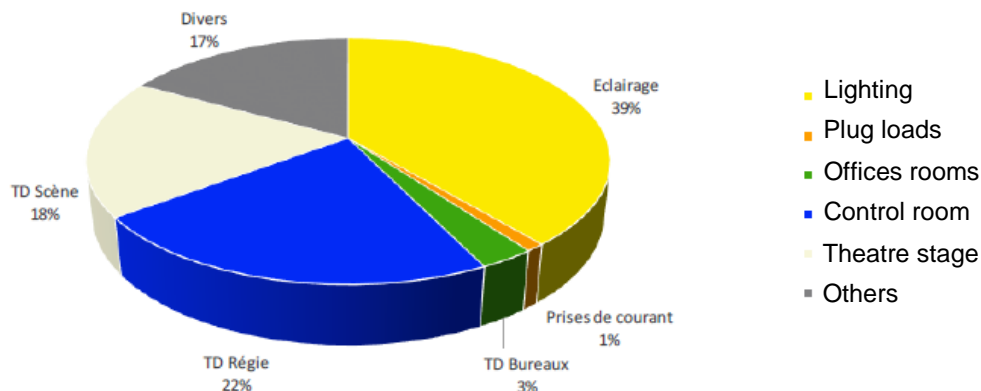


Figure 106 : Distribution of all end-uses of the building over one year.

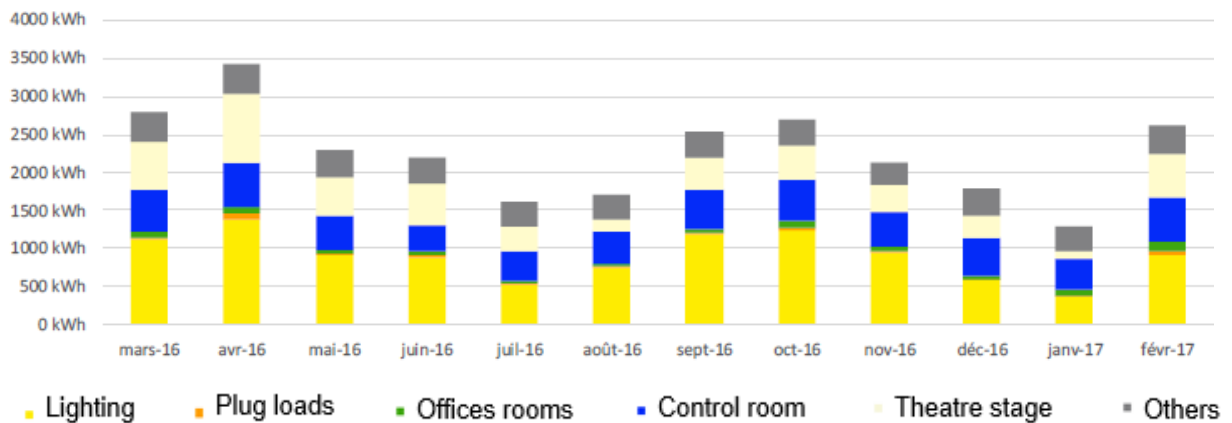


Figure 107 : Energy consumption by end-uses on a monthly basis for one year of occupancy (2016-2017)

LESSONS LEARNED AND RECOMMENDATIONS

Lessons learned

This project shows that it is possible to feel comfortable in big spaces like a lecture theater with an adapted airflow design in the tropics. Air conditioning and mechanical ventilation can thus be avoided. Moreover, the lecture theater consumes 5 times less energy than a classical auditorium and produces 28 times more its low consumption. The lecture theater is the first positive energy and bioclimatic lecture theater in the world.

Recommendations

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BUILDING STRENGTHS AND WEAKNESSES

Strengths



Passive Design



Energy Efficiency



Renewable Energy

Weaknesses

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.

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>.

