Africa-Europe Bioclimatic Collaboration 21

Africa-Europe BioClimatic buildings for XXI century

REPORT ON ADDITIONAL 12 CASE STUDIES OF EUROPEAN AND AFRICAN BIOCLIMATIC BUILDINGS

WP3 – PERFORMANCE INDICATORS AND GUIDELINES FOR XXI CENTURY BIOCLIMATIC BUILDINGS AND DISTRICTS

D.3.9

Report

Public

ABC21 is funded by the EU's H2020 programme

ABC 21 project

This document has been developed as part of the project titled "**ABC 21 – Africa-Europe BioClimatic buildings for XXI century**".

The sole responsibility for the content of this presentation lies with the authors. This report reflects only the author's view. The Executive Agency for Small and Medium sized Enterprises is not responsible for any use that may be made of the information it contains.

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 894712.

Document information

Name:	Report on additional 12 case studies of European and African Bioclimatic Buildings
Date:	24.2.2023
Work Package:	WP3: Performance indicators and guidelines for xxi century bioclimatic buildings and districts
Task:	T3.4: Case studies of European and African Bioclimatic Buildings

Authors

Name	Email	Institution
Virginie Grosdemouge	virginie.grosdemouge@univ-reunion.fr	UR
François Garde	francois.garde@univ-reunion.fr	UR

Contributors

Name	Email	Institution
Lorenzo Pagliano	lorenzo.pagliano@polimi.it	PoliMi
Silvia Erba	silvia.erba@polimi.it	PoliMi
Andrea Sangalli	andrea.sangalli@polimi.it	PoliMi
Alessio Dionigi Battistella	alessio.battistella@polimi.it	PoliMi
Gian Luca Brunetti	gianluca.brunetti@polimi.it	PoliMi
Humera Mughal	mughalhumera2@gmail.com	PoliMi
Ernest Dione	ernes.dione@gmail.com	DEEC
Vincent Sambou	vincent.sambou@ucad.edu.sn	UCAD
Kossi Imbga	kossiimbga@yahoo.fr	UNZ
Vincent Kitio	vincent.kitio@un.org	UN-Habitat
Arnaud Valea	watival2@gmail.com	UNZ

Revision

Version	Date	Author	Description of changes
V0	31.05.2023	Virginie Grosdemouge & François Garde	Document creation
V1	26.07.2023	François Garde	Updated version
V2	13.09.2023	Lorenzo Pagliano	Updated version
V3	22.09.2023	François Garde	Updated version
V4	01.11.2023	Lorenzo Pagliano	Updated version

V5	09.11.2023	François Garde	Updated version
V6	15.01.2024	Lorenzo Pagliano	Updated version
V7	16.01.2024	Silvia Erba	Final formatted version

Executive summary

ABC 21 aims to increase the energy performance, the level of comfort and sustainability of African and European buildings through the identification, strengthening and effective deployment of affordable

- bioclimatic designs,
- passive cooling systems and
- local materials

under the challenging African climate and urbanization context and the problems of EU aging building stock.

The presented work is part of WP3 / Task 3.4 “Case studies of European and African Bioclimatic Buildings”.

Within this Task, a first technical report 3.8 has been delivered in a first phase with a review of 12 fully documented case studies of bioclimatic buildings located in Europe and Africa, with data collected from architects and technical experts.

In terms of structure, the present report 3.9 named “Report on 12 additional case studies of European and African bioclimatic buildings” is split into two parts, Part A and Part B.

- Part A “Report on 12 additional case studies of European and African bioclimatic buildings”;
- Part B “Report on monitoring feedback of selected case studies”.

Part A presents in fact a total of 24 case studies:

- a review of 12 additional fully documented case studies of bioclimatic buildings located in Europe and Africa, with data collected from architects and technical experts (analysis performed in Phase 2);
- an updated version of the first 12 case studies of report 3.8 with updated data (analysis performed in Phase1 and subsequently updated);

Given the general lack of monitored data on energy and comfort performance of buildings and surveys of subjective comfort sensation and preference, it has been decided to generate additional data within the ABC21 project.
All the results and analysis produced via the monitoring and surveys are available in a separated deliverable: D3.9B: “Report on monitoring feedback of selected case studies”.

ABC21 is funded by the EU's H2020 programme

Part B also highlights the real difficulty to get measured data and information on subjective comfort sensations in general and in particular in Africa, possibly due to insufficient financial resources available for research and training. International support in the framework of climate protection and compensation should possibly address this issue with resources targeted to research and training in Africa. Further investment in more precise and openly accessible assessment of energy and comfort performances are needed in EU also. Too often buildings are advertised as sustainable, without the baking of sound and openly available data and analysis.
Measurement campaigns have been conducted on site for selected buildings with different levels of quality of monitoring to address this lack of data and verify the achieved level of comfort, especially for the case studies located in Africa.
We produced data for 9 buildings (3 for Reunion Island, 3 for Senegal, 1 for Kenya, 1 for Burkina, 1 for Portugal, 1 for Italy).
This is a first step and a real added value of the ABC21 project in providing data in an area where they are scarce/absent.

In total, 24 case studies have been selected to be presented within the ABC21 project. All the case studies have been chosen for their ability to showcase exemplary realization of ***bioclimatic architecture***, especially in terms of suitability to specific local climate conditions, use of ***passive cooling strategies*** (including natural ventilation), use of energy efficient systems, effective use of daylighting, use of local materials, with low embedded energy and sustainable production.

The reports compiles available technical and non-technical information of the buildings selected.

An analysis of the local climate and a description of the main bioclimatic features are proposed for each case study.

The lessons learned from these buildings with exemplary bioclimatic architecture and low energy technologies have provided input to the technical guidelines and tools for future-proof passive design in warm climates and might be a useful basis for effective communication to stakeholders about the merits of ***bioclimatic architecture*** and ***passive systems***. They might also provide elements for devising future research projects and international collaboration.
.

Abbreviations

Organisations

Term	Name
DEEC	Direction de l'Environnement et des Etablissements Classés/Ministère de l'Environnement et du Développement Durable
NW	North West
PoliMi	Politecnico di Milano
SW	South West
UCAD	Université Cheikh Anta Diop de Dakar
UNZ	Université Norbert Zongo
UR	University of La Reunion

Scientific abbreviations

Term	Name
Fq	Frequency
Nb	Number
NW	North West
POE	Post Occupancy Evaluation
RH	Relative humidity
SR	Solar radiation
SW	South West
T	Air temperature
Tg	Black globe temperature
Va	Air velocity
WS	Wind speed

Part A

“Report on 12 additional case studies of European and African bioclimatic buildings”

CONTENTS

1. Introduction

ABC 21 aims to increase the energy performance, the level of comfort and sustainability of African and European buildings through the identification, strengthening and effective deployment of affordable bioclimatic designs, passive cooling systems and local materials under the challenging African climate and urbanization context and the problems of EU aging building stock.

In this context, this technical report gives:

- a review of 12 additional fully documented case studies of bioclimatic buildings located in Europe and Africa, with data collected from architects and technical experts (Phase 2);
- an updated version of the first 12 case studies of report 3.8 (Phase1), with updated data.

All the case studies have been chosen for their ability to give exemplary realization of the bioclimatic approach, especially in terms of suitability to specific local climate conditions, use of passive cooling systems (including natural ventilation), use of energy efficient systems, effective use of daylighting, use of local materials, with low embedded energy and sustainable production.

This report provides a compilation of architectural and technical features of the buildings selected. An analysis of the local climate and a description of the main bioclimatic features are proposed for each case study.

The lessons learned from these buildings with exemplary bioclimatic architecture and low energy technologies have provided inputs to the technical guidelines and tools for future-proof passive design in warm climates and might be a useful basis for effective communication to stakeholders about the merits of ***bioclimatic architecture*** and ***passive systems***. They might also provide elements for devising future research projects and international collaboration.

1.1 Scope and objectives

The principal objective of these showcase of buildings is to prove to the public and private sectors the advantages in terms of energy and comfort performance of bioclimatic architecture. The case studies selected are presented and well documented to draw a picture of best practices for the application of bioclimatic design, use of passive techniques and local materials.

1.2 Document Structure

The document is structured as follows:

- Section 2 describes the methodology used;
- Section 3 gives an overall description of the case studies, the template used and the online Google Map;
- Section 4 gives information about the contact persons for each case studies

- Case studies are described in Annex A (Phase 2) and Annex B (Updated case studies of Phase 1)

2. Methodology

The methodology followed consisted of:

- The proposition and selection of potential case studies of bioclimatic buildings located in Europe and Africa, especially in warm climates, according to a defined set of criteria. This stage included the research of projects on different websites online, in research papers or from our ABC21 project partners and allies.
- The creation of a template form based on a common language and the indicators defined in the project, documenting the case studies selected with technical data collected from the architects and/ or design team.
- For each case study, the template was filled out with architectural, environmental, and technical data. This includes an in-depth description of the main general strategies developed to design climate responsive building, the passive and low energy solutions used, the calculated key performance indicators, Post Occupancy Evaluation results (i.e. structured users' feedback on their comfort sensations and preferences). The strengths and weaknesses of each project are highlighted.
- The collection of measured existing data, from previous measurement and assessment campaigns or – in a selection of cases – with new measurement and Post Occupancy Evaluation (comfort) surveys performed within the ABC21 project. This has allowed to calculate different key performance indicators in terms of energy performance and comfort.

The 24 case studies have been selected according to a list of mandatory and optional criteria, defined as follows (see Table 1):

Table 1: List of mandatory and optional criteria used for the selection of the case studies

Mandatory criteria	Optional criteria
Cooling dominated climate	Use of renewables (PV, Solar thermal, wind, geothermal, etc.)
Occupied and in operation at least in the past 1 year (in use)	Use of local materials, with low-embedded energy
Data accessibility: Plans, details, cross-sections, photos, and technical data of the bioclimatic features	Buildings designed according to performance standards or a benchmarking/labelling program
Bioclimatic design and Passive techniques, especially passive cooling solutions	Performance data: Energy and thermal comfort assessment, POE, Users' feedback.
Low energy systems	
Building type: Residential (single family house, social multi apartments building, etc.) / Hostels / Offices/ Educational (schools, university, etc.) / Hospitals	
Building Height: 5 storeys maximum	

The selection of the case studies was also realised by considering as much as possible two important concepts in this project, namely the **affordability** and **replicability** of the buildings. The mandatory and optional criteria have been set by the working group of this task to facilitate the selection of the case studies based on their expertise and previous research projects, such as the IEA Task 40. The mandatory criteria mainly focus on ***bioclimatic design*** and ***passive systems***.

3. Case studies collection | Phase 1 and 2

This section presents the 24 case studies that have been selected in Phase 1 and Phase 2 (see Figure 1), and the structure of the template that has been designed to allow a uniform description of the case studies.

3.1 General overview

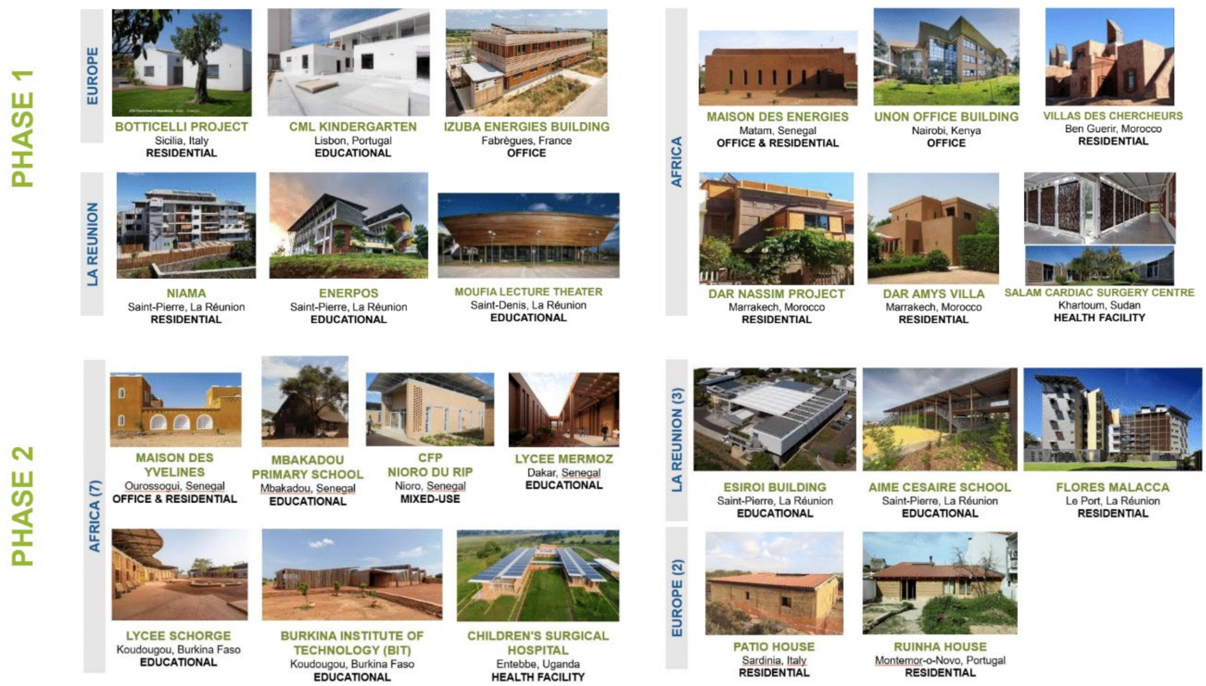


Figure 1: Presentation of the 24 case studies (Phase 1 and Phase 2)

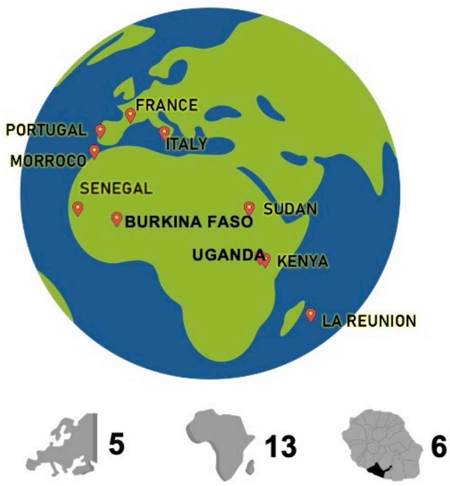


Figure 2 : Location of the 24 case studies. 5 case studies are located in Europe, 13 in Africa and 6 in La Réunion.

ABC21 is funded by the EU's H2020 programme

3.2 Structure of the case study template

This section presents the structure of the template form filled out for the 24 case studies selected in Europe, La Réunion and Africa. Each project has been fully described in a consistent manner in terms of general information, bioclimatic solutions, energy efficient solutions and renewable energy systems, as well as key performance indicators.

The template is divided in 15 main categories:

1. Geographical and climate information;
2. Building information;
3. Stakeholders;
4. Project description;
5. Site integration;
6. Climate analysis;
7. Key bioclimatic design principles;
8. Infrastructures and regulations to enable sufficiency action;
9. Building fabric and materials;
10. Energy efficient building systems;
11. Renewable energy;
12. Building analysis and key performance indicators;
13. Lessons learned and recommendations;
14. Building strengths and weaknesses;
15. References.

IMPORTANT NOTICE: The climate analysis has been performed according to the weather files that have been downloaded from the "climate.onebuilding.org" website. We propose here a way of representing the weather data, but the responsibility of the quality of the data remains obviously with the source climate.onebuilding.org.

Furthermore, there is a need for continuous measurement and storage of weather data and for the development of future weather data. For continuous measurement and storage, we have partnered with the THAMO project (and financed the installation of some weather stations close to case studies). For the development of future climate weather files, see deliverable D3.6. of ABC21.

3.3 Creation of an online Google map

A google map has been created and allows accessing online to a general description of each case study by clicking on its icon -i.e. Name of the building. The map is available at the following address:
https://www.google.com/maps/d/edit?mid=17XfM002Vtmc1N8ezKrEUi4qbwlwPiJQ&usp=drive_link

A comprehensive description of each case study is downloadable as well by clicking on the icon of the selected building.

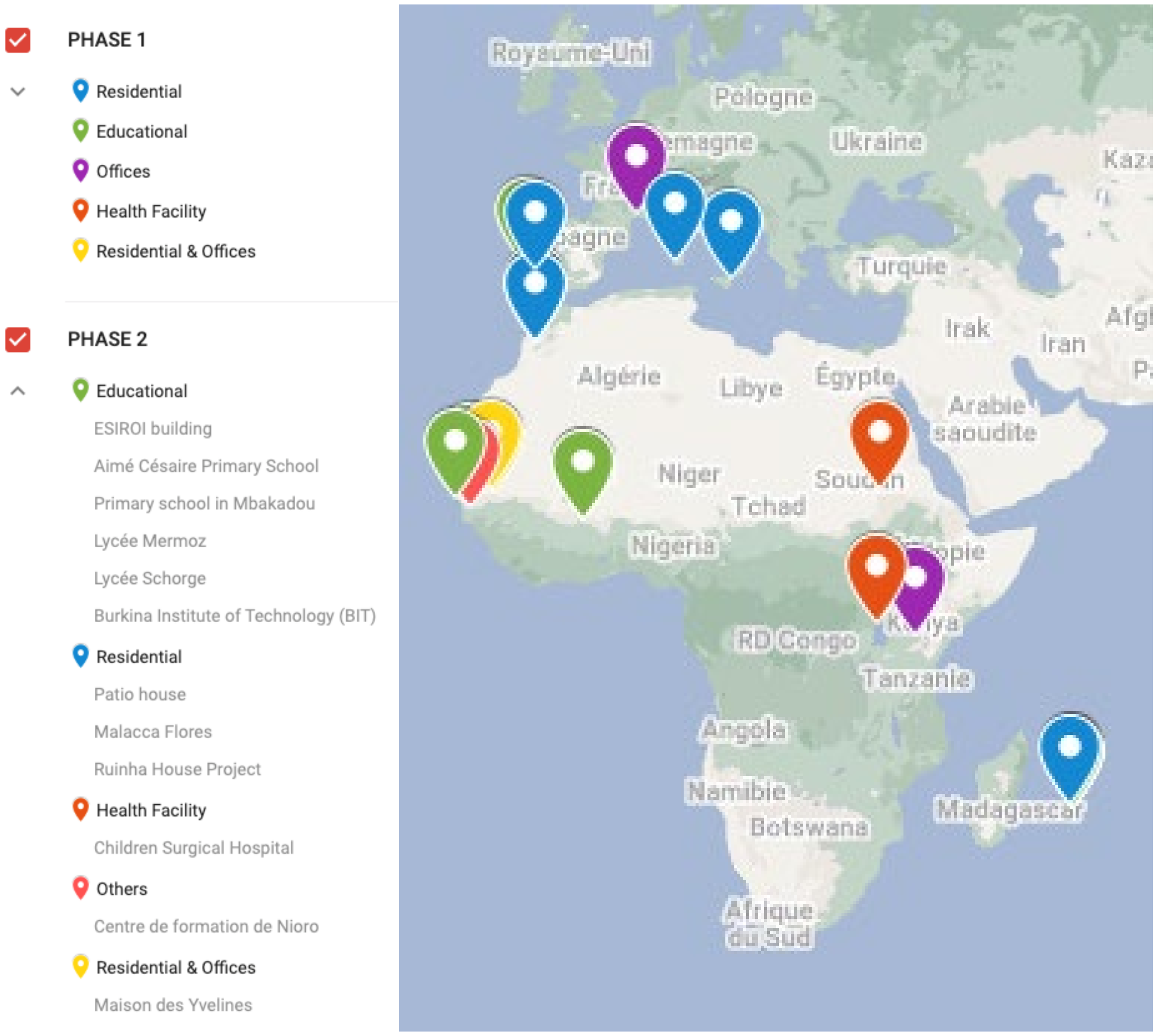


Figure 3 : Google map giving the location of the 24 bioclimatic case studies, by building type. By clicking on each icon, some general features about the selected building are available. It is also possible to download a pdf version of a comprehensive description of the building The link to access the map is : https://www.google.com/maps/d/edit?mid=17XfM002Vtmc1N8ezKrEUi4qbwlwPiJQ&usp=drive_link

4. List of contact persons by country and building project

For each project, some contact persons from the ABC21 project were designated to collect from the design team and the users all the information needed to fill out the template. The two tables below list the names of the contact persons which were responsible of the case study project for Phase 2 and Phase 1.

PHASE 2

Table 2 : Contact person by country and building project ***(Phase 2)***

Project Name/Country	Contact person	Institution	Email address
EUROPE			
Patio house/ Italy	Alessio Battistella Andrea Sangalli	PoliMi	alessio.battistella@polimi.it andrea.sangalli@polimi.it
Ruinha House/ Portugal	Alessio Battistella Virginie Grosdemouge	PoliMi UR	alessio.battistella@polimi.it virginie.grosdemouge@univ-reunion.fr
LA REUNION			
ESIRO Building/ France (La Réunion) **Aimé Cesaire School / France (La Réunion)** **Flores Malacca / France (La Réunion)**	Virginie Grosdemouge François Garde	UR	virginie.grosdemouge@univ-reunion.fr garde@univ-reunion.fr
AFRICA			
Maison des Yvelines/ Senegal **CFP Nioro/ Senegal** **Lycée Mermoz/ Senegal**	Ernest Dione Vincent Sambou Virginie Grosdemouge	DEEC UCAD UR	ernest.dione@gmail.com vincent.sambou@ucad.edu.sn virginie.grosdemouge@univ-reunion.fr
Mbakadou primary School/Senegal	Virginie Grosdemouge Ernest Dione Silvia Erba Alessio Battistella	UR DEEC PoliMi	virginie.grosdemouge@univ-reunion.fr ernest.dione@gmail.com silvia.erba@polimi.it alessio.battistella@polimi.it
Lycée Schorge/Burkina	Virginie Grosdemouge Alessio Battistella Kossi Imbga Arnaud Valea Andrea Sangalli Lorenzo Pagliano Silvia Erba	UR PoliMi UNZ	virginie.grosdemouge@univ-reunion.fr alessio.battistella@polimi.it kossiimbga@yahoo.fr watival2@gmail.com andrea.sangalli@polimi.it lorenzo.pagliano@polimi.it silvia.erba@polimi.it
Burkina Institute of Technology / Burkina	Virginie Grosdemouge Silvia Erba Alessio Battistella Kossi Imbga Arnaud Valea Andrea Sangalli Lorenzo Pagliano	UR PoliMi UNZ	virginie.grosdemouge@univ-reunion.fr silvia.erba@polimi.it alessio.battistella@polimi.it kossiimbga@yahoo.fr watival2@gmail.com andrea.sangalli@polimi.it lorenzo.pagliano@polimi.it

ABC21 is funded by the EU's H2020 programme

Children's surgical hospital / Uganda	Virginie Grosdemouge Alessio Battistella	UR PoliMi	virginie.grosdemouge@univ-reunion.fr alessio.battistella@polimi.it

PHASE 1

*Table 3: Contact person by country and building project **(Phase 1)***

Project Name/Country	Contact person	Institution	Email address
EUROPE			
Botticelli Project/ Italy	Silvia Erba Alessandra Barbieri Lorenzo Pagliano	PoliMi	silvia.erba@polimi.it alessandra.barbieri@polimi.it lorenzo.pagliano@polimi.it
CML Kindergarten/ Portugal	Daniel P. Albuquerque Guilherme Carrilho da Graça	FC.ID	gcg@fc.ul.pt
IZUBA Energies Building / France	Virginie Grosdemouge Aristide Moucazambo Lorenzo Pagliano	UR	virginie.grosdemouge@univ-reunion.fr 38003499@co.univ-reunion.fr lorenzo.pagliano@polimi.it
LA REUNION			
Niama/ France (La Réunion) **ENERPOS / France (La Réunion)** **Moufia Lecture Theater / France (La Réunion)**	Virginie Grosdemouge François Garde Aristide Moucazambo	UR	virginie.grosdemouge@univ-reunion.fr garde@univ-reunion.fr 38003499@co.univ-reunion.fr
AFRICA			
Maison des Energies/ Senegal	Ernest Dione Virginie Grosdemouge	DEEC UR	ernes.dione@gmail.com
UNON Office Building / Kenya	Vincent Kitio Virginie Grosdemouge Andrea Sangalli Gian Luca Brunetti	UN Habitat	vincent.kitio@un.org virginie.grosdemouge@univ-reunion.fr andrea.sangalli@polimi.it gianluca.brunetti@polimi.it
Villas des Chercheurs/ Morocco	Asmae Kaldoune Virginie Grosdemouge Andrea Sangalli	AUI UR	A.Khaldoune@aui.ma virginie.grosdemouge@univ-reunion.fr andrea.sangalli@polimi.it
Dar Nassim Project/ Morocco	Asmae Kaldoune Virginie Grosdemouge Andrea Sangalli	AUI UR	A.Khaldoune@aui.ma virginie.grosdemouge@univ-reunion.fr andrea.sangalli@polimi.it
Dar Amys Villa/ Morocco	Asmae Kaldoune Virginie Grosdemouge Andrea Sangalli	AUI UR	A.Khaldoune@aui.ma virginie.grosdemouge@univ-reunion.fr andrea.sangalli@polimi.it
Salam Cardiac Surgery Centre/ Sudan	Aristide Moucazambo Virginie Grosdemouge	UR	38003499@co.univ-reunion.fr virginie.grosdemouge@univ-reunion.fr

5. Analysis of the different climates and adapted strategies

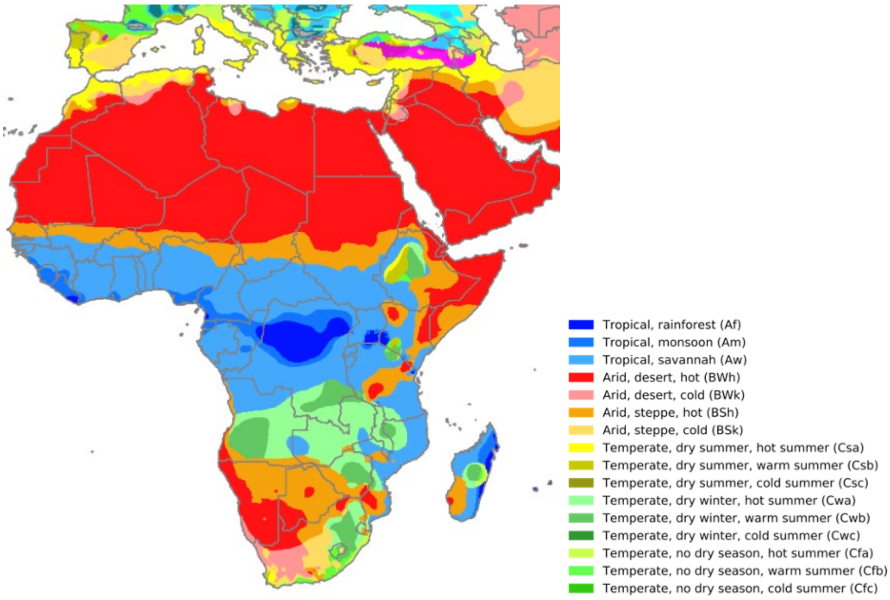


Figure 4 : Köppen-Geiger climate classification in Africa and South of Europe (Kottek et al., 2006; Peel et al., 2007a)

Table 4 : Description of Köppen climate symbols and defining criteria Source : (Peel et al., 2007b)

1st	2nd	3rd	Description	Criteria*
A			Tropical	$T_{cold} \geq 18$
	f		- Rainforest	$P_{dry} \geq 60$
	m		- Monsoon	Not (Af) & $P_{dry} \geq 100 - MAP/25$
	w		- Savannah	Not (Af) & $P_{dry} < 100 - MAP/25$
B			Arid	$MAP < 10 \times P_{threshold}$
	W		- Desert	$MAP < 5 \times P_{threshold}$
	S		- Steppe	$MAP \geq 5 \times P_{threshold}$
		h	- Hot	$MAT \geq 18$
		k	- Cold	$MAT < 18$
C			Temperate	$T_{hot} > 10$ & $0 < T_{cold} < 18$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Cs) or (Cw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a or b) & $1 \leq T_{mon10} < 4$
D			Cold	$T_{hot} > 10$ & $T_{cold} \leq 0$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Ds) or (Dw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a, b or d)
		d	- Very Cold Winter	Not (a or b) & $T_{cold} < -38$
E			Polar	$T_{hot} < 10$
	T		- Tundra	$T_{hot} > 0$
	F		- Frost	$T_{hot} \leq 0$

*MAP = mean annual precipitation, MAT = mean annual temperature, T_{hot} = temperature of the hottest month, T_{cold} = temperature of the coldest month, T_{mon10} = number of months where the temperature is above 10, P_{dry} = precipitation of the driest month, P_{sdry} = precipitation of the driest month in summer, P_{wdry} = precipitation of the driest month in winter, P_{swet} = precipitation of the wettest month in summer, P_{wwet} = precipitation of the wettest month in winter, $P_{threshold}$ = varies according to the following rules (if 70% of MAP occurs in winter then $P_{threshold}$ = 2 x MAT, if 70% of MAP occurs in summer then $P_{threshold}$ = 2 x MAT + 28, otherwise $P_{threshold}$ = 2 x MAT + 14). Summer (winter) is defined as the warmer (cooler) six month period of ONDJFM and AMJJAS.

Table 5 : The ABC21 case studies and their climate type. 6 different type of climate have been identified.

Country	Name of project	Nearest city	Climate type
Portugal	Ruinha House	Montemor-o-Novo	Csa: Temperate, Dry and Hot summer
	CML Kingergarten	Lisbon	Csa: Temperate, Dry and Hot summer
Italy	Botticelli project	Catane, Sicily	Csa: Temperate, Dry and Hot summer
	Patio House	Portoscuso, Sardinia	Csa: Temperate, Dry and Hot summer
France	Izuba energies building	Montpellier	Csa: Temperate, Dry and Hot summer
La Réunion	ESIROI Building / Niama / Aimé Cesaire Primary School / ENERPOS Moufia Lecture theater Malacca Flores	Saint-Pierre Saint-Denis Le Port	Aw : Tropical, Savannah, dry winter
Morocco	Villa des chercheurs	Ben Guerir	BSh : Arid, steppe, hot
	Dar Amys Villa	Marrakech	BSh : Arid, steppe, hot
	Dar Nassim Project	Marrakech	BSh : Arid, steppe, hot
Senegal	Maison des Yvelines /	Ourossogui	BWh : Arid, Desert, Hot
	Maison des énergies	Matam	BWh : Arid, desert, hot
	Mbakadou	Louga	BWh : Arid, desert, hot
	CFP Nioro	Nioro	BWh : Arid, desert, hot
	Lycée Mermoz	Dakar	BSh : Arid, steppe, hot
Burkina	Burkina institute of technology	Koudougou	BSh : Arid, steppe, hot
	Lycée Shorge	Koudougou	BSh : Arid, steppe, hot
Soudan	Salam Cardiac Surgery Centre	Khartoum	BWh : Arid, desert, hot
Uganda	Children's surgical hospital	Entebbe	Af : Tropical, rainforest
Kenya	UNON Office Building	Nairobi	Cwb: subtropical highland climate. Temperate, dry winter, warm summer

Table 4 shows that the 24 case studies can be classified into 6 different families of climate type according to the Köppen-Geiger classification. Below is the list of these climate type :

<u>Europe :</u>
- Csa : France, Portugal and Italy (Sicily and Sardinia);

<u>Africa :</u>
- BSh : Morocco, Burkina;
- BWh : Senegal (inland) and Soudan;
- Cwb : Kenya (Nairobi)
- BSh Senegal (Dakar)
- Af : Uganda;

<u>La Reunion :</u>
- Aw

To each climate corresponds a set of passive strategies that can be identified thanks to the Givoni's bioclimatic charts. The next section explains how to use them.

5.1 Use of the Givoni's bioclimatic charts to identify passive design strategies for a specific climate

In the late 60s Givoni developed a bioclimatic chart for buildings, similar to the psychrometric chart as per the variables as the one used by AC engineers but with different objectives. Six main zones have been identified, each of them corresponding to specific design strategies. These zones have been set-up by Givoni (Givoni, 1992) and are now presented and used in lots of references (Butera et al., 2014).
The idea is to plot from the weather data file of a specific location, the values of outdoor temperature and humidity on the chart, using an online software like the one developed by Andrew Marsch (https://drajmarsh.bitbucket.io/psychro-chart2d.html) or a desktop application as Climate Consultant. The best passive strategies are then suggested for this specific climate.

The six main zones for passive design strategies are listed below (it is assumed that efficient solar shading solutions and the use of vegetation to protect the building from solar radiation are passive strategies already used by default):

1. Comfort zone;
2. Natural ventilation zone (also termed "***comfort ventilation***" by Givoni (Givoni, 1991)
3. Evaporative cooling zone;
4. High thermal mass zone or mass cooling zone;
5. Hight thermal mass and night ventilation zone (also named "***nocturnal convective cooling"*** zone by Givoni(Givoni, 1991));
6. Passive heating zone (Internal gains, passive solar heating, active solar).

Outside those zones, it is also possible to use a combination of passive systems (evaporative cooling, radiation to the sky,…) for a specific climate (for example different strategies for the dry and humid seasons), or to additionally use active systems (i.e. Heating, Air conditioning, Air conditioning and dehumidification), but the energy use for those active systems would be reduced thanks to the bioclimatic approach (see Table 5). Climate Consultant software in fact proposes the number of hours during which each strategy might be usefully adopted. We signal here that both the Marsch tool and the Climate Consultant need now be updated to the last comfort Standards (i.e. EN 16798:2017 and ASHRAE 55:2020, represented analytically and graphically in the online tools at https://comfort.cbe.berkeley.edu/).

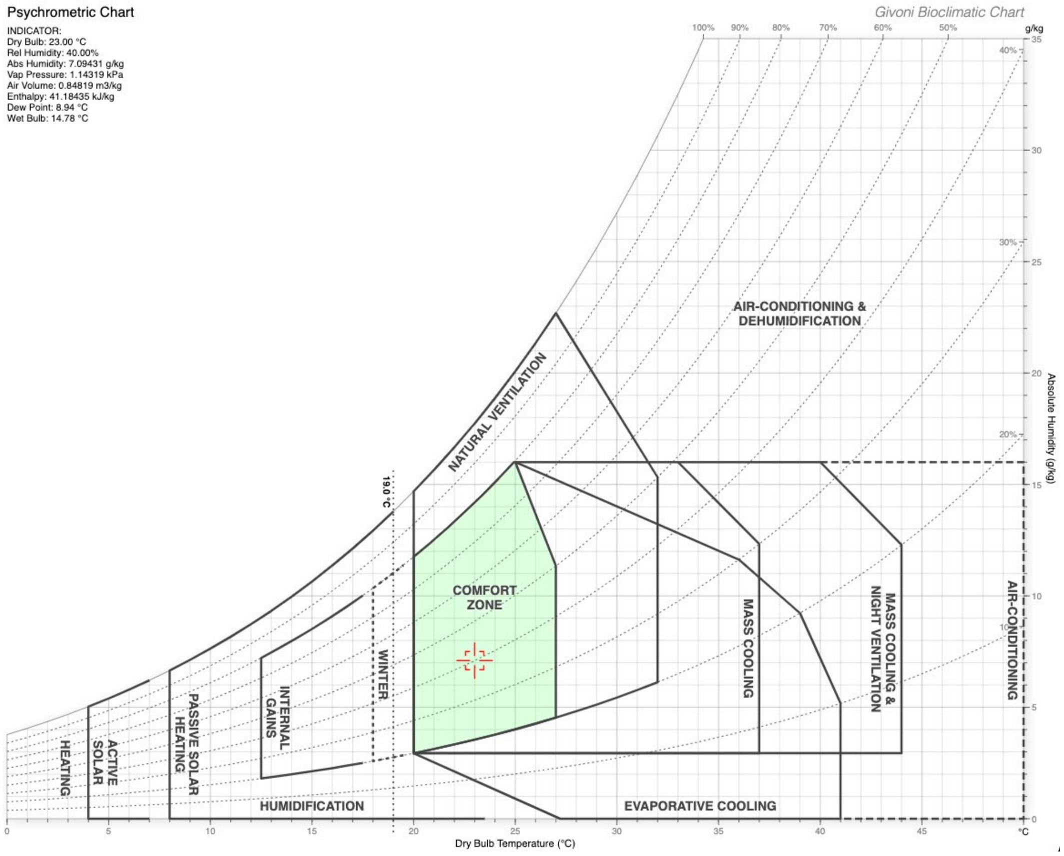


Figure 5 : Givoni bioclimatic charts generated from the online tool developed by Andrew Marsh. These main zones have been identified by (Givoni, 1992) and used by (Butera et al., 2014) to identify the most appropriate design strategies for a specific climate.

1. ***Comfort zone***

   This zone is comfortable in a closed space under still air conditions in specific boundaries in terms of temperature (20-27°C) and relative humidity (20%-80%). The users should be able to adapt their clothing level, and the indoor space is protected against solar radiation to avoid overheating.

   This comfort zone has been updated in ASHAE 55:220, in particulare there no more lower and upper limit on R.H. as for comfort. Limits to R:H might come from IAQ objectives, regulated by other standards.

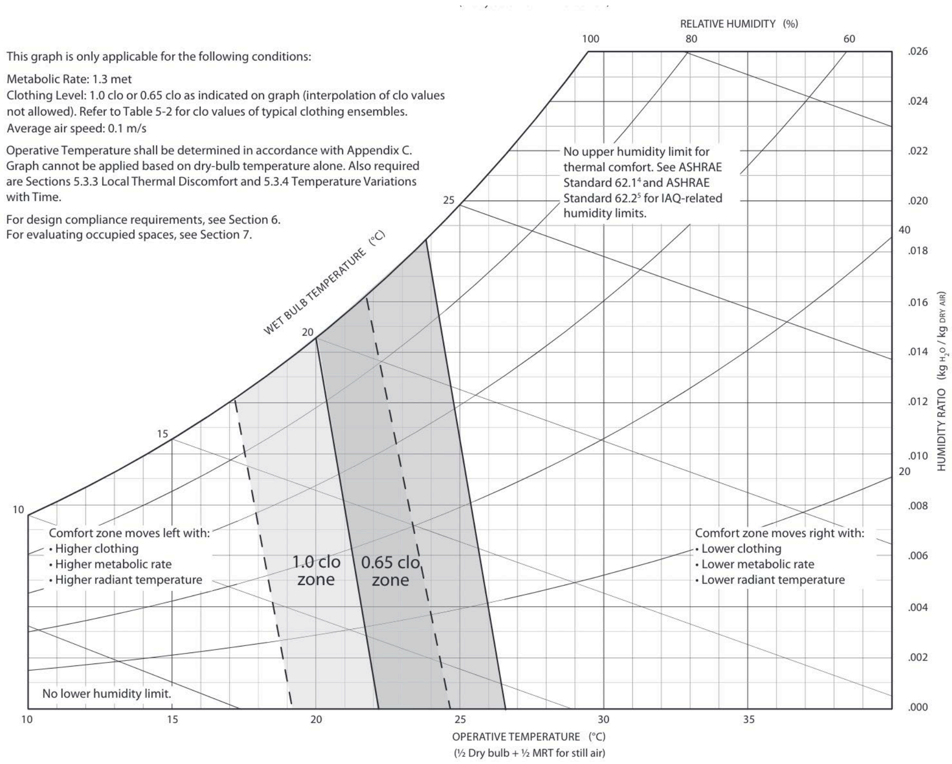


Figure 6: from ASHRAE 55 : 2020. Aanlytical Comfort Zone Method. Note the specification « No upper humidity limits for thermal comfort ».

2. ***Natural ventilation (also termed <u>"comfort ventilation"</u> zone by Givoni*** (Givoni, 1991)***)***
   When the temperatures in the indoor space are above 26°C, it is possible to achieve comfort by creating an air movement with air velocity up to 1 m/s or 2 m/s on the occupants. These conditions occur in hot and humid climates (Aw, Af) or in the South of Europe (Csa, Cwa). The appropriate strategy in this case is to use natural cross ventilation (favored e.g. by designing narrow buildings with 25% of the main façades allocated for openings). This strategy can be used during daytime (if the outdoor air temperature does not exceed 31°C) or at night to provide direct human comfort. In the case of windless days, efficient ceiling fans can also be used as an alternative.

3. ***Evaporative cooling:***
   Givoni distinguishes here two different ways to cool buildings: direct evaporative cooling and indirect evaporative cooling.
   Direct evaporative cooling consists in cooling the dry air taken from outdoor thanks to water evaporation and bringing it into the indoor spaces; this increases the indoor relative humidity. This passive technique can be used in the case of hot and arid climates (BSh, BWh).
   Indirect evaporative cooling consists in using the phase change from liquid to vapor to cool a medium which will be used to cool the indoor air without adding vapor to it. A possible implementation foresees evaporation on a roof-pond (Krüger et al., 2010).

4. ***High thermal mass, or mass cooling***
   This passive strategy can be used when outdoor temperature are around 37°C max with high difference of day-night temperature (ideally 20°C) and when the mean outdoor temperature remains inside the comfort zone. The building acts like a filter. The use of high thermal mass materials significantly reduces the transfer of the outdoor temperature oscillation to the indoor temperature. The indoor temperature oscillates in a narrower band, within comfort limits. This passive technique can be used in climates such as Bsh, Bwh.

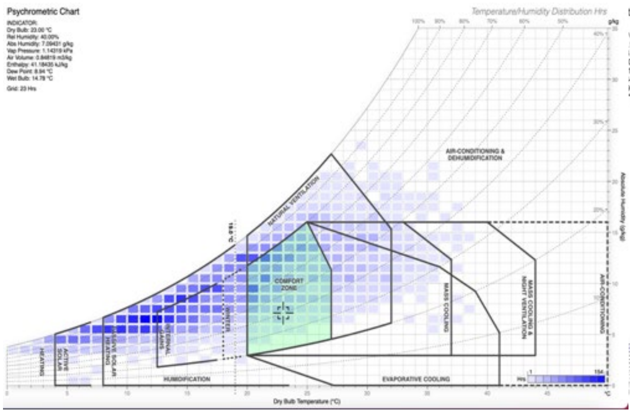
5. ***Hight thermal mass and night ventilation (also "named "nocturnal ventilative cooling" by Givoni*** (Givoni, 1991)***);***
   This zone is a combination of high thermal mass and the use of nocturnal ventilation to cool the building at night. This technique is used for outdoor temperature above 37°C. The night outside air is brought through the building by natural ventilation and cools the interior exposed thermal masses. This allows to have a comfortable and fresh building in the morning and maintain the temperature in the comfort range during the daytime. Windows can remain opened in the morning but must be closed when outdoor temperature raises to the level of indoor. Efficient ceiling fans can also be installed to expand the indoor comfort zone. This passive technique can be used in climates such as Bsh, Bwh.

6. ***Passive heating zone***
   Passive solar heating can be used for outdoor temperature below 13°. In that case, thermal insulation and glazed areas facing the sun in winter are recommended. The climates concerned are Csa and Cwa.

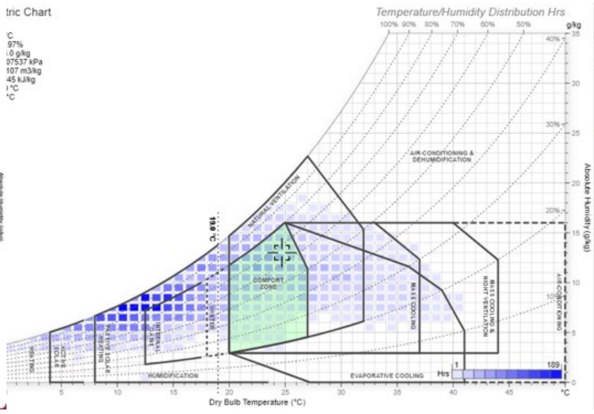
5.2 Givoni's bioclimatic charts by country and name project

The figures below gives the climate representation using Givoni's bioclimatic charts for all the case stuides of ABC 21. This representation allows to identify the main passive design strategies for each climate that are summarized in Table 5. Please note the intensity of the blu color is proportional to the number of hours corresponding to each bin of temperature and humidity, but the end of scale and hence the meaning of each shade of blue is different in each graph.

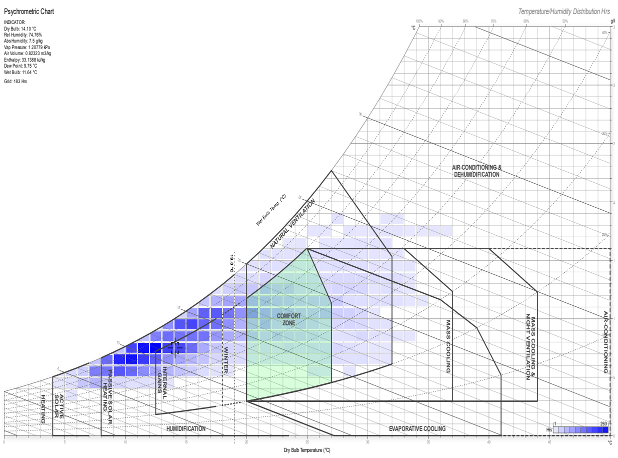
EUROPE :



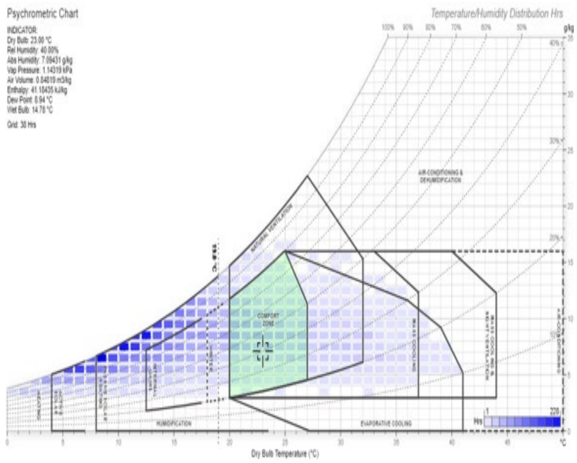
ITALY : Botticelli project (Sicily), Csa



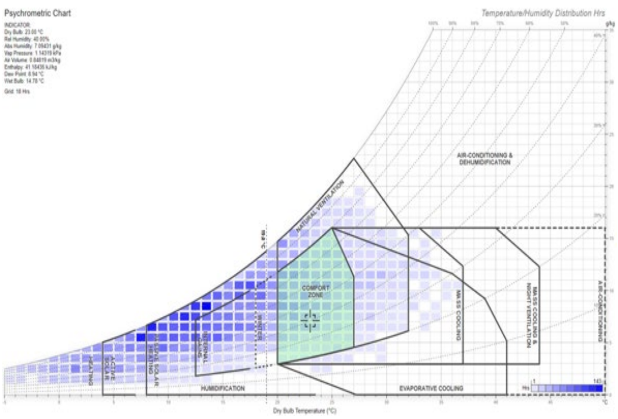
ITALY : Patio house (Sardinia), Csa



PORTUGAL : CLM Kindergarten, Csb/ Csa



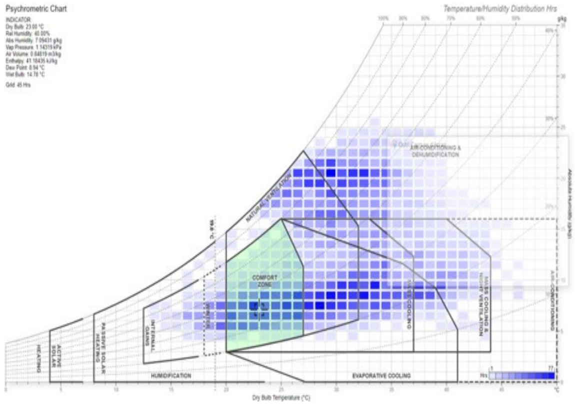
PORTUGAL : Ruinha House, Csa



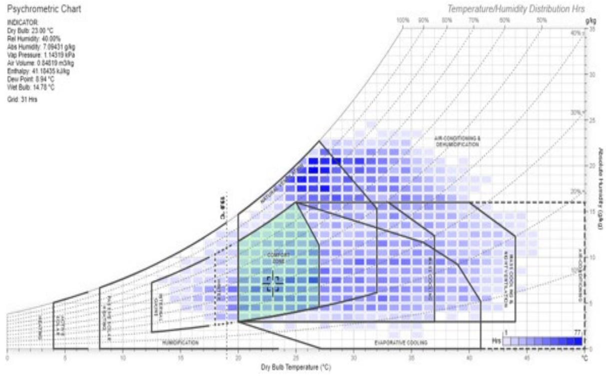
FRANCE : Izuba Energies building, Csa

ABC21 is funded by the EU's H2020 programme

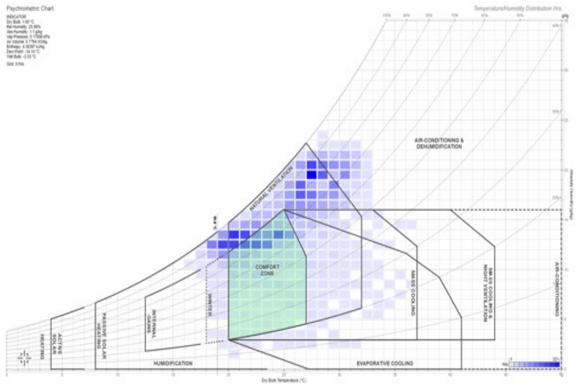
AFRICA :



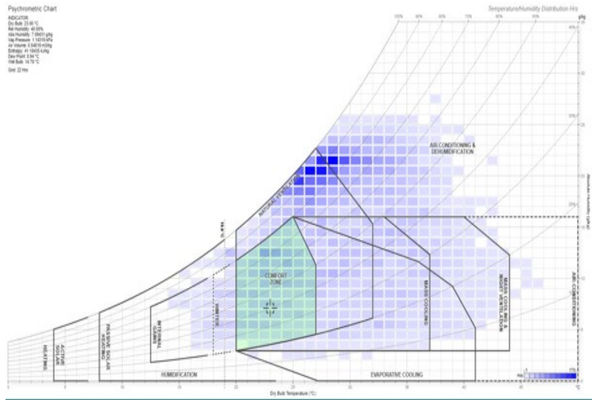
SENEGAL : Maison des énergies, Maison des Yvelines (Matam), BWh



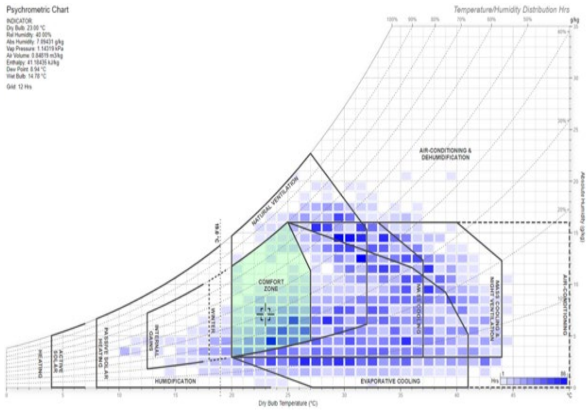
SENEGAL : Mbakadou primary school, BWh



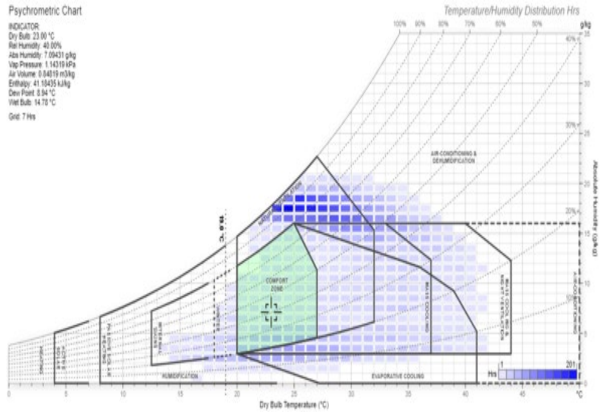
SENEGAL : Lycée Mermoz, Dakar, BSh



SENEGAL : CFP Nioro, BWh



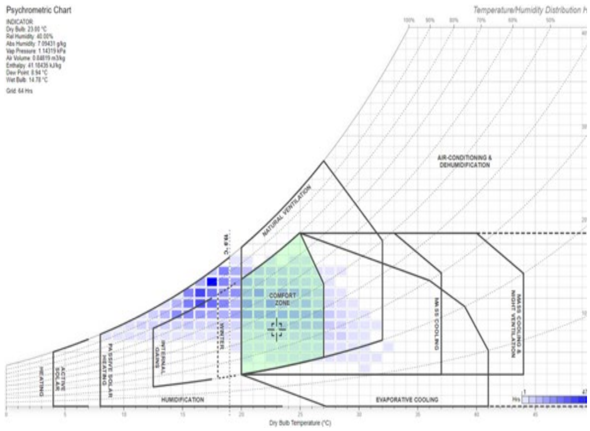
SOUDAN : Salam cardiac surgery centre, BWh



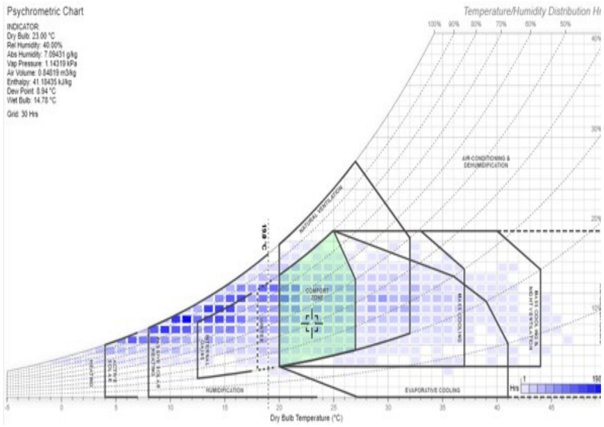
BURKINA : BIT and Lycée Schorge, BSh

Important comment : according to the Köppen classification, the climate in Dakar is BSh, like in Morocco. But the analysis of Givoni bioclimatic chart of Dakar clearly shows that it is closer to a tropical climate like in La Reunion (Aw), probably because of the influence of the ocean. Comfort ventilation is then the main passive cooling strategy.

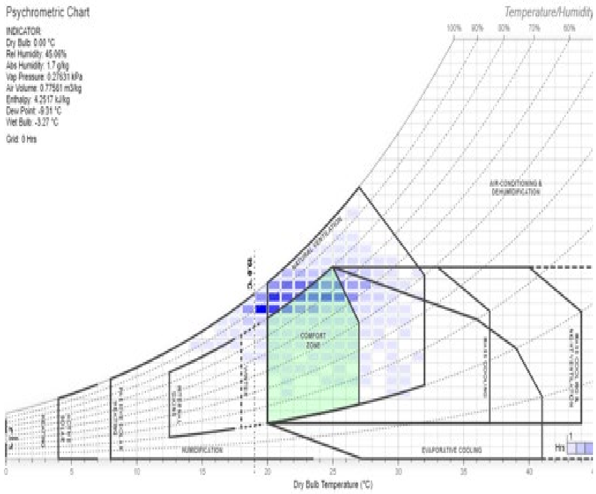
ABC21 is funded by the EU's H2020 programme



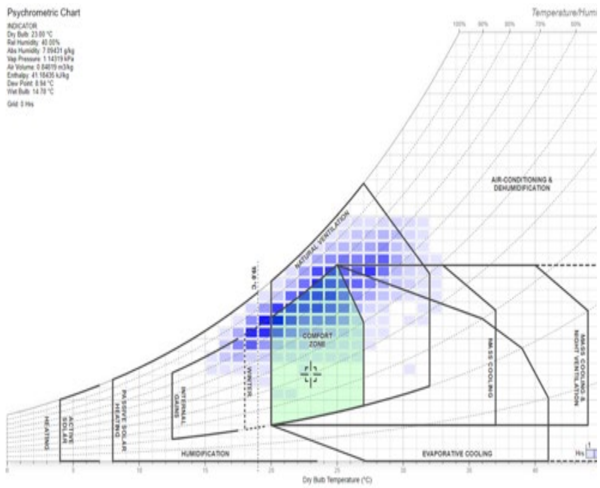
KENYA : UNON Building, Cfb



MOROCCO : Villas des chercheurs, Dar Amys villa, Dar Nassim Project, BSh



UGANDA, Af



LA REUNION, Aw

ABC21 is funded by the EU's H2020 programme

SYNTHESIS : PASSIVE DESIGN STRATEGIES BY TYPE OF CLIMATE

Table 5 below gives the synthesis and the set of passives strategies that are recommended by climate type.

Table 6 : Main passive combination of strategies by climate type. (The climate in the Dakar region is supposed to be BSh but looks closer to Aw)

	Natural ventilation/Comfort ventilation	Evaporative cooling	High thermal mass / Mass cooling	Nocturnal ventilative cooling	Passive heating
Csa	X	X	X	X	X
Cfb	X				X
Aw, Af	X				
Dakar (BSh?)	X				
BSh	X	X	X	X	
BWh	X	X	X	X	

Table 7 : Description of Köppen climate symbols and defining criteria. Source : (Peel et al., 2007b)

1st	2nd	3rd	Description	Criteria*
A			Tropical	$T_{cold} \geq 18$
	f		- Rainforest	$P_{dry} \geq 60$
	m		- Monsoon	Not (Af) & $P_{dry} \geq 100 - MAP/25$
	w		- Savannah	Not (Af) & $P_{dry} < 100 - MAP/25$
B			Arid	$MAP < 10 \times P_{threshold}$
	W		- Desert	$MAP < 5 \times P_{threshold}$
	S		- Steppe	$MAP \geq 5 \times P_{threshold}$
		h	- Hot	$MAT \geq 18$
		k	- Cold	$MAT < 18$
C			Temperate	$T_{hot} > 10$ & $0 < T_{cold} < 18$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Cs) or (Cw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a or b) & $1 \leq T_{mon10} < 4$
D			Cold	$T_{hot} > 10$ & $T_{cold} \leq 0$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Ds) or (Dw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a, b or d)
		d	- Very Cold Winter	Not (a or b) & $T_{cold} < -38$
E			Polar	$T_{hot} < 10$
	T		- Tundra	$T_{hot} > 0$
	F		- Frost	$T_{hot} \leq 0$

*MAP = mean annual precipitation, MAT = mean annual temperature, T_{hot} = temperature of the hottest month, T_{cold} = temperature of the coldest month, T_{mon10} = number of months where the temperature is above 10, P_{dry} = precipitation of the driest month, P_{sdry} = precipitation of the driest month in summer, P_{wdry} = precipitation of the driest month in winter, P_{swet} = precipitation of the wettest month in summer, P_{wwet} = precipitation of the wettest month in winter, $P_{threshold}$ = varies according to the following rules (if 70% of MAP occurs in winter then $P_{threshold}$ = 2 x MAT, if 70% of MAP occurs in summer then $P_{threshold}$ = 2 x MAT + 28, otherwise $P_{threshold}$ = 2 x MAT + 14). Summer (winter) is defined as the warmer (cooler) six month period of ONDJFM and AMJJAS.

6. Summary of the design principles and lessons learnt by climate type

EUROPE | hot-summer Mediterranean climate - Csa (Portugal, Italy, France)

Five case studies have been selected for Europe within the ABC21: three of them are residential houses, one is an educational building and the last one is an office building.

RUINHA HOUSE
Montenor-o-Novo, PT
RESIDENTIAL

CML KINDERGARTEN
Lisbon, PT
EDUCATIONAL

PATIO HOUSE
Sardinia,IT
RESIDENTIAL

BOTTICELLI PROJECT
Sicilia, IT
RESIDENTIAL

IZUBA ENERGIES BUILDING
Montpellier, FR
OFFICE

Vegetation :
None of the buildings presents a dense vegetation area around it. This is a specific aspect that must be improved.

Solar shading systems :
All the projects use efficient shading systems: fixed or mobile vertical louvres (Botticelli project, CML Kindegarten, Izuba Energies building), overhangs (Patio House, Ruinha house), vertical wooden slats (Izuba Energies building).

Passive cooling strategies and bioclimatic principles:

Comfort ventilation:
All the projects are naturally cross ventilated, except the CML Kindergarten case study which uses a single sided ventilation driven by stack effect.
In terms of feedback, natural cross ventilation is very efficient in all projects.
The stack driven natural ventilation system used in CML Kindergarten is very effective and self-regulating. during the spring and winter periods but demonstrates its limits in summer. A design with natural cross ventilation might have avoided this summer period of discomfort.

Evaporative cooling:
In terms of passive cooling strategies, only Ruinha house uses evaporative cooling system (during warmer hours water is sprayed on the rammed earth walls). In some (not all) of the locations, summer high temperature hours are relatively dry and might allow a contribution by evaporative cooling.

High thermal mass:
Four of the case studies use thermal mass with a high level of external insulation.
Only the CML Kindergarten use concrete and 8 cm rockwool-type insulation, which is normal due to the climate in Lisbon.

Nocturnal ventilative cooling:
Theoretically, the four projects that have high thermal mass and are naturally cross ventilated, use Nocturnal ventilative cooling in summer as a cooling strategy.

Use of local / geo- and bio-sourced materials

Three case studies use bio-sources materials for the construction and insulation of walls and roofs

- Ruinha house: Exterior walls in rammed earth with around 55 cm thickness
- Patio house: The external walls and the roof are highly insulated with straw bales.
- Izuba building: Walls : wood frame + earth-straw and mud brick, Roof : Straw bale 34 cm thick.

Ceiling fans

Ceiling fans are installed in all the spaces of the Izuba building. They allow to extend the range of temperatures felt comfortable compared with a situation with no air movement.

In all the other projects, there are no installed ceiling fans.

Lessons learnt

Four of the projects (except the CML kindergarten case study) work well in terms of thermal performance in summer. The measured data have demonstrated that the passive cooling strategies proved to be efficient both in summer and in winter. Specifically, in summer, the indoor conditions remain in the Givoni comfort zone with air velocity at 1 m/s.

The stack driven natural ventilation (NV) system used in CML Kindergarten is very effective and self-regulating. This system can meet the airflow rate goals during the spring and winter periods. The system showed its limits during hot days, when the indoor air temperature could reach 35°C.

Unfortunately, the residential case studies are single detached houses. In case of a wide and dense population, it is difficult to state that the case studies are affordable and replicable at the scale of a residential building.

Recommendations for Csa: Temperate, Dry and Hot summer**.**

<u>Vegetation:</u>
We recommend shading the surroundings of the buildings with native trees and to avoid mineral surfaces around the building. Car parking, if needed, must be located underneath the building to free spaces for vegetation around the building.

<u>Comfort ventilation: Natural cross ventilation highly recommended</u>

It is recommended to design systematically buildings that are naturally cross ventilated for the Mediterranean climates.

Windows must be designed to boost and adjust natural cross ventilation. The tilt and turn windows (e.g. those of Izuba building) are not fully adapted for this. It is better to use for example double glazed louvers for office buildings.

Tilt and turn windows used in Izuba energies building

Thermally insulated, double glazed louvres

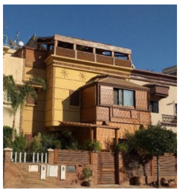
<u>Ceiling fans :</u>

We recommend installing ceiling fans for all case studies. They allow to extend the range of temperatures felt comfortable compared with a situation with no air movement. With an air speed of 1 m/s, the felt temperature is reduced by 3,3 °C, according to ASHRAE 55:2020 “elevated air speed method”.

AFRICA | BSh: Dry, Semi-Arid, Hot (Morocco, Burkina)

Five case studies have been selected within the ABC21 project for the BSh climate-type: 3 of them are residential houses. The other 2 are educational buildings.

VILLA DES CHERCHEURS
Ben Guerir, MA
RESIDENTIAL



DAR NASSIM PROJECT
Marrakech, MA
RESIDENTIAL

DAR AMYS VILLA
Marrakech, MA
RESIDENTIAL

LYCEE SHORGE
Koudougiou, BF
EDUCATIONAL

BURKINA INSTITUTE OF TECHNOLOGY
Koudougiou, BF
EDUCATIONAL

Vegetation :

Among the Moroccan case studies, only the Dar Amys villa shows an interesting percentage of planted areas. As for the case studies in Burkina Faso, as part of the institution's ecological commitment, 2 000 trees have been planted, such as mango trees, flamboyant trees, orange trees, to create a forest around the campus in the next years.

Solar shading systems:

All the Moroccan case studies have efficient solar shading systems (metallic venetian blinds and shutters, overhangs), sized properly to be efficient in the warm period. The buildings in Burkina have large detached roof that shade the terrace roof and the openings and walls. They also use low-cost louvered shutter systems and porous skin in eucalyptus wood in outdoor corridors to create a buffer space between the outside and the inside.

Passive cooling strategies and bioclimatic principles:

Comfort ventilation :
All the projects are naturally ventilated. Not all the spaces are naturally cross ventilated for Dar Nassim. Dar Amys villa uses natural cross ventilation. The 'Villa des chercheurs' uses single side ventilation.
The educational buildings in Burkina Faso are naturally cross ventilated.

Evaporative cooling :
This passive cooling strategy is not used for these projects, but might be considered, given the dry conditions for a number of months.

High thermal mass :

Villa des chercheurs has a high level of thermal mass with 40 cm local stones and external insulation, whereas Dar Nassim and Dar Amy villas have a medium level of thermal mass (20 cm of clay brick).
The educational buildings in Burkina Faso have massive clay walls with a thickness of 35 cm
.

Nocturnal ventilative cooling :
Nocturnal Ventilative Cooling is exploited only in Dar Amys and Dar Nassim villas, while it might be quite effective, given the many months with large day-night temperature swing.

Use of local / geo-and bio-sourced materials

Villa des chercheurs: The roof and the external walls are highly insulated with hempcrete material. It uses stone extracted from local quarries.

Dar Amys & Dar Nassil villas : Fired earth bricks are used for the exterior walls but bio source materials are not used for thermal insulation (polystyrene, glass wool)

In Burkina, the walls of each module are composed of locally sourced laterite stone. The "screens" that wrap around the modules are made of locally available eucalyptus wood. They effectively protect from the sun but might be too little permeable to air movement and one of the causes of monitored relatively low air velocity in the classes.

Energy efficient systems & renewables

Dar Nassim: Smart Inverter air conditioners with a high COP coupled with 2 kWp of PV panels and solar thermal panels for DHW.
Dar Amys: earth to air heat exchanger (EAHE).

Ceiling fans
Ceiling fans are installed only in some classrooms of the Institute of Technology in Burkina. In the other buildings, they are not installed.

Lessons learnt

The Moroccan case studies demonstrate that the passive features set up allowed to reach their main objectives: to reduce energy needs for heating and cooling while maintaining comfortable indoor conditions.

The design of the Burkina buildings is more focused on hot conditions (without a cool season). It shows that a low tech architecture based on the vernacular experience coupled with the use of local materials can be successful with contemporary structures. These projects can be easily duplicated in all countries in Africa with a BSh/ BWh climate-type. The concept of large detached roofs that acts as a big umbrella is easy to design and to duplicate. Also the design of corridors that act as buffer spaces is interesting, but care should be taken to allow for sufficient openings for cross ventilation of the rooms.

Recommendations for Dry, Semi-Arid, Hot climate (BSh)

Vegetation: We recommend shading the surroundings of the buildings with native trees and to avoid mineral surfaces around the building. Car parking spaces, if needed, must be located underground to free spaces for vegetation around the building.

Solar shading: The concept of large, detached roofs that acts as a big umbrella must be promoted, as well as the design of outdoor corridors / buffer spaces.

Comfort ventilation: Natural cross ventilation highly recommended. It is recommended to design systematically buildings that are naturally cross ventilated and design shading in a way that does not conflict with the desired level of airflow.

Evaporative cooling: This passive cooling strategy is not enough used and must be promoted, given the dry conditions for a number of months.

Nocturnal ventilative cooling: In the climate of Burkina, the building managers / users must be trained to use properly this passive cooling strategy (e.g. open the spaces at night and close them when the temperature is too high)

Geo- and bio-sourced materials: Use of bio-sourced materials for thermal insulation is recommended for the Moroccan villas.

Ceiling fans: We recommend installing ceiling fans for all the case studies. They allow to further improve of daytime comfort conditions when outdoor air is too warm for adopting comfort ventilation via windows, and hence they are also complementary to Nocturnal ventilative cooling.

AFRICA | Dry, Arid Desert, Hot climate - BWh (Senegal and Soudan)

Five case studies have been selected within the ABC21 project for the BWh climate-type: 2 of them are office and residential buildings. The other 2 are educational buildings. The last one is a hospital.

MAISON DES YVELINES
Ourossogui, SN
OFFICE, RESIDENTIAL

MAISON DES ENERGIES
Matam, SN
OFFICE, RESIDENTIAL

MBAKADOU PRIMARY SCHOOL
Mbakadou, SN
EDUCATIONAL

CFP NIOR0
Nioro, SN
EDUCATIONAL

SALAM CARDIAC SURGERY CENTER
Kartoum, SD
HEALTH FACILITY

ABC21 is funded by the EU's H2020 programme

Vegetation :

In Maison des Energies in the exterior courtyard, the presence of small gardens supports the reduction of the air temperature at the different zones.

Salam centre : Shrubs and trees were used to protect the buildings from the heat and to mitigate the effects of the harsh climate.

In Nioro, the planted patios create a comfortable microclimate between the buildings.

Mabakadou and Maison des Yvelines don’t have a good percentage of green areas.

Solar shading systems :

All the case studies are efficient in terms of solar shading. CFP Nioro and the Salam Centre use the concept of large, detached roofs, which is totally adapted to the climate. Bamboo blinds are also used in the hospital in the outdoor corridors to create thermal buffer spaces.

Passive cooling strategies and bioclimatic principles :

Comfort ventilation :

All the buildings are naturally cross ventilated.

Evaporative cooling :

An adiabatic (evaporative cooling) system is installed in CFP Nioro, but users don’t have the control on it.

High thermal mass :

All the case studies have high thermal mass and they all used geo- and bio-sourced materials

Nocturnal ventilative cooling :

Nocturnal ventilative cooling is not used in these buildings, most probably because a lack of training.

Use of local /geo- and bio-sourced materials

All the case studies use geo- or bio-sourced materials for thermal mass or insulation (earth, mud, adobe bricks, mudbricks, typha)

Energy efficient systems & Renewables

The Salam center has mixed modes of ventilation and conditioning (natural ventilation, mechanical ventilation, and air conditioning). The hospital is cooled by a solar cooling system.

Split systems are installed in Maison des énergies and Maison des Yvelines with ceiling fans as well.

In Nioro, some spaces are equipped with split-systems, ceiling fans and an adiabatic (evaporative cooling) system.

Ceiling fans

Ceiling fans are installed in each room of Maison des énergies and Maison des Yvelines. The occupants can use them with or without split systems. Nioro has also ceiling fans installed in all spaces.

Lessons learnt

The presence of vegetation is effective and is really appreciated by the users.

Different artificial materials are used for insulation: mineral wool, perlite, polystyrene. In order to have a more sustainable design, it's better to use only natural and local materials for insulation.

Salam centre, Mbakadou School and CFP Nioro are very good case studies that use the passive cooling principles of vernacular architecture with the use of local materials that can serve as examples of affordability and replicability. Also, the principle of mixed-mode spaces is interesting but the users must be trained. The principle of mixing adiabatic (evaporative cooling) and air conditioning systems with ceiling fans can be duplicated.

Recommendations for Dry, Arid Desert, Hot climate (BWh)

Vegetation: We recommend shading the surroundings of the buildings with native trees and to avoid mineral surfaces around the building. Car parks, if needed, must be located underneath the building to free spaces for vegetation around the building.

Solar shading: The concept of large, detached roofs that acts as a big umbrella must be promoted, as well as the design of outdoor corridors / buffer spaces.

Comfort ventilation: Natural cross ventilation highly recommended
It is recommended to design systematically buildings that are naturally cross ventilated.

Evaporative cooling: This passive cooling strategy is not enough used and must be promoted. The users must also be trained.

Nocturnal ventilative cooling
The managers / users must be trained to use properly this passive cooling strategy (open the spaces at night and close them when the temperature is too high). During parts of the year when the night temperature drop is limited, additional heat sinks might be exploited, (exchange with soil, radiation to deep sky,…)

Geo- and bio-sourced materials
Use of bio-sourced materials for thermal insulation is recommended

Ceiling fans and mixed-mode buildings: We recommend to install ceiling fans for all the case studies. They allow to reduce significantly the period of discomfort when outdoor air temperature is too high for comfort ventilation, in particular they are complementary to Night ventilative cooling. They also can be used in parallel with Adiabatic systems and AC systems. The concept of mixed-mode spaces must be promoted. The occupants must also be trained to use the combination of these passive and active solutions.

.

LA REUNION and SENEGAL Dakar | Tropical wet savanna climate Aw & UGANDA | Tropical rainforest climate Af

8 case studies have been selected within the ABC21 project for the Aw & Af climate-types: 2 of them are social housing residential buildings. 5 of them are educational buildings. The last one is a hospital in Uganda.

NIAMA
Saint-Pierre, RU
SOCIAL HOUSING

FLORES MALACCA
Le Port, RU
SOCIAL HOUSING

ENERPOS
Saint-Pierre, RU
EDUCATIONAL

ESIROI
Saint-Pierre, RU
EDUCATIONAL

MOUFIA THEATER
Saint-Denis, RU
EDUCATIONAL

AIME CESAIRE PRIMARY SCHOOL
Bois d'Olives, RU
EDUCATIONAL

CHILDREN'S SURGICAL HOSPITAL
Entebbe, UG
HOSPITAL

LYCEE MERMOZ
Dakar, SN
EDUCATIONAL

Vegetation :
All the case studies have a very good percentage of green spaces around the buildings.

Solar shading systems :
All the buildings have efficient shading systems.
Aime Césaire School, Flores Malacca, Children's surgical hospital ENERPOS and ESIROI have a detached roof that acts as a big canopy. This canopy shades the roofs underneath, the openings and walls as well, and creates comfortable outdoor shaded areas for the users. Outdoor corridors for Flores Malacca are designed using a timber structure to avoid high mass materials that store solar energy.
Different solar protection strategies have been implemented depending on the orientation and the type of openings to be protected such as horizontal overhangs, vertical and horizontal wooden blades and light-weight detached corridors.

Passive cooling strategies and bioclimatic principles :
<u>Comfort ventilation :</u>
All the case studies (except some classroom of Lycée Mermoz and the hospital) are naturally cross ventilated, with an appropriate value of window to wall ratio (above 20%).
The passive cooling strategies have been all inspired by the traditional architecture.

Low pressure shafts are used for the Lecture theater and the administrative area of the ESIROI building. Low pressure shaft is an efficient alternative to cross natural ventilation in case of noisy environments or large buildings. One can note that the airflow design principles has been tested and validated in a wind tunnel testing facility in Paris.
The hospital does not use natural ventilation as it is fully air-conditioned.

Evaporative cooling :
Not adapted to tropical climates with high humidity. None of the buildings use this strategy.

High thermal mass :
As the hospital is fully air-conditioned, high thermal mass is used for this case study. The rammed earth has a high level of thermal inertia, which makes it easy to control the temperature in the building, reducing temperature oscillations.

Nocturnal ventilative cooling :
Nocturnal ventilative cooling is not used in these buildings, most of the time not adapted to tropical climates where day-night oscillation of outdoor temperature is not large enough.

Use of local / geo- and bio-sourced materials
The case studies of La Reunion usually don’t use bio-sourced materials due to limited availablity of these materials in the island.
As for the hospital, the excavated land has been used to build the load-bearing walls with the rammed earth technique. The same architectural principles used for traditional houses were used in an innovative way.

Energy efficient systems & Renewables
The hospital is fully conditioned thanks to a standard energy cooling system (7°/12°C water chiller unit). All the Air Handling Units are equipped with a water recovery system with a dedicated circulation pump that performs a free pre-cooling of the external air, through a battery system.
The air conditioned spaces of the ESIROI building are cooled thanks to a 7°/12° cold water network produced by an energy efficient chiller with a high SEER of 4,19.
In terms of renewables, all the buildings (except Niama, Aimé Cézaire and Mermoz) have large BIPV roofs that allow to produce at least 30% of their total demand.
The Moufia lecture theatre and the ENERPOS building are Plus energy buildings. Their energy use (electricity) is five time less than a standard building (20 kWh/m^{2}y vs 100 kWh/ m^{2}y) and they produce 7 times more electricity thanks to PV panels.
The ESIROI Building is a near zero energy building (96% of the delivered energy is produced by PV) as well as Flores Malacca (88%) and the hospital in Uganda (30%)
For a critical review of the concept of net zero over a year and why it might still imply CO_2 emissions unless “energy needs for heating and cooling” have not been minimized and the resulting time-flexibility of demand systematically exploited, see the ABC21 “Report on indicators of overall building energy performance“.

.
Hot water is systemically produced by solar thermal panels.

Ceiling fans
We recommend to install ceiling fans for all the case studies. They allow to significantly reduce the period of discomfort specifically when the *night ventilative cooling* is used or when there is no wind outside. They also can be used in combination with AC systems with high set-point temperature (28°C) to reduce the energy use. The concept of mixed-mode spaces must be promoted. The occupants must also be trained to use the combination of these passive and active solutions.

Lessons learnt
Unfortunately, it was not possible to perform comfort interviews with the people and to contact the design team of the hospital.
The users of the case studies of La Reunion are overall satisfied. The only case study where people complained was Aime Cesaire School because of the lack of solar shading. For the Malacca Flores case study, the building works so well that people from the surroundings come to look for the fresh environment generated by vegetation. An unwanted consequence is that people who live in the building complain about safety issues.
The management of natural ventilation is as essential in summer as in winter. In places like Saint-Pierre (south of La Reunion) with strong winds in winter, people complain about discomfort during that time.
Ceiling fans play a pivotal role in summer comfort, especially for days without wind.
All the case studies got the inspiration from the vernacular architecture and are easily replicable.

ABC21 is funded by the EU's H2020 programme

Recommendations for Tropical Rainforest climate & Tropical Savanna with dry winter Climate (Af & Aw).

Vegetation : We recommend shading the surroundings of the buildings with native trees and to avoid mineral surfaces around the building. Car parks, if needed must be located underneath the building to free spaces for vegetation around the building.

Solar shading: The concept of large, detached roof that acts as a big umbrella must be promoted, as well as the design of outdoor corridors / buffer spaces. It is recommended to use light materials (timber) for shadings.
Dark coloured metal solar shadings are not recommended.

Comfort ventilation: Natural cross ventilation highly recommended
It is recommended to design systematically buildings that are naturally cross ventilated with at least 20% of window to wall ratio.
We recommend installing a weather station on site prior to the design stage to get all the wind data (intensity, main direction) necessary for a good airflow design.
Wind tunnel tests are highly recommended for complex buildings in a dense environment.
Noise and safety issues as well as visual intimacy should be considered when designing a building since these aspects can have a negative impact on the proper functioning of the bioclimatic strategies set up, especially on natural ventilation.
A high level of porosity of the facades combined with optimized solar shading devices and green spaces around the building is recommended since these measures ensure good visual and thermal comfort even in harsh tropical conditions.

High thermal mass is not recommended for naturally cross ventilated buildings in this climate types.

Geo- and Bio-sourced materials
Use of bio-sourced materials for thermal insulation is recommended.

Ceiling fans and mixed-mode buildings :
We recommend to install ceiling fans for all the case studies. They allow to significantly reduce the period of discomfort when outdoor air temperature is too high for comfort ventilation, in particular they are complementary to Night ventilative cooling. They also can be used in parallel with Adiabatic systems and AC systems. The concept of mixed-mode spaces must be promoted. The occupants must also be trained to use the combination of these passive and active solutions.

AFRICA | Temperate, Dry winter, Warm summer - Cwb (Kenya)

One case study – an office building in Nairobi, Kenya – has been selected for the Cwb climate-type.

UNON BUILDING
Nairobi, KE
OFFICE

The main lesson learnt of the UNON building is that air conditioning is not necessary in Nairobi. It is possible to design a comfortable bioclimatic office building in Nairobi with no active air conditioning systems.

Recommendations Temperate, Dry winter, Warm summer (Cwb)
Thermal comfort conditions can be easily reached with a well ventilated building, an appropriate orientation and insulation in walls and roofs in subsequent projects, using local materials, such as bio-sourced fibres. Ceiling fans are not necessary as well.

7. Reference

Butera, F., Adhikari, R., Aste, N., 2014. SUSTAINABLE BUILDING DESIGN FOR TROPICAL CLIMATES. Principles and Applications for Eastern Africa. UN-Habitat - UNON, Publishing Services Section, Nairobi, Kenya.

Givoni, B., 1992. Comfort, climate analysis and building design guidelines. Energy Build. 18, 11–23. https://doi.org/10.1016/0378-7788(92)90047-K

Givoni, B., 1991. Performance and applicability of passive and low-energy cooling systems. Energy Build. 17, 177–199. https://doi.org/10.1016/0378-7788(91)90106-D

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World map of the Köppen-Geiger climate classification updated.

Krüger, E., González Cruz, E., Givoni, B., 2010. Effectiveness of indirect evaporative cooling and thermal mass in a hot arid climate. Build. Environ. 45, 1422–1433. https://doi.org/10.1016/j.buildenv.2009.12.005

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007a. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci. 11, 1633–1644.

ANNEX Part A

ANNEX A : Description of Case studies | PHASE 2

ANNEX B : Description of Case studies | PHASE 1

ANNEX A : Description of Case studies | PHASE 2

EUROPE

Case study 2-01 : Patio House, Italy

Case study 2-02 : Ruina House, Portugal

LA REUNION

Case study 2-03 : Aimé Cézaire primary school, La Réunion

Case study 2-04 : ESIROI Building, La Reunion

Case study 2-05 : Flores Malaca, La Réunion

AFRICA

Case study 2-06 : Burkina Institute of technology, Burkina

Case study 2-07 : Lycée Schorge, Burkina

Case study 2-08 : CFP Nioro, Sénégal

Case study 2-09 : Lycée Mermoz, Sénégal

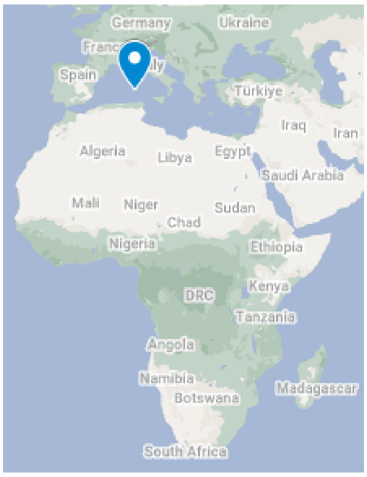
Case study 2-10 : Maison des Yvelines, Sénégal

Case study 2-11 : Mbakadou School, Sénégal

Case study 2-12 : Children surgical Hospital, Uganda

ABC21 is funded by the EU's H2020 programme

CASE STUDY 2-01: PATIO HOUSE | ITALY



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Via delle Mimosa 18, 09010 Portoscuso Sud, Sardinia, Italy
Latitude; Longitude	39.217703, 8.374674 (39°13'03.7" N, 8°22'28.8" E)
Climate zone (Köppen–Geiger classification)	Csa: Warm temperate climate with dry and hot summer
BUILDING INFORMATION	
Building Type	Residential
Project Type	New construction
Completion Date	2017
Number of buildings	1
Number of storeys	1
Total Floor Area (m²)	162 (patio 23 m² + porch 22 m²)
Net Floor Area (m²)	104
Thermally conditioned space area (m²)	104
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	104
Total cost (€)	210 000
Cost /m² (€/m²)	1 300
Performance Standards or Certification	Classe A4: 38,95 kWh/m²
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	Vincenzo Fadda
Architect / Designer	Arch. Michele Ricci, Ing. Giovanna Nardini
Construction manager	Greenlab Srl
Environmental consultancy	Ing. Casu Gabriele
Structural Engineer, Civil Engineer	Ing. Claudia Conti

PROJECT DESCRIPTION

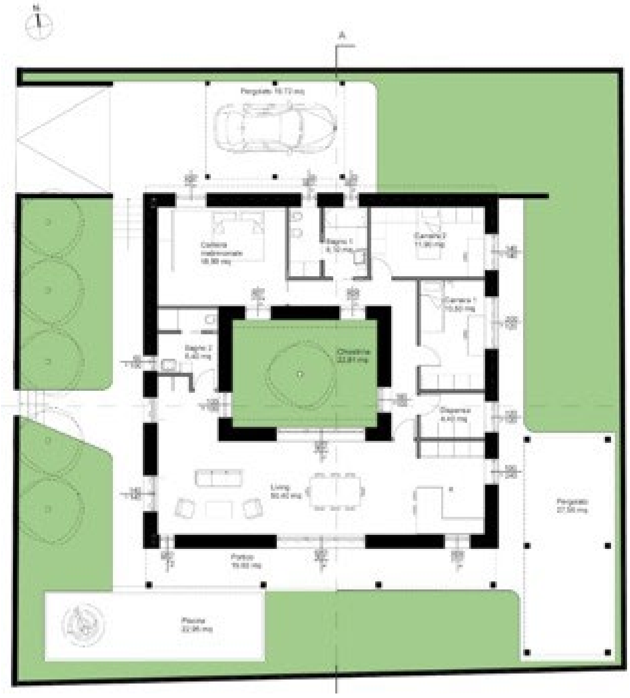


Figure 1 : Ground floor plan of the Patio House.

The project stems from the desire to create a sustainable and innovative building, in energy class A+ suitable for the Sardinian Mediterranean climate, made with natural materials: the client immediately requested a straw house.

The architectural design was therefore based on choices that would optimize not only the quality of the spaces but also energy efficiency and environmental sustainability.

The biggest problem was to create a building which, even if placed within a subdivision and therefore an urbanized area, managed to maintain its privacy. The traditional Sardinian house, especially that of the Sulcis area, had a courtyard, an external but private space, hence the intention of resuming a classic typology typical of warm Mediterranean countries: the house with an internal courtyard.

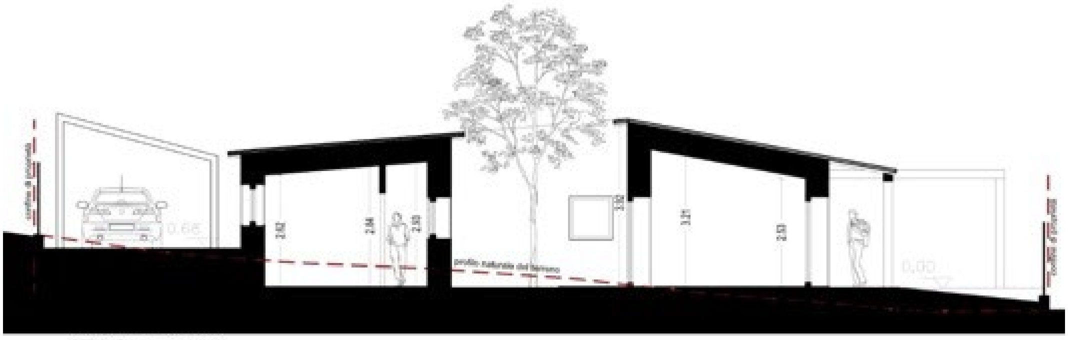


Figure 2 Section of the project.

SITE INTEGRATION

Figure 3 : (a) Aerial view (Source: Google Map) and (b) photograph of the geographical context of the project.

The building is located in Sardinia, in the Sulcis area in the province of Carbonia-Iglesias, on the outskirts of a small town of 5000 inhabitants close to the Tyrrhenian Sea, within an urban subdivision. The neighbourhood is surrounded by small trees and shrubs, typical vegetation of the "Macchia Mediterranea".

CLIMATE ANALYSIS

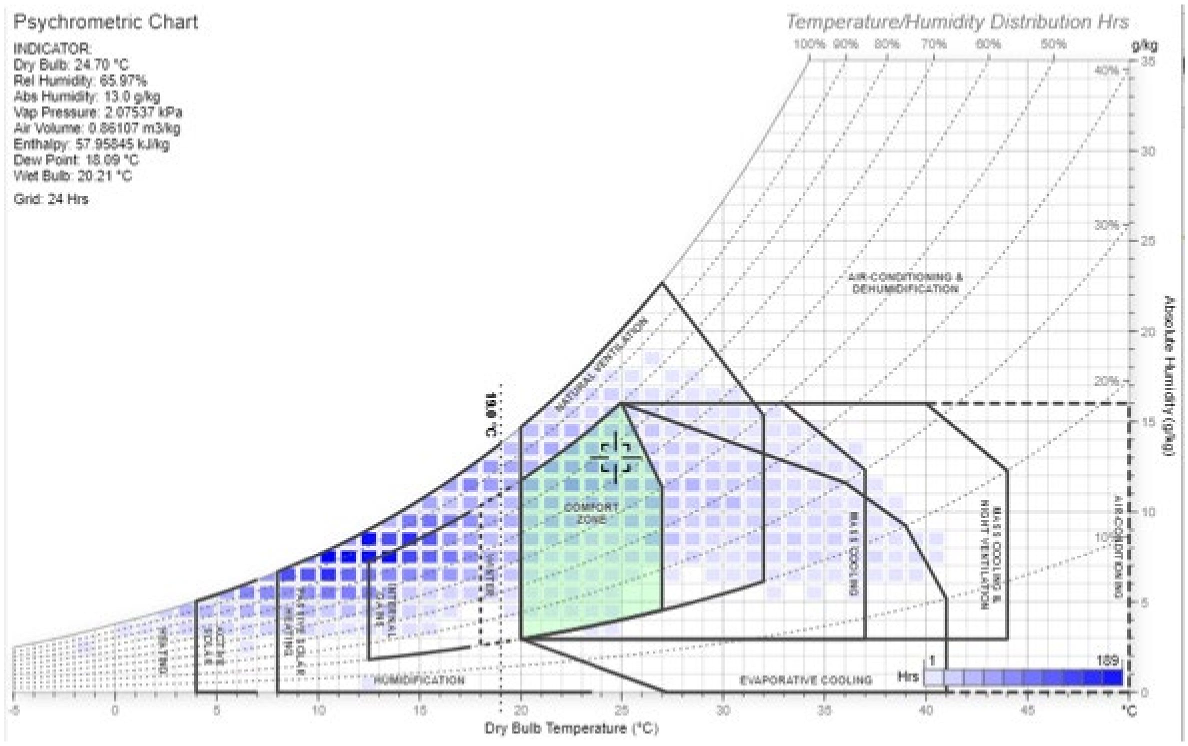


Figure 4: Givoni Bioclimatic chart for the climate of the region of Portoscuso, Sardinia, Italy using Andrew Marsh online tool [2]. Weather data are extracted from the PVGIS tool of the jrc for the 2005 – 2020 period.

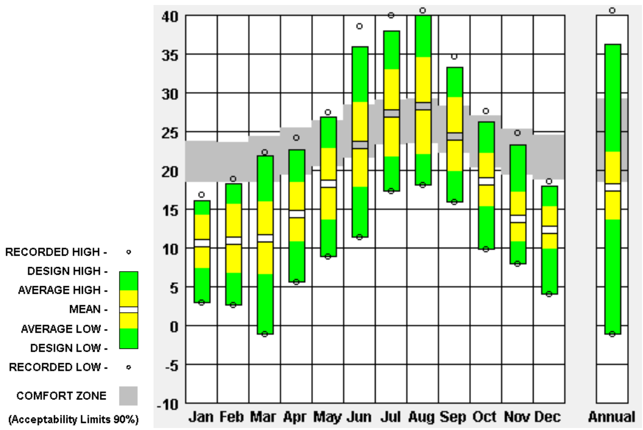


Figure 5: Temperature range by month for the region of Portoscuso, Sardinia, Italy (Source: Climate consultant – Adaptative Comfort model).

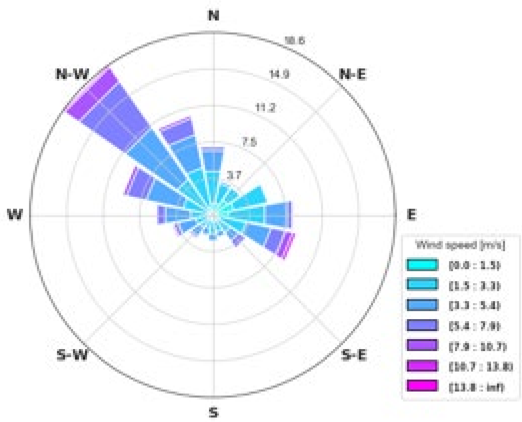


Figure 6: Wind rose for the region of Portoscuso, Sardinia, Italy

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **1 987** Wh/m² (Dec.) Max: **7 776** Wh/m² (Jul.) Mean: **4 878** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **1 149** CDD 10°C: **2 970**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **1 297** CDD: **99**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **1 276** CDD 26º: **247**

ABC21 is funded by the EU's H2020 programme

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	**Comfort ventilation (**cross natural ventilation) **Nocturnal convective cooling** **High level of insulation** in straw bales Its **optimal and aerodynamic shape** allows to minimize the amount of heat in hot periods and enhance natural ventilation. The **inner courtyard** favours the formation of cool areas inside the house which create natural ventilation in summer, decreasing the perceived temperature. The building is plastered externally with a white natural lime plaster. The white colour was chosen for landscape and energy reasons, decreasing summer overheating. On the south-west side there is a small bio-pool which, in addition to having a recreational purpose, also has the function of creating a microclimate and cooling the hot summer air.
Passive heating strategy	**Solar radiation** **High level of insulation** in straw bales The **optimal shape** of the building involves the minimum heat loss in cold periods. Besides, **large glass windows on the south side and optimized solar protection** allow solar radiation to penetrate the building during the winter months. Another feature of the building is its positioning in the ground, which has a difference in height of about two meters in the north-south axis. The house tries to make the most of the morphology and remains buried for about 90 cm on the north side for two reasons: to use the ground as thermal insulation on the colder side (the ground has a constant temperature all year round) and to have a north facade lower than the others and therefore obtain a more aerodynamic shape and protected from the Mistral wind.

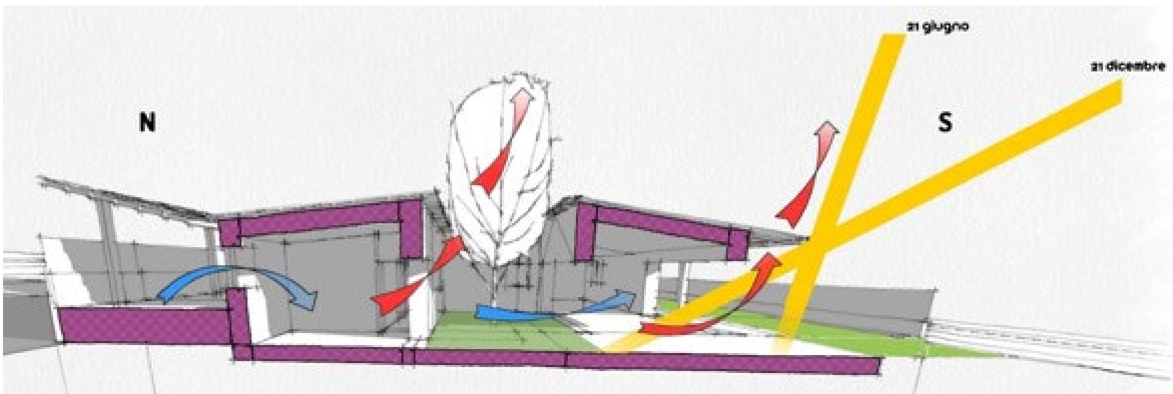


Figure 7: Section of the building showing the passive features set up.

Solar protection	The porch on the south side were designed to protect the building from direct solar during the summer period. Pergola on the East side for relaxation but also for lunch and dinner outdoors. A second pergola to the north instead has the dual function of carrying the solar and photovoltaic panels and covering the car park.

Building orientation	The main façades of the house are Est-West oriented.
Insulation	The high level of insulation in straw bales enables a thermal lag of the walls of 21 hours while the roof, which is ventilated and insulated with straw bales and raw earth, enables a thermal lag by no less than 16 hours.
Vegetation	The house is surrounded by small trees and shrubs, typical vegetation of the "Macchia Mediterranea". The vegetation does not contribute to shade the house, explaining why additional passive shading strategies had to be adopted.
Natural daylighting	The inner courtyard and the large glass windows provide natural light to the rooms of the building, especially the ones located in the northern part.
Use of local and embedded materials	**Straw bale and cork** The supporting structure of the building is made of wood, offering a " light ", flexible and highly resistant building. The masonry closure and thermal-acoustic insulation is made with **straw bales grown and built a few kilometres away**; the latter conceptually used as bricks, in addition to being a high-performance insulator, it guarantees breathability, durability, resistance to fire, earthquakes and environmental sustainability. Inside the house, the plasters will be made of raw earth. This natural material will contribute to a high internal comfort by acting as a hygro-regulator, avoiding condensation and mould; the use of raw earth for plaster and as a building material in general is part of the tradition of this region.
Water saving and flood management	The presence of small trees and shrubs, as well as pervious surfaces, in the courtyard and around the house allows to manage rainwater.
Waste management	Selective waste collection
Others features	Covered car park.


(a)


(b)

Figure 8: Exterior view of the (a) South and (b) West façades

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** Ratio with number of users: -
Ceiling fans	In every room, even those conditioned: **No**
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: **No**
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	In every room, even those conditioned: **Yes**
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.: **NA** *It is not necessary since the building is a detached residential house and the users are aware how to use the building correctly.*

Figure 9: General sketch of the house

Figure 10 : Interior view of the living room

BUILDING FABRIC AND MATERIALS	
Roof	Composition: Ventilated wooden roof / Raw earth / Straw bale / Double wooden plank Thickness: 55 cm
Walls	Composition: Natural lime plaster / lime and sawdust mortar / Straw bale / Mortar and sawdust / Raw earth plaster Thickness: 55 cm
Windows	PVC frame
Basement floor	Insulation with expanded clay

Figure 11: The supporting structure of the building is made of wood.

Figure 12: The external walls are highly insulated with straw bales.

(a)

(b)

Figure 13 : Construction of the roof: (a) step 1 and (b) step 2.

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	5 split systems Cooling rated capacity of 2.43 kW and 8300 Btu/hr
Low-energy heating systems	5 split systems Heating rated capacity of 3.22 kW and 11000 Btu/hr
Ceiling fans	None
Mechanical ventilation / air renewal	None
Domestic Hot Water	None
Artificial lighting	LED lamps (150W in total)
Control and energy management	None

RENEWABLE ENERGY	
PV	None
Solar thermal	2 panels – South oriented
Wind	None
Geothermal	None
Biomass	None

ABC21 is funded by the EU's H2020 programme

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

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: **≥98%**
6. Percentage of time inside the Givoni comfort zone of 0m/s: **≈30%**
7. Number of hours within a certain temperature range

Hot period (1st Aug. to 30th Sep. 2022) Occupation time: 6:00pm to 8:00am	Living Room		Bedroom	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<22°C	0	0%	**0**	0%
22°C≤Ta<24°C	0	0%	**0**	0%
24°C≤Ta<26°C	**86**	8,3%	**176**	17,2%
26°C≤Ta<28°C	**801**	77,8%	**798**	77,8%
28°C≤Ta<30°C	**143**	13,9%	**52**	5,1%
30°C≤Ta<32°C	0	0%	**0**	0%
32°C≤Ta<34°C	0	0%	**0**	0%
34°C≤Ta<36°C	0	0%	**0**	0%
Ta≥36°C	0	0%	**0**	0%

Energy performance indicators

1. Energy needs for heating: **10.24** [kWh/m²/year]
2. Energy needs for cooling: **12.90** [kWh/m²/year]
3. Energy use for lighting: - [kWh/m²/year]
4. Energy needs for Sanitary Hot water: **14.57** [kWh/m²/year]
5. Total Primary energy use: **38** [kWh/m²/year]
6. Renewable Primary energy generated on-site: - [kWh/m²/year]
7. Renewable Primary energy generated on-site and self-consumed: - [kWh/m²/year]
8. Renewable Primary energy exported to the grid: - [kWh/m²/year]
9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): - %
10. Delivered energy (from electricity bills): - [kWh/m²/year]

Acoustic comfort indicators

1. Airborne sound insulation
2. Equivalent continuous sound Level
3. HVAC noise level
4. Reverberation time
5. Masking/barriers

Visual comfort indicators

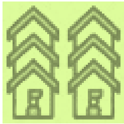
1. Light level (illuminance)
2. Useful Daylight Illuminance (UDI)
3. Glare control

ABC21 is funded by the EU's H2020 programme

	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	Owners are very satisfied by the comfort conditions of the house.

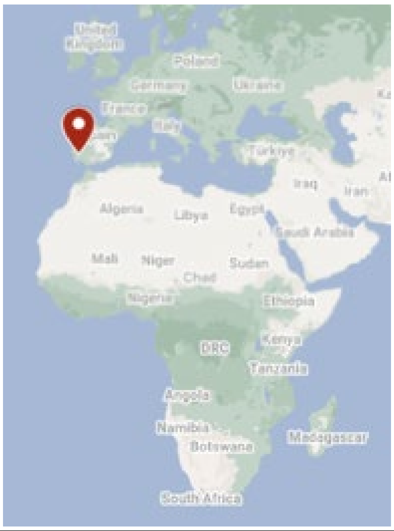
LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	The monitoring was initially planned for situations where AC would be of. This did not prove possible since the week of measurements coincided with a particularly hot period, with a couple of days with minimum temperatures at night of 28 °C. Hence AC was turned on between 1 p.m. and 6 p.m in the bedrooms. Consequently, it is difficult to disentangle the effect of the envelope and passive techniques from the one of the active AC. We notice anyway that the air conditioning is activated just for a few hours, even in a challenging weather condition, with outdoor max reaching 34-38 °C and night temperature never falling below 25-26 °C. Passive features appear able to attenuate the impact of the heat wave. PV on the roof might supply energy for the few hours when AC is turned on, during the hot hours of the afternoon. On the contrary the patio does not seem to play its role of buffer space in summer as initially planned by the architects, probably because of the lack of solar shading systems. The outdoor conditions inside the patio are very similar to the airport ones,. We would point out, however, that in the original design a tree was planned on the patio.
Recommendations	Patio: we recommend lowering the outdoor temperature in summer by planting a tree (deciduous tree, pergola with wine tree), and to install a retractable shading system in textile or pergola with fixed or rotating louvres. A tree in the courtyard was indeed foreseen in the project. Insert connection to a cold sink: earth to air heat exchanger, ground at 5 m depth (temperature of the soil at 5-6 m depth is stable and equal to the average air temperature over the year, in this area between 16 and 17 °C; if a ground exchanger would be situated at a lower depth, the temperature of the soil can be kept low by shading and by watering periodically the surface, to benefit of evaporative cooling), evaporative cooling being hindered by humidity. Bedrooms and living room: to avoid or to reduce the use of AC, we recommend to install ceiling fans in all indoors spaces (one for each bedroom and 2 for the living room). The ratio is one ceiling fan/ 10 m2. Once the courtyard would be shaded it would be useful to have a ceiling fan also there. External solar protection with movable slats are optimal for regulating light and solar access and for allowing ventilation while protecting from intrusion. In case absent on some of the openings they should be added, and an effective operating strategy should be integrated by the users of the house.

Increase the inertia of the straw wall: by increasing the thickness of the interior clay-based plaster or even through a single-row brick wall.

BUILDING STRENGTHS AND WEAKNESSES		
	Strengths	
		
Passive Design	**Energy Efficiency**	**Replicability**
	Weaknesses	

REFERENCES
https://www.archetica.com/index.php?option=com_content&view=article&id=42:casa-a-patio&catid=12&Itemid=124

CASE STUDY 2-02: RUINHA HOUSE | PORTUGAL

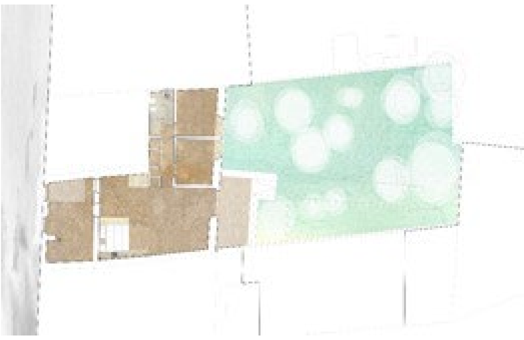


GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Ruinha nº34, Montemor-o-Novo, Portugal
Latitude; Longitude	38.64812,-8.21353
Climate zone (Köppen–Geiger classification)	Cwa: Warm temperate climate with dry winter and hot summer
BUILDING INFORMATION	
Building Type	Residential
Project Type	Extension and Refurbishment
Completion Date	2021
Number of buildings	1
Number of storeys	1 with mezzanine
Total Floor Area (m²)	156.5
Net Floor Area (m²)	126.2
Thermally conditioned space area (m²)	90 (heated space)
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	90
Total cost (€)	120 000
Cost /m² (€/m²)	800
Performance Standards or Certification	None
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	Tânia Teixeira + André Pereira/ 938137907
Architect / Designer	Tânia Teixeira/ CRU atelier, 938137907
Construction manager	Tânia Teixeira/ CRU atelier, 938137907
Structural Engineer, Civil Engineer	Domingos Dias Pereira/ Edilestreito, 914992550
Energy Consultant and Electrical Engineer	André Pereira, 914318313

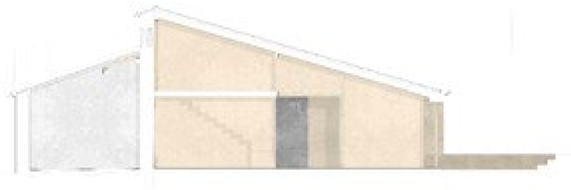
ABC21 is funded by the EU's H2020 programme

PROJECT DESCRIPTION

Ruinha House Project is a self-built refurbishment located in Montemor-o- Novo city centre. Rammed earth walls with around 200 years meets contemporary ones. The same material, earth, separated by two centuries of history. The house with around 100 m2 is located in a very old and narrow street, Ruinha. Ruinha means literally small street. It is one of the oldest streets of the outer city wall. In a street characterized by ground floor houses with big chimneys that are so characteristic of Alentejo, the facade is kept with its prominent chimney. Responding to this paradigm, an entrance patio was predicted to function as a buffer zone articulating exterior and interior, public and private zones. The rusted metal doors and window allow light and wind to cross. The patio catches the south light and brings it in all day long, in a house that is oriented east-west. The Alentejo Blue colour chosen for the south facing patio wall refreshes the light that enters the house. It mixes also with the blue sky. In the patio there is a outdoor kitchen and storage space. The patio leads to the main room. It is the social area of the house, with a large open kitchen and the living room with a fire place in its core. In the future there will be a mezzanine that will host the library and office, that will be kept open to the living room. From the 4 high windows on the top, we can see the Castle. These high windows help cross ventilate the room and release the hot air. The house is turned into the back garden that faces East where there is more privacy and nature can enter through the large windows framed by the new rammed earth walls. The elements connect with nature, earth and wood. A small corridor illuminated by a translucent glaze connects the social area to the small bedrooms. The bedroom windows are at the high of the garden floor, where a typical "namoradeira", a bench, is created. The toilet is a monolith of traditional Moroccan plaster tadelakt, from walls to the floor. The light enters above the shower in a zenithal light and through an indirect zenithal light above the sink. The texture and colour of the lime plaster give a dynamic to the walls.



.(a)



.(b)

(c)

(d)

Figure 14 : (a) Ground floor plan, (b) section (c) East facade and (d) West façade of the Ruinha House

SITE INTEGRATION

Figure 15 : (a) Aerial view of the project in its surrounding environment (Source: Google Map)

Ruinha 34 House is located in the historical center of Montemor-o-Novo small town, located in the rural area of Alentejo, southern Portugal. The house with around 100 m^2 is located in a very old and narrow street, Ruinha. Ruinha means literally small street. It is one of the oldest streets of the outer city wall. The plots of this town area are characterised by small one floor houses with big chimneys that are so characteristic of Alentejo and with a vegetable garden on the back. The houses are made a mix of traditional rammed earth and stone/brick masonry.

CLIMATE ANALYSIS

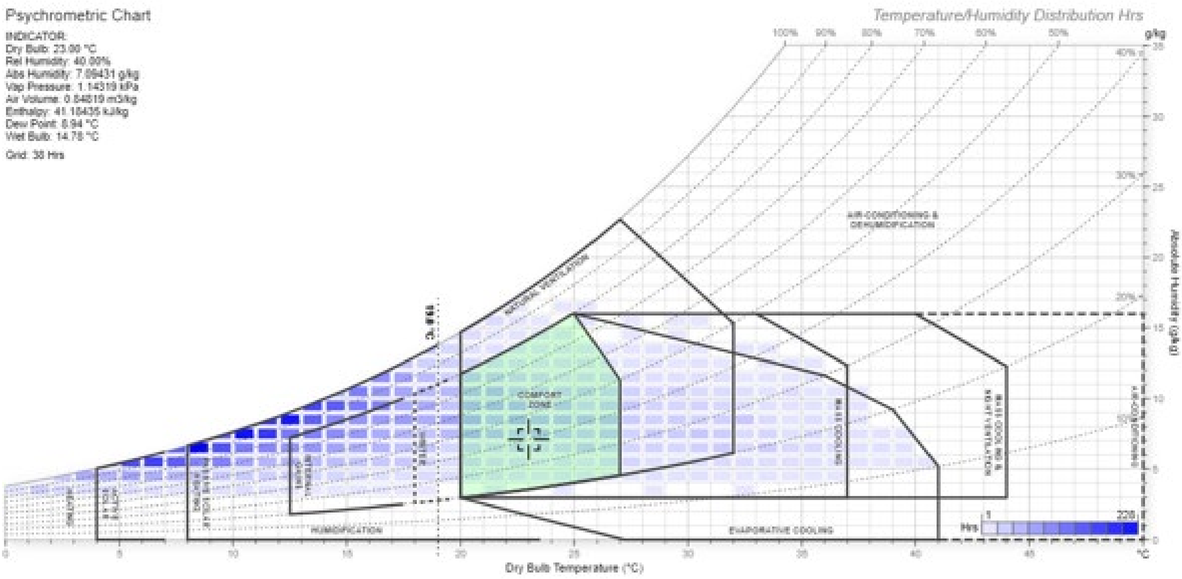


Figure 16: Givoni Bioclimatic chart for the climate of Monter-o-Novo, in Portugal using Andrew Marsh online tool [2]. Weather data are extracted from the PVGIS tool of the jrc for the 2005 – 2020 period.

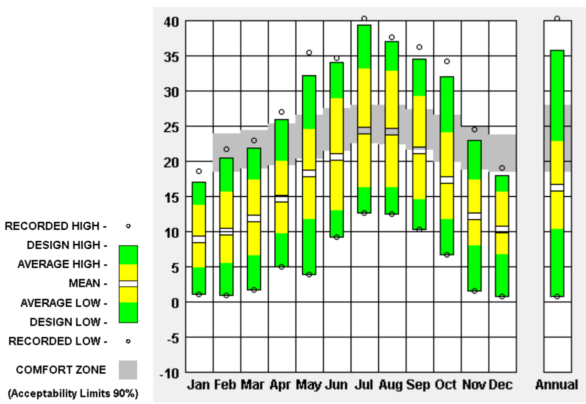


Figure 17: Temperature range by month for Monter-o-Novo, Portugal (Source: Climate consultant – Adaptative Comfort model).

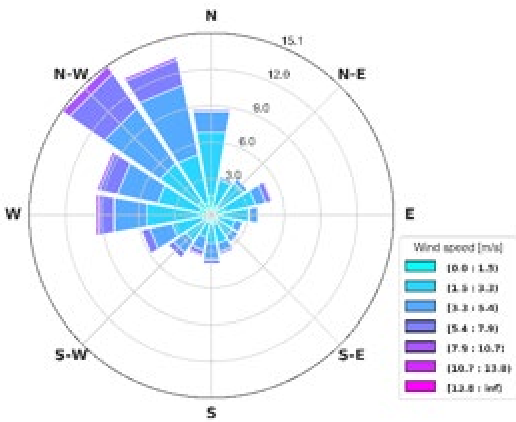


Figure 18: Wind rose for Monter-o-Novo, Portugal

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **2 226** Wh/m² (Dec.) Max: **7 824** Wh/m² (Jul.) Mean:**4 899** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **1492** CDD 10°C: **2493**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **1694** CDD: **117**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **1638** CDD 26º: **208**

Figure 19 : General view of the East facade with the garden

Figure 20 : Outside window shadow

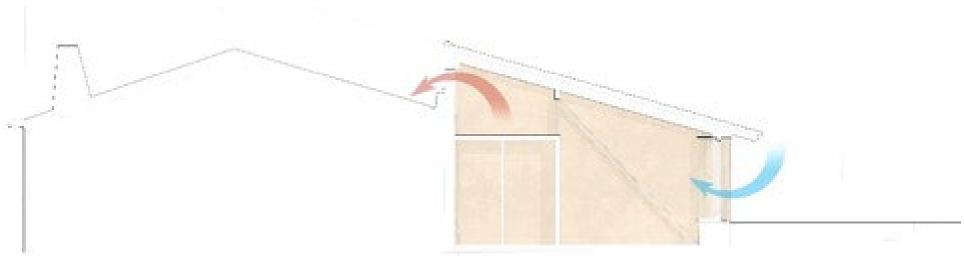
KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	**Comfort ventilation (**cross natural ventilation) **Nocturnal ventilative cooling** **Thermal inertia** of the rammed earth walls Natural cross ventilation in each room. Night ventilation combined with thermal inertia due to colder nights (in the order of 15º ºC lower than the daily maximum temperature). Exposed rammed earth walls and clay and lime plasters. In extreme hot days (above 38°C), water is sprayed in the rammed earth walls and earth lime plasters to help cool the building via evaporative cooling. During the day shadings outside the windows are placed, especially on the eastern façade which has the biggest windows turned to the garden. Both the garden and the entrance patio contribute to refresh the air.
Passive heating strategy	**Passive solar heating** **Thermal inertia** of the rammed earth walls
Solar protection	Outside shadings
Building orientation	The exposed façades of the building are East-West oriented.
Insulation	Only the roof is insulated with 16 cm of recycled cotton wool
Vegetation	Front patio towards West with a small pot garden, East vegetable garden with fruit trees mainly deciduous, All the rooms have also air purifying plants.

ABC21 is funded by the EU's H2020 programme

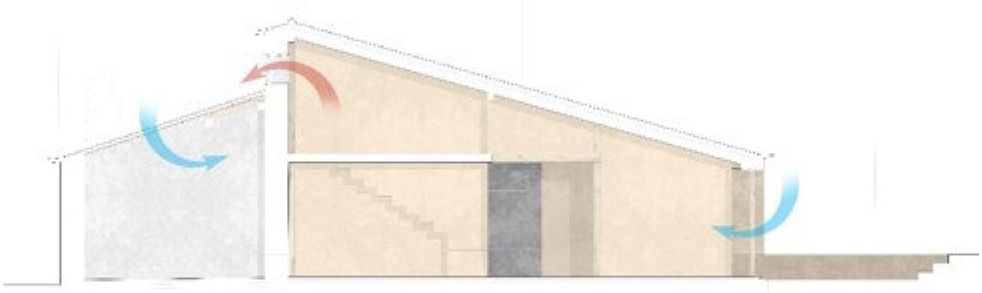
Natural daylighting	All the rooms take benefit from natural lighting thanks to the large windows and the patio.
Use of local and low embedded-energy materials	Rammed earth (new and old) on outer walls, wattle-and-daub/light earth partition walls, lime plasters, stone from demolition of the old wall, handmade terracotta tiles.
Water saving and flood management	▪ Water saving taps, ▪ A future rain water deposit for garden watering will be implemented, ▪ No heat recovery on hot water drain.
Waste management	▪ Reuse of the demolition materials like stones and tiles, ▪ Recycling station on the kitchen, ▪ Double compost pile in the garden.
Others features	Semi-open entrance patio for general storage, bike and surfboard storage, laundry drying space

Figure 21 : Interior view of the kitchen

Figure 22 : Interior view of the living room.



(a)



(b)

Figure 23 : Schemes of the cross-ventilation principle: (a)in the bedroom and (b) in the entrance patio on the left and in the living room from the garden on the right.

ABC21 is funded by the EU's H2020 programme

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** Ratio with number of users: -
Ceiling fans	In every room, even those conditioned: **No** *Pre-installed in the living room*
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…)	**Yes** *(in the entrance patio)*
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.: **No** *It is not necessary since the building is a private house and the users are aware how to use the building correctly.*

Figure 24: Interior view of the entrance

Figure 25 : View of the interior patio

Figure 26 : View of the central fireplace

BUILDING FABRIC AND MATERIALS	
Roof	Wood boards, smart vapour barrier (Intello Proclima), 16 cm of recycled cotton wool between structural wood beams, OSB board, breathable waterproof membrane, traditional ceramic tile roof with clamps to improve breathing.
	Overall R-value: 4,366 [m^2K/W]
Walls	Exterior walls in rammed earth with around 55 cm thickness. Interior walls in wattle-and-daub/light earth with earth lime plaster and clay paint with 14 cm.
	Overall R-value 0,761 [m^2K/W]

ABC21 is funded by the EU's H2020 programme

Windows	Wood frame with 80 mm thickness double glazed on east façade and aluminium with thermal cut double glazed with 70 mm thickness
	Window-to-wall ratio (WWR): EAST Facade $7.5m^2/30m^2$=0.25; SOUTH Facade: 0; WEST Facade: $6.1m^2/38.4m^2$=0.16
	U-value | Wood windows specification (λ = 0,14 W/(m °C) => 2,42 [W/(m² °C)] | Aluminium windows specification Uw=1,8
	Visual transmittance= 89%
Basement floor	No Basement floor but an aerated floor base with a box of gravel of 30cm

Figure 27: View of the rammed earth wall from the interior.

Figure 28:. View of the exposed rammed earth wall from the exterior.

Figure 29 : Exterior view of the main façade in rammed earth and the hanging roof protection made of traditional ceramic tiles.

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	**None**
Low-energy heating systems	Wood burner to heat water with 80% energy efficiency, that heats up anticorrosion liquid to an insulated 800L inertia deposit with a C efficiency rate. This deposit feeds the heated pavement and the hot water domestic grid. The heating system is intelligent and controlled in every room with a "nest" thermostat, allowing different temperatures per space, and an interactive use with adaptive learning (the thermostats learns your life patterns and gets information from weather predictions to be more and more efficient).
Ceiling fans	Ceiling fan pre installed in the living room.

Mechanical ventilation / air renewal	Only in the toilets
Domestic Hot Water	Wood burner and heat storage in winter time. Electrical resistance fed by photovoltaic panels in mid season and summer.
Artificial lighting	All rooms have natural light. All artificial light in LED. Living room: 0,5W/m^2 Toilet: 2,8W/m^2 Bedrooms: 0,7 W/m^2
Control and energy management	Off-grid house with photovoltaic production energy production controlled by an application. All the big appliances are programmed to work at the solar peak manually or thanks to the application. Kitchen stove work with Propane bottled gas (1 bottle of 12kg every 2-3 months)

Figure 30 : View of the wood burner.

Figure 31 : View of the "Nest" thermostat

Figure 32 : View of the pipes and system that feeds the heated pavement and the hot water domestic grid.

RENEWABLE ENERGY	
PV	9 mono crystalline panels on the eastern roof of 255W. Total Peak Power = 2295 W with accumulation of 2 lithium batteries;; 9 m^2 surface of PV Architectural integration: aligned with the eastern roof towards the garden, not visible from the street. Azimuth= 17º (degrees from south tilt angle)
Solar thermal	None
Wind	None
Geothermal	None
Biomass	Biomass wood stove with 80% efficiency for central heating and domestic water heating

Figure 33: 9m² of mono crystalline panels are installed on the eastern roof.

Figure 34 : View of the Growatt Hybrid inverter to PV systems, specially designed for storing current in batteries.

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

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: **99.7%**
6. Percentage of time inside the Givoni comfort zone of 0m/s: **76%**
7. Number of hours within a certain temperature range:

Hot period (28th Jun.to 30th Sep. 2022) Occupation time: 6:00 pm to 8:00am	Living room		Bedroom	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<22°C	**87**	**5.3%**	**51**	**3.1%**
22°C≤Ta<24°C	**392**	**24,1%**	**262**	**16.1%**
24°C≤Ta<26°C	**587**	**36%**	**687**	**42.1%**
26°C≤Ta<28°C	**292**	**17.9%**	**415**	**25.5%**
28°C≤Ta<30°C	**186**	**11.4%**	**179**	**11%**
30°C≤Ta<32°C	**78**	**4.8%**	**35**	**2.1%**
32°C≤Ta<34°C	**7**	**0.4%**	**1**	**0%**
34°C≤Ta<36°C	**0**	0%	0	0%
Ta≥36°C	**0**	0%	0	0%

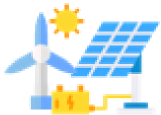
Energy performance indicators

1. Energy needs for heating: [kWh/m²/year]
2. Energy needs for cooling: [kWh/m²/year]
3. Energy use for lighting: - [kWh/m²/year]
4. Energy needs for Sanitary Hot water: [kWh/m²/year]
5. Total Primary energy use: [kWh/m²/year]
6. Renewable Primary energy generated on-site: - [kWh/m²/year]
7. Renewable Primary energy generated on-site and self-consumed: - [kWh/m²/year]

	8. Renewable Primary energy exported to the grid: - [kWh/m^2/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): - %
	10. Delivered energy (from electricity bills) : - [kWh/m^2/year]
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	Owners are very satisfied by the comfort conditions either in summer or in winter
	LESSONS LEARNED AND RECOMMENDATIONS
Lessons learned	Thanks to the bioclimatic design (large thermal capacity of walls, external shading, thermal buffer of the patio, thermal insulation of the roof) and passive techniques (night ventilative cooling) summer comfort conditions are within the Adaptive or Givoni comfort range; during the hottest hours of the day comfort conditions can be met if an air velocity of 1 m/s can be achieved We did not measure air velocity indoor, but it is possible that this velocity might not be achievable all the time by cross ventilation and/or it would be counterproductive (by bringing indoor air too hot) with respect to the benefits of *night ventilative cooling*. An easy improvement of the passive cooling strategy, in hot hours of the day, would hence be to close windows to limit the intake of hot air and achieve air velocity of around 1 m/s by installing and using ceiling fans appropriately sized and positioned, and thus complete the *comfort ventilation strategy.* Complementary strategies which might additionally ameliorate summer conditions at hot daytime hours are: - Additional shading of the garden and patio by deciduous trees or climbing plants on trellises - A ground exchanger for pre-cooling intake air during the day

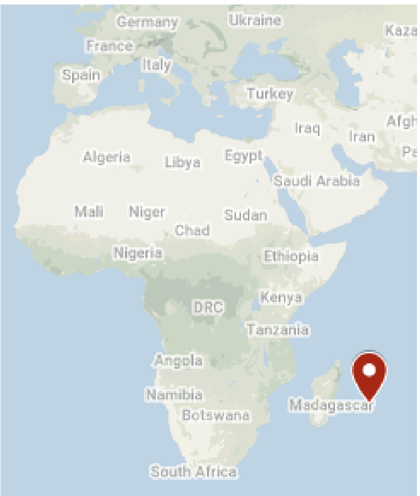
- Evaporative cooling, e.g. in the patio, during the hot hours of the day, when relative humidity is at low level, might create a cool space.

Recommendations	The main recommendations are to understand how critical it is to work with the appropriate materials and optimal knowledge of their performance

BUILDING STRENGTHS AND WEAKNESSES		
Strengths		
		
Passive Design	**Energy Efficiency**	**Renewable Energy**
Weaknesses		
-		

REFERENCES
-

CASE STUDY 2-03: AIME CESAIRE SCHOOL | LA REUNION



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	24 rue des Oliviers Bois d'Olives, 97432 Saint-Pierre, La Réunion
Latitude; Longitude	-21.295968339045405, 55.46041647459686
Climate zone (Köppen–Geiger classification)	Aw: Equatorial savannah with dry winter
BUILDING INFORMATION [1][2]	
Building Type	Educational (Kindergarten and primary school)
Project Type	New construction
Completion Date	2017
Number of buildings	1
Number of storeys	3
Total Floor Area (m²)	-
Net Floor Area (m²)	1 684
Thermally conditioned space area (m²)	44,5 (technical and IT rooms)
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	1 330
Total cost (€)	4 886 463
Cost /m² (€/m²)	2901.7
Performance Standards or Certification	PERENE tool (acronym for Energy performance of buildings)
Awards	International winner of the Green Solutions Awards 2017 – Energy & Hot Climate category – Construction21
STAKEHOLDERS [2][3]	
Building Owner/ Representative	City council of Saint-Pierre (La Réunion)
Architect / Designer	APA - Antoine Perrau Architectures
Environmental consultancy	LEU Réunion
Structural Engineer, Civil Engineer	GECP

MEP consultancy	ATELIER D'INGENIERIE REUNIONNAIS
Landscape design	Michel Reynaud
Others	CREATEUR, DOREMI CONSEIL, CPS

PROJECT DESCRIPTION [2][3]

Figure 35 : Exterior view of the North-West façade of the building. (© Hervé DOURIS)

Figure 36 : Exterior view of the South-East façade of the building. (© Hervé DOURIS)

The Aimé Césaire school is composed of 12 classrooms (5 nursery classes, 7 elementary classes) and the associated external spaces, representing 1.676 m² of built surfaces, 345 m² of sheltered surfaces (courtyards and shelters) and 1.680 m² of exterior surfaces. The project is based on a sustainable development approach specific to tropical and subtropical climates, supported by the PERENE calculation tool. The building proposes a bioclimatic architecture which structures the organization of the volumes and the technical choices of the project.

This school was designed following two differentiated zones. The first one protects the spaces to the point of covering them with a unifying shading structure. This is the space of the youngest. The other one opens its courtyards and its playgrounds around and under the buildings, and is protected by their vegetation forming a boundary with respect to the trade winds of the eastern sector. This is the space of the elementary school.

The school is the first place of experience with the educational environment. The main objective was to design an architecture that would allow children to form their spatial, visual and sensory references. Bioclimatic design is therefore a tool for raising awareness among the youngest and can be used by teachers for educational purposes.

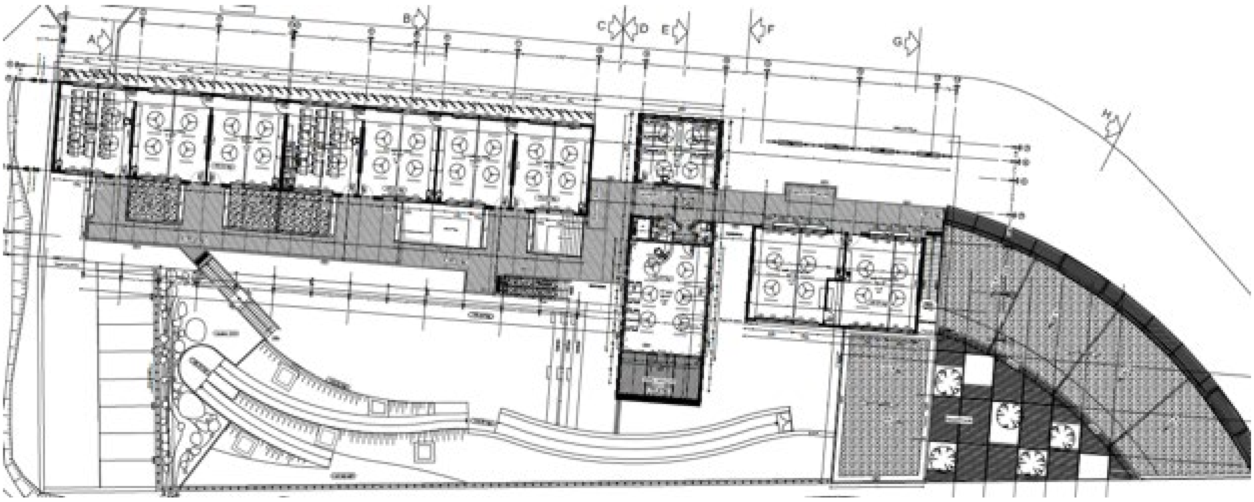


Figure 37: Floor plan of the second floor of the school. © Antoine Perrau Architecture.

SITE INTEGRATION [3]

Figure 38 : Aerial view of the building in its surrounding environment. (Source: Google Map)

The 12-classroom school is located in the neighbourhood of “Bois d’Olive” at Saint-Pierre, La Reunion. The Bois d'Olives neighborhood is a spontaneous and continuous urbanization of agricultural land under land pressure. It is in this context, mixed with vernacular housing, collective housing and facilities, that the Aimé Césaire school is located. The building faces the entrance of the high school located on the other side of the Laurent Vergés Avenue, which is itself well served by public transportation. A minimal disruption of the site is operated which allows to limit the impact of the project on the territory. The project proposes a very sober volumetric impact deployed by making the best use of the effects of site and natural slopes, slightly embedded upstream and on piles downstream.

CLIMATE ANALYSIS

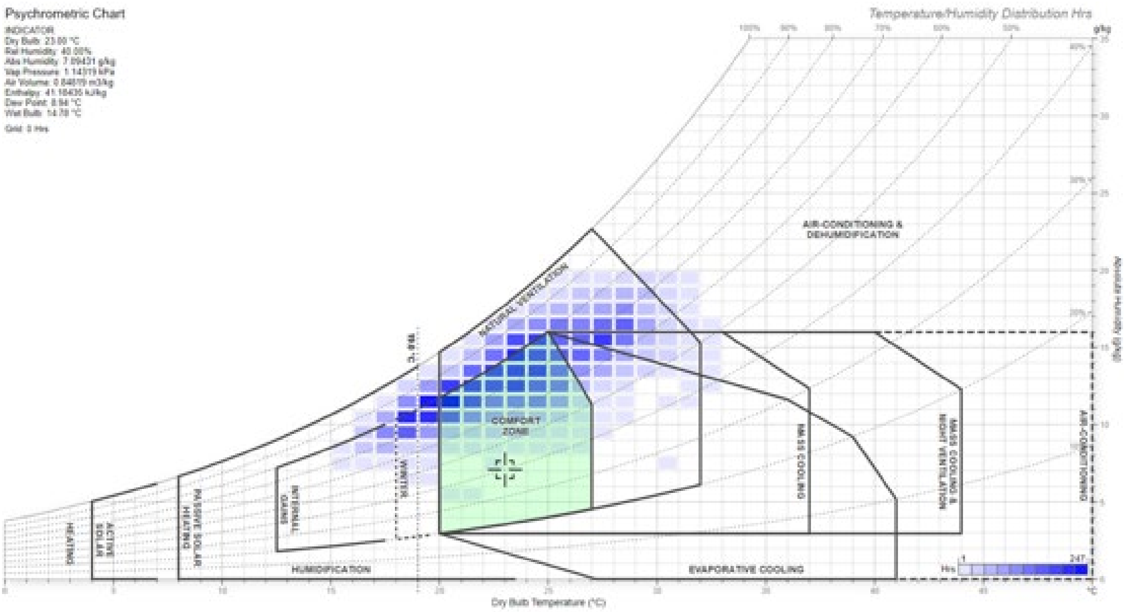


Figure 39: Givoni Bioclimatic chart for the climate of Saint-Pierre, La Reunion using Andrew Marsh online tool [2].

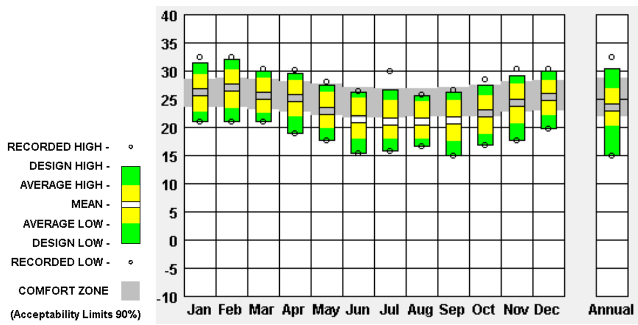


Figure 40: Temperature range by month for Saint-Pierre, La Reunion (Source: Climate consultant – Adaptative Comfort model).

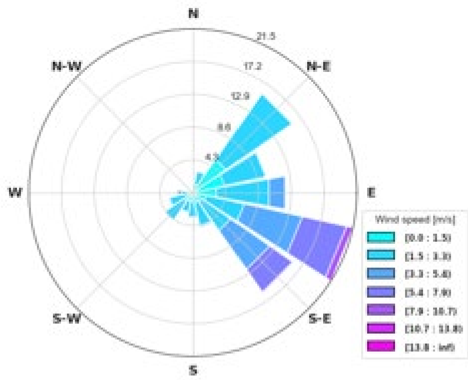


Figure 41: Wind rose for Saint-Pierre, La Reunion (Beaufort wind scale).

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **3 933** Wh/m² (Jun) Max: **7 580** Wh/m² (Dec) Mean: **5 750,25** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **9** CDD 10°C: **4977**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **158** CDD: **8**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **20** CDD 26º: **171**

KEY BIOCLIMATIC DESIGN PRINCIPLES [2][3]	
Passive cooling strategy	**Comfort ventilation** (natural cross ventilation) All the classrooms and offices are naturally ventilated. This was made possible thanks to the design of a simple, elongated and thin building form, the optimal orientation of the building, the general interior organization of the classrooms as well as the use of full-height **glass louvers** located on opposite facades, with a high porosity.
Passive heating strategy	None
Solar protection	Solar and climatic protection of indoor and outdoor spaces are provided by the large roof that acts as a canopy and covers the various built volumes and unbuilt spaces, as well as different solar protection strategies for each orientation. Bioclimatic pergolas placed in the courtyards also create shaded spaces that serve both as a friendly playground area and as a climate refuge.
Building orientation	The main facades of the building are oriented NW/SE. Urban issues and the need to fit into the site were of course predominant in the building's layout. However, they were able to combine with a satisfactory solar exposure (even if not completely optimal) and with an orientation very favourable to thermal breezes.
Insulation	Thermal and acoustic insulation of the roof are ensured by a double-skinned reflective metal cover and two green roofs.

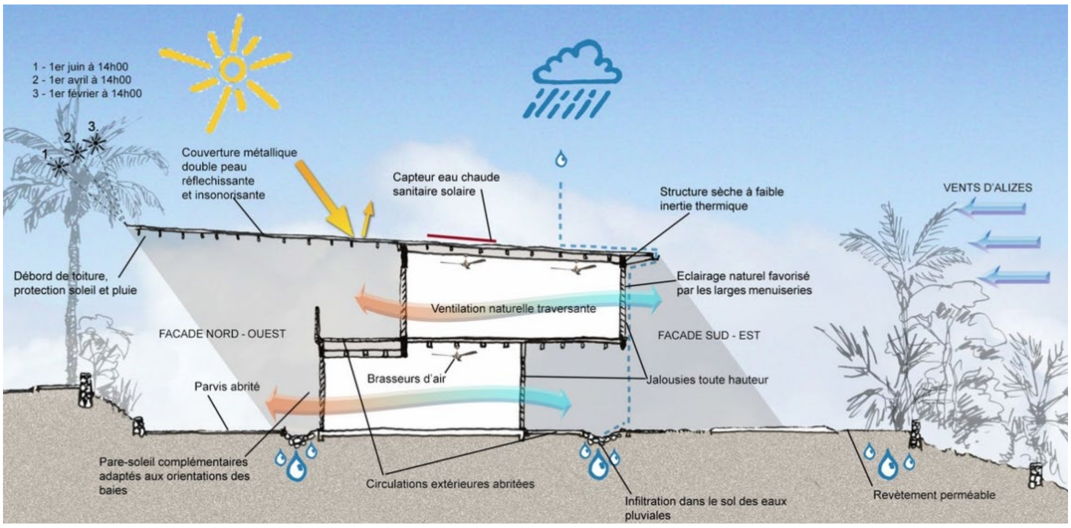


Figure 42: Cross section of the passive solutions set up for the school. © Antoine Perrau Architectures

Vegetation	The vegetation is used as a design element aiming, through omnipresent gardens designed on the forest model, at hygrothermal comfort, visual comfort and air quality by dust filtration. The gardens also contribute to the pleasantness of the place. The vegetation at the interface of Vergés Avenue provides protection from the prevailing east/southeast winds. Endemic species were chosen for their ability to adapt to the local climate and thus limit the need for watering and maintenance.
Natural daylighting	Daylighting autonomy during school hours is maximize thanks to thin buildings, reflective ceilings and full-height louvers on both facades.
Use of local and embedded materials	None. The choice of a "dry" wood-frame architecture has been considered as a relevant response to the issues of hygrothermal comfort. The use of concrete was restricted to the infrastructure and the dining room for structural and maintenance reasons.
Water saving and flood management	Management of rainwater by infiltration and temporization on the plot thanks to drainage ditches and embankments.
Waste management	Specific bins for recyclable waste (paper, cardboard, plastic and metal)
Others features	The choice of materials was determined by their durability, low maintenance and sanitary quality. The exterior materials are used raw and/or without paint: Class IV pine frame, Douka (exotic wood) cladding and decking, thermo-lacquered composite panel cladding, natural aluminum finish roofing and rubble stone cladding. For the interior materials, the choice of healthy products was privileged: Acrylic-based interior paints without VOCs (organo-volatile compounds), rubber floors recognized for their low VOC emissions, plasterboard partitions (hygrometry regulation quality).

(a) (b) (c)

Figure 43: Different solar protection strategies have been set up according to the orientation of the facades: (a) The umbrella roof is the key feature of the project, (b) Vertical textile sunshades on metal frame in front of the primary classrooms and composite cladding in front of the dining room, and (c) Double skin with horizontal wood strips on the facade of the kindergarten classes (N-W) on pedestrian pathway. © Hervé DOURIS

Figure 44 : Wooden pergola and trees in the kindergarten playground.

Figure 45: View on the second-floor exterior corridors.

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: 5 bike racks** If yes, Ratio with number of users: -
Ceiling fans	In every room, even those conditioned: **Yes**
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.: **No**
BUILDING FABRIC AND MATERIALS	
Roof	The **umbrella roof** is composed of (from outside to inside): ▪ Steel roofing sheet [0.04m] (COVERIB, Ondulit) ▪ Air gap [0.06m] ▪ Double-sided pre-painted galvanized steel ribbed sheet [0.04m]
Windows	Type of materials: Clear glass louvers – different height [1.9m, 2.40m or 2.90m]
	Window-to-wall ratio (WWR): - (% of glazed area)
Walls	The majority of the **Exterior walls** are composed of (from outside to inside): ▪ Composite cement siding (HardiePlank type) [0.022m] ▪ Counter batten section 25/40 mm (treated pine) ▪ Rainscreen film ▪ Timber frame 58/168 mm (treated pine) with 0.1-68 m of rock wool ▪ FERMACELL panel [0.0125m]
	The **Interior Walls** are structured as: ▪ FERMACELL panel [2 × 0.0125m] ▪ Timber frame 46/120 mm (in treated pine) with 0.12m of rock wool ▪ FERMACELL panel [2 × 0.0125m]

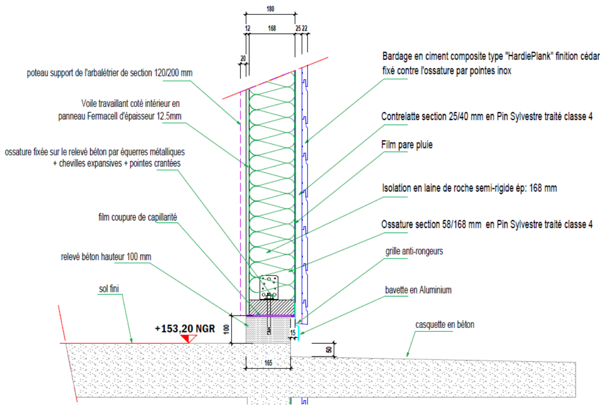


Figure 46: section of the exterior wall of the first floor of the primary school. © Antoine Perrau Architecture.

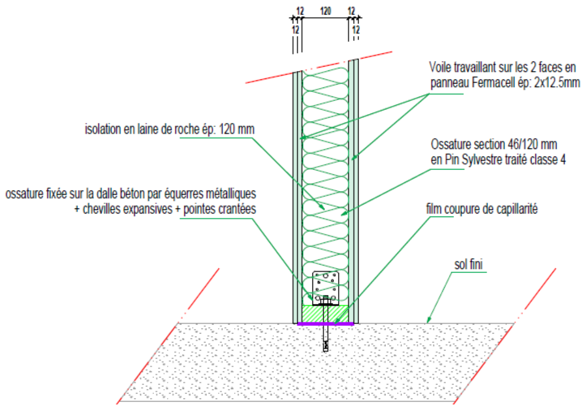


Figure 47: section of the partition walls.© Antoine Perrau Architecture.

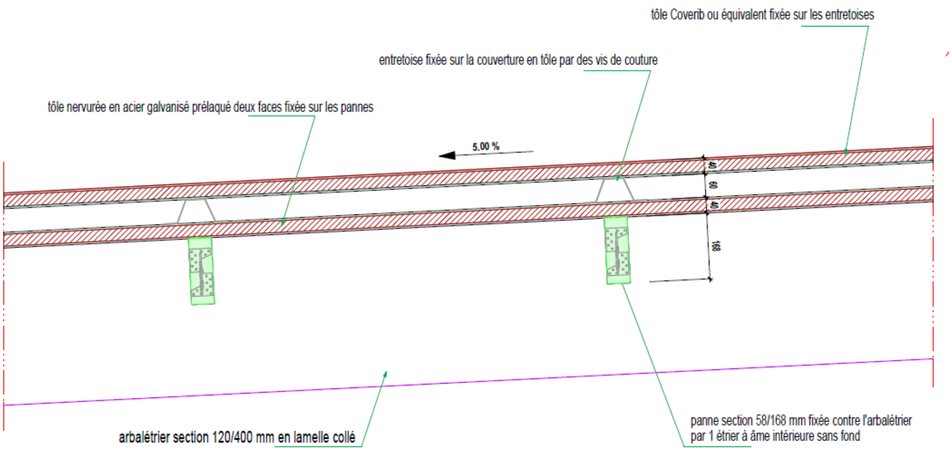


Figure 48: section of the umbrella roof. © Antoine Perrau Architecture.

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	Only the IT and technical room are air-conditioned thanks to energy efficient split systems (European energy efficiency category: A+ / EER (Energy Efficiency Ratio) measured by Eurovent superior to 3.4)
Low-energy heating systems	None
Ceiling fans	**Brand / Model: Hunter Carera -** Model 24241 A total of **88 ceiling fans** with a **132 cm blade diameter** are installed in the offices, the classrooms and the canteen. The use of ceiling fans guarantees additional air speed during windless days. They are used in conjunction with the comfort ventilation strategy to create air movement on the skin of the occupants, increasing their comfort. The **maximum power** used for one ceiling fan is **67 W**, with a ratio of **one ceiling fan per 10-15 m².** Ceiling fans have **three speed levels** and a **maximum speed of 190 Rpm.**
Mechanical ventilation / air renewal	The principle of ventilation/ air renewal retained is as follows: ▪ comfort ventilation of the premises (preferred solution) through the openings,

	▪ specific ventilation of the pantry and the laundry by mechanical extraction through a hood, ▪ ventilation by single flow mechanical extraction of the checkrooms and the kitchen storerooms.
Domestic Hot Water	The hot water needs are covered by: ▪ A solar hot water production system for the kitchen and the restaurant; ▪ Instantaneous electric water heaters for the other needs, such as the cleanliness room or the locker rooms.
Artificial lighting	Fluorescent and LED lights have been installed depending on the type of rooms and usage. The installed electric density for artificial lighting ranges from 8 to 11 W/m^2. The exterior lighting is provided by luminaires controlled automatically by a twilight switch and programmable timer with the possibility of manual control from the administration building.
Control and energy management	None

Figure 49: All classrooms are naturally ventilated and equipped with efficient ceiling fans. © Hervé DOURIS

Figure 50 : Interior view of the school canteen. © Hervé DOURIS

Figure 51 : View of the full-height glass louvers from the exterior corridor

Figure 52 :View of the green roof

RENEWABLE ENERGY	
PV	None
Solar thermal	Solar thermal panels, totalling 30 m², ensure the supply of hot water in the kitchen and the restaurant.
Wind	None
Geothermal	None
Biomass	None

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

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 1 m/s: **Ground Floor: 90-95 %** **First floor: 24-70%**
6. Percentage of time inside the Givoni comfort zone of 0 m/s: **Ground Floor: 0 %** **First floor: 0%**

7. Number of hours within a certain temperature range: **Hot period (26th Feb. to 12th March 2022) / Occupation time: 8:00am to 4:00pm**

	GROUND LEVEL							
	E1		E2		E4		E5	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
T<22°C	0	0%	0	0%	0	0%	0	0%
22°C≤T<24°C	0	0%	0	0%	0	0%	0	0%
24°C≤T<26°C	1	1%	1	1%	0	0%	2	1%
26°C≤T<28°C	45	33%	55	41%	43	32%	102	76%
28°C≤T<30°C	85	63%	78	58%	86	64%	31	23%
30°C≤T<32°C	4	3%	1	1%	6	4%	0	0%
32°C≤T<34°C	0	0%	0	0%	0	0%	0	0%
34°C≤T<36°C	0	0%	0	0%	0	0%	0	0%
T≥36°C	0	0%	0	0%	0	0%	0	0%

	FIRST LEVEL							
	P1		P3		P4		P5	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
T<22°C	0	0%	0	0%	0	0%	0	0%
22°C≤T<24°C	0	0%	0	0%	0	0%	0	0%
24°C≤T<26°C	0	0%	1	1%	0	0%	0	0%
26°C≤T<28°C	3	2%	15	11%	23	17%	5	4%
28°C≤T<30°C	32	24%	**94**	70%	**82**	61%	42	31%
30°C≤T<32°C	**72**	53%	**24**	18%	27	20%	**85**	63%
32°C≤T<34°C	**28**	21%	1	1%	3	2%	**3**	2%
34°C≤T<36°C	0	0%	0	0%	0	0%	0	0%
T≥36°C	0	0%	0	0%	0	0%	0	0%

ABC21 is funded by the EU's H2020 programme

Energy performance indicators	1. Energy needs for heating (kWh/y/m2)
	2. Energy needs for cooling (kWh/y/m2)
	3. Energy use for lighting (kWh/y/m2)
	4. Energy needs for Sanitary Hot water (kWh/y/m2)
	5. Total Primary energy use: **89 [kWh/m^2/year] (total Primary Energy Factor (PEF) equal to 3.3 for electrical energy from the grid)**
	6. Renewable Primary energy generated on-site (kWh/y/m2)
	7. Renewable Primary energy generated on-site and self-consumed (kWh/y/m2)
	8. Renewable Primary energy exported to the grid: **0 [kWh/m^2/year]**
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation) (%)
	10. Delivered energy (from electricity bills): **27 [kWh/m^2/year]**
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	No POE has been conducted for this school, but we had some negative feedback from the teachers, specifically for the classrooms at the first floor. Two classrooms present uncomfortable indoor conditions due to the lack of solar shadings of the South-East facades coupled with a bad insulation of the roof. Users complain about the hot conditions of work in summer. They complain as well about the too important air movements in the classrooms.

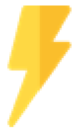
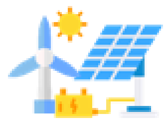
LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	Overall, the classrooms at the ground level are comfortable with comfort conditions that are reached 90% of the time during the hot season. Despite the bioclimatic and passive design of the school, the measurement campaign has pointed out a bad thermal behaviour for all the classrooms at the first level that lead to higher air temperatures and dissatisfaction. Comfort conditions in those classrooms are reached only 25%-40% of the time only.
Recommendations	It is recommended:

- to improve the insulation of the roof;

- to install horizontal solar shadings for the classrooms located at the first-floor level that are exposed to solar radiation.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

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

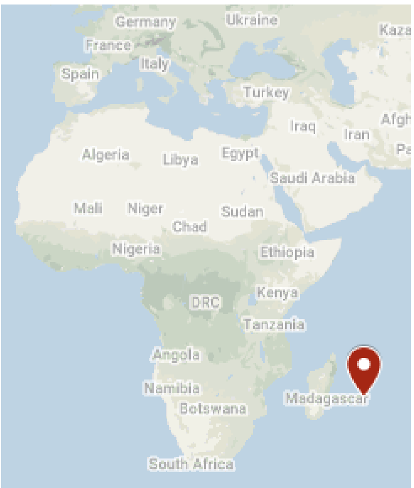
Weaknesses

Lack of efficient solar shading systems for 2 classrooms facing SE, at the second floor and low insulation of the roof.

REFERENCES

1. https://labreunion.fr/projets/ecole-aime-cesaire/
2. https://www.construction21.org/france/case-studies/h/groupe-scolaire-de-bois-d-olives.html
3. https://www.envirobat-reunion.com/SPASSDATA/ALGEDIM/QOKQWR/D717/D71755.pdf

CASE STUDY 2-04: ESIROI BUILDING | LA REUNION



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	40 avenue de Soweto, Saint-Pierre, La Réunion, France
Latitude; Longitude	-21.340362377393678, 55.49108279968073
Climate zone (Köppen–Geiger classification)	Aw: Equatorial savannah with dry winter
BUILDING INFORMATION [1][2]	
Building Type	Educational - University
Project Type	New construction
Completion Date	2020
Number of buildings	1
Number of storeys	5
Total Floor Area (m²)	-
Net Floor Area (m²)	3 531
Thermally conditioned space area (m²)	1 461 m^2 (only air conditioning: 651 m^2 / air conditioning and ceiling fans: 810m^2)
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	2 070
Total cost (€)	10 171 145 €
Cost /m² (€/m²)	2 618.1
Performance Standards or Certification	PREBAT-REUNION approach - A quality approach which rewards buildings with low environmental impact, supported by ADEME Réunion.
Awards	None
STAKEHOLDERS [2][3]	
Building Owner/ Representative	University of La Reunion
Architect / Designer	LAB Réunion
Assistance to the contracting authority	SODIAC
Thermal consultancy	LEU Réunion

Environmental consultancy	LEU Réunion
Structural Engineer, Civil Engineer	A3 Structures
MEP consultancy	INSET SUD
Others	CREATEUR (roads and services infrastructure), Delhom Acoustique (Consulting firm in acoustics)

PROJECT DESCRIPTION

Figure 53 : Exterior view of the eastern façade.

Figure 54 : Exterior view of the western façade.

The new building of the ESIROI (Ecole Supérieure d'Ingénieurs Réunion Océan Indien) houses all the courses offered by the engineering school, i.e., the Integrated Preparatory Cycle (CPI) and its three engineering cycle specialties (Agri-food, Computer Science and Telecommunications, Building and Energy). One wing of the building also accommodates an extension of the IUT (University and Technological Institute) located on the same campus.
The bioclimatic approach is directly inspired by traditional "Creole" architecture: Protection from the sun, comfort ventilation and vegetation.
Through its aeraulic operation optimized thanks to studies in a physical wind tunnel, the choice of a mixed metal / light wall structure alternative to all-concrete, and the importance of vegetation within the project, ESIROI demonstrates local knowledge in bioclimatic design with low environmental impact to the future engineers who will be trained there.

SITE INTEGRATION

Figure 55 : Aerial view of the building in its surrounding environment.

The new building of the ESIROI is located on the Terre Sainte university campus, in Saint Pierre, La Reunion, which hosts different university buildings, such as ENERPOS and the modules of the IUT. The building is erected on rocky grounds with a steep slope towards the sea and the lateral ravines. The premises are surrounded by native plants and benefit from the vegetation of the nearby ravine.
The site is isolated from the "urban" fabric of the town of St Pierre but it is well served by public transportation and easily accessible by car.

CLIMATE ANALYSIS

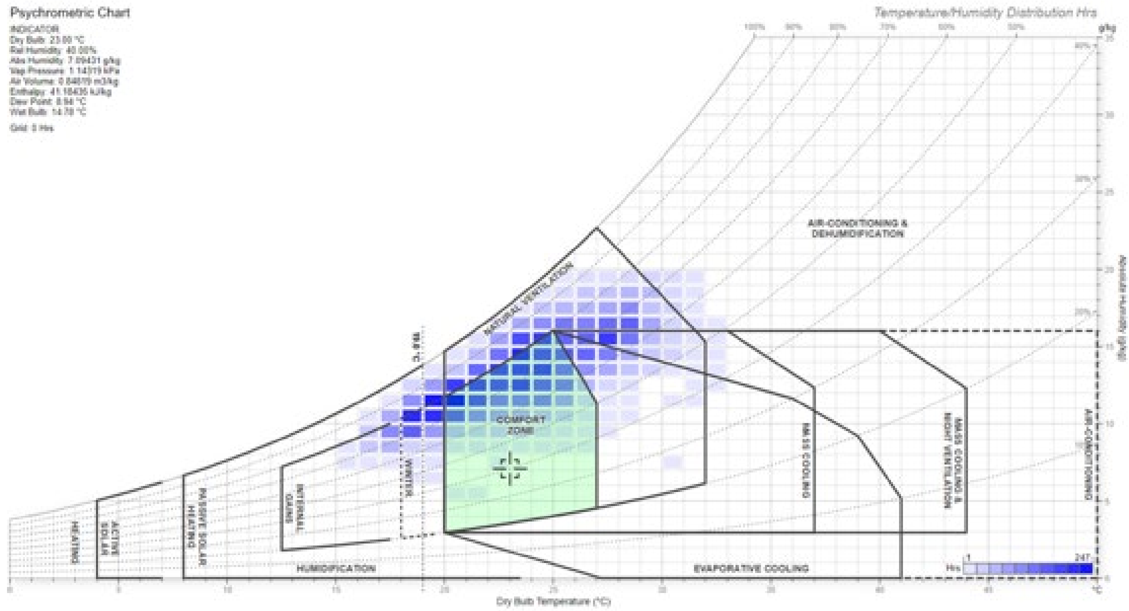


Figure 56: Givoni Bioclimatic chart for the climate of Saint-Pierre, La Reunion using Andrew Marsh online tool [2].

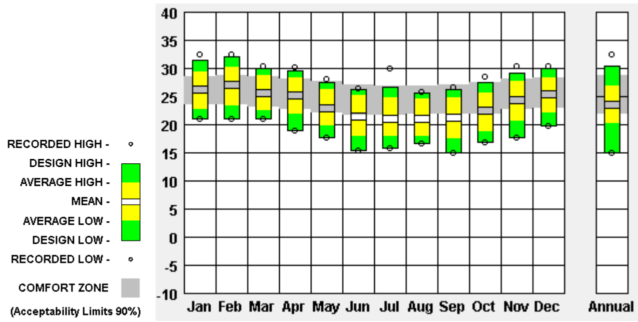


Figure 57: Temperature range by month for Saint-Pierre, La Reunion (Source: Climate consultant – Adaptative Comfort model).

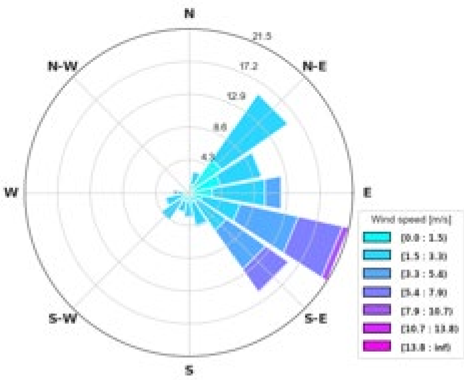


Figure 58: Wind rose for Saint-Pierre, La Reunion (Beaufort wind scale).

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **3 933** Wh/m² (Jun) Max: **7 580** Wh/m² (Dec) Mean: **5 750,25** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **9** CDD 10°C: **4977**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **158** CDD: **8**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **20** CDD 26º: **171**

KEY BIOCLIMATIC DESIGN PRINCIPLES [2]	
Passive cooling strategy	**Comfort ventilation** (natural cross ventilation and night ventilation) The shape of the building itself, in a "C" shape, optimises the phenomenon of pressure/depression, the driving force behind natural ventilation. The passive solutions for ventilation include large openings manually adjustable by users on opposite sides of the building to create cross-currents of air and vacuum well systems. Airflow engineering played a pivotal role in validating, optimising and dimensioning the comfort ventilation principle of the premises. The airflow design has been validated by using a wind tunnel testing facility (Eiffel laboratory).
Passive heating strategy	None
Solar protection	Limitation of thermal overheating of the rooms thanks to different solar protection such as detached horizontal solar shading systems (1m from the facade) in aluminium, wooden strips and the large roof canopy. The external common areas are also protected from the sun by the use of these tensioned canvas. This system required the roof structure to be sized to withstand possible cyclonic seasons.
Building orientation	From the beginning of the project, important thought was given to the orientation of the building, to take advantage of the intensity of the prevailing winds in the hot season, and to minimise it in the cool season. In addition, the work on the orientation makes it possible to create "blind" gables to the east and west, limiting solar gain on the façades.
Insulation	The roof is insulated thanks to 10 cm insulating material. No insulation for the exterior walls.
Vegetation	Dense vegetation around and inside the building to take advantage of all the benefits of vegetation such as evapotranspiration, shading, dust absorption. Creation of a vegetated roof terrace above the IUT extension and all the advantages linked to such a choice (roof insulation, limitation of the project's impermeability, rainfall temporisation upstream of the outlets, etc.).

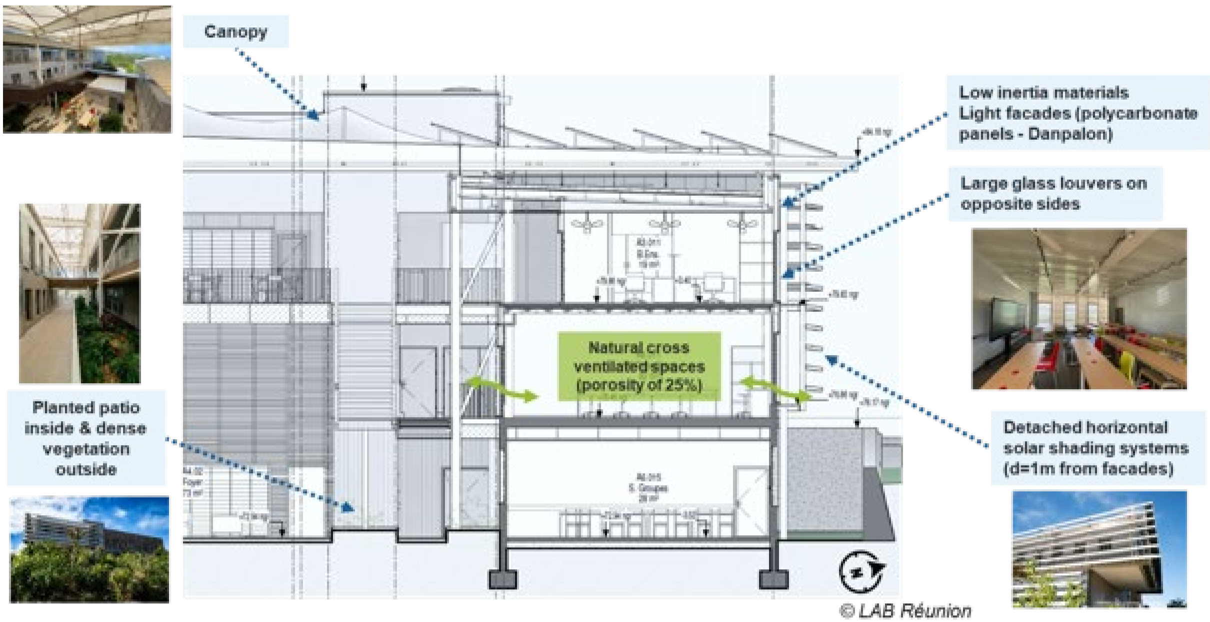


Figure 59: Cross section of the bioclimatic strategies implemented in the ESIROI building. The main strategies include natural cross ventilation, low inertia materials, efficient solar shading systems, dense vegetation and efficient ceiling fans in all rooms.

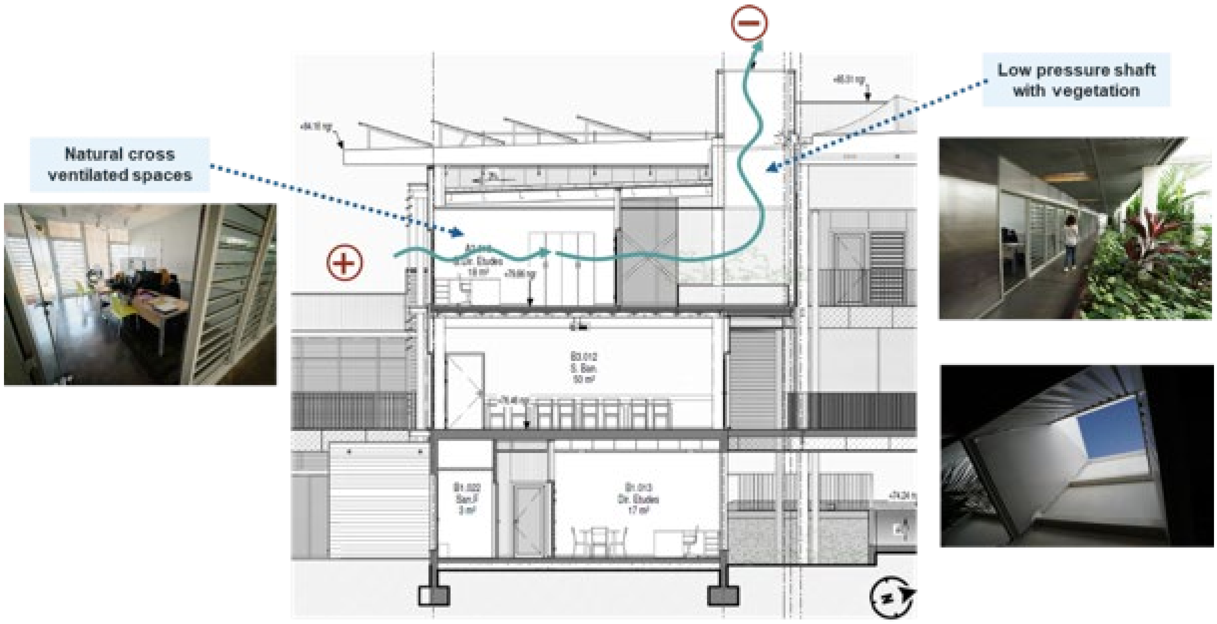


Figure 60 : Cross section of the low-pressure shaft principle, with the vegetated interior patio and the full height glass louvers.

Natural daylighting	An innovative **translucent material** was used in the façade to take advantage of natural light in addition to the large windows. Indeed, Danpalon® panel is developed from a high-quality synthetic material, polycarbonate, and its performance is certified by certification bodies. Its translucency allows excellent light transmission, which reduces the amount of artificial lighting required in the premises. In cold weathers It can be installed in systems made by two panes (Danpatherm), similar to double glazing units, with thermal transmittance down to 0,5 W/(m^{2}K)
Use of local and embedded materials	None. Choice to use mixed materials as an alternative to the all-concrete project in order to reduce greenhouse gas emissions. The upper parts of the building are made of metal structures and light facades.
Water saving and flood management	The outdoor gardens contribute to rainwater management. The idea is to limit as much as possible the creation of buried networks by keeping as much as possible on the surface the path of the drop of water which expresses itself and is thus understood through the landscape. Thus, obstacles to the planted areas calibrated to receive water will be avoided. The soils will be composed of mixtures of topsoil, earth and stone and cyclopean blocks in order to increase the temporization of the water while being favourable to the clinging of the plants.
Waste management	Specific bins for recyclable waste (paper, cardboard, plastic and metal)
Others features	▪ Work on thermal zoning: Grouping of rooms with the same cooling strategy. ▪ The possibility for users to access the building by soft modes of transport such as **cycling or walking**, thanks to the presence on site of **changing rooms equipped with showers, individual secure lockers** as well as adapted parking spaces for vehicles. ▪ Installation of efficient equipment to reduce internal thermal loads. ▪ Four EVBOX Type 2S charging stations for electric vehicles have been installed in the R-2 parking lot, with two outlets per station. The installed power is 61,4 kW.

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** If yes, Ratio with number of users: **0.04** *(11 outdoor bike racks for 300 users)*
Ceiling fans	In every room, even those conditioned: **Yes**
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.: **No** However, all users are made aware of the environmental aspects of the project through technical visits of the site to each class of students and administrative staff members.

(a) (b)

Figure 61: Different solar protection strategies have been set up such as (a) detached horizontal solar shading systems in aluminum and (b) wooden strips

BUILDING FABRIC AND MATERIALS	
Roof	The **PV roof** is composed of (from outside to inside): ▪ PV over-roof ▪ Glass wool insulation [0.10m] ▪ Metal roof panels U-value= 0.37 [W / m²K] Overall R-value: 2.5 [m^2K/W]
	The **terrace roof** is composed of (from outside to inside): ▪ Waterproofing ▪ Glass wool insulation [0.10m] ▪ Concrete [0.23m] U-value= 0.35 [W / m²K] Overall R-value: 2.63 [m^2K/W]

	The **sheet metal roof** is composed of (from outside to inside): ▪ ONDULIT Steel Roofing System ▪ Glass wool insulation [0.10 m] U-value= 0.45 [W / m²K] Overall R-value: 2.0 [m^2K/W]
Windows	Louvered windows of different dimensions Type of materials: clear glass Thickness: 0.006 m
	Window-to-wall ratio (WWR): Superior to **20%** for the naturally ventilated rooms.
Walls	The majority of the **exterior walls of the offices and classrooms** are composed of DANPALON® polycarbonate panels.
	Thickness= 0.016m U-value= 1.9 [W / m²K] Overall R-value: 0.53 [m^2K/W]

(a) *(b)*

Figure 62 : (a) Aerial view of the canopy and (b) view of the canopy from the inside.

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	The classrooms and offices on the upper floors are naturally ventilated, with the use of fans when necessary. The practical rooms and laboratories equipped with state-of-the-art professional equipment are air-conditioned and located on the lower levels of the building. Some rooms are in mixed-mode, i.e., air-conditioning and fans. The production of cold water is carried out by a LENNOX chiller (Model Ecomfort) with its hydraulic station (D+ Edrive), with a **maximum power** of **82.4** kW and an European seasonal energy efficiency ratio (**ESEER**) of **4.19.** Wall-mounted monosplit units are installed in the storage rooms. Three models from the Airwell brand are used for this emergency cold production, with different power (0.9kW, 1.15 kW and 1.75 kW). The units switch on automatically at night when the chiller is switched off and they switch on during the day when the temperature rises more than 2°C above the set point after 10 minutes. Finally, chilled water terminals have been installed in the air-conditioned classrooms. Ducted units and indoor units, both from the Sabiana Brand and with a maximum power of 139 kW, are present in the various rooms.
Low-energy heating systems	None

Ceiling fans	**All offices and classrooms** are equipped with efficient **ceiling fans.** Two high performance air movers for large volumes have also been installed to improve comfort in **external common areas**. The use of ceiling fans guarantees additional air speed during windless days. They are used in conjunction with the comfort ventilation strategy to create air movement on the skin of the occupants, increasing their comfort. The mean surface covered by a ceiling fan is equal to 12.5 m^2. With the exception of 8 premises, the ceiling fans are designed for surfaces between 9 and 15 m². The outcome of the French PREBAT program recommends 1 fan for 15 m^2.
	**1. Brand / Model: Hunter / Industrie II** a. Where: offices and classrooms b. Number: 158 c. Diameter: 132 cm d. Maximum power: 66 W e. Others: 3 speed levels / maximum speed of 157 Rpm.
	**2. Brand / Model: Hunter Industrial ECO HVLS fan** a. Where: Exterior common areas b. Number: 2 c. Diameters: 305 cm (10ft) and 488cm (16ft)
Mechanical ventilation / air renewal	The air treatment is composed of: - an air treatment unit for the kitchen area and another one for the amphitheatre (SAIVER brand) ; - a ventilation system for the laboratories and practical rooms composed of 12 motorized fans for the extraction of the fume hoods, a compensation box and motorized dampers; - Two ventilation systems for fresh air and extracted air (VMC) of 0.2 kW.
Domestic Hot Water	In the building, there are three systems for the production of domestic hot water: - solar hot water, - centralised production by recovery from the chiller and - electric backup and instantaneous water heaters. The domestic hot water produced for the needs of the kitchen comes from a centralized solar production, composed of 10 m² of solar collectors installed on the roof of the building, and a 600L Cordivari tank with a heat exchanger and an auxiliary heating element. The second system is a heat recovery system produced by the chiller. The heat output recovered from the chiller is 28.2 kW. The chiller is equipped with a desuperheater for each refrigeration circuit, to which a primary network equipped with heat recovery is connected and feeds the recovery tank located in the technical room. The instantaneous DHW tanks are small, placed close to the needs and operate with an electric resistance. They are placed under the

sinks and benches of the cafeteria and the energy physics laboratory. These 4.5kW tanks are used for rooms far from the two other systems.

Artificial lighting

The building has several types of lighting equipment, such as:

- Suspended (for example Milena LED and SIGMA II LED from PXF LIGHTING and others);
- Surface mounted such as the Bari ECO DLN IP65 LED model from PXF LIGHTING and others;
- Ceiling recessed mounting (Start Flat Panel LED from SYLVANIA, GreenSpace Accent Gridlight model from PHILIPS and others)

All the lights installed are LED. This type of lighting is the most energy efficient with low consumption and long life. The installed electric density for artificial lighting is equal to 6.0 W/m^2.

Control and energy management

The ESIROI buildings and the IUT extension are equipped with three monitoring systems:

- Two electricity consumption monitoring systems: The first one composed of 10 energy meters installed at the output of the divisional panels and the second one based on detailed energy sub-metering by usage (interior and exterior lighting, plug loads, fans, etc.).
- A system for monitoring the consumption of air conditioning and ventilation operations: Input and output module to centralise information on the operation of the HVAC equipment, the air temperatures and relative humidity of certain rooms as well as the delivered energy of each conditioned zone.

Figure 63: Interior view of a typical classroom.

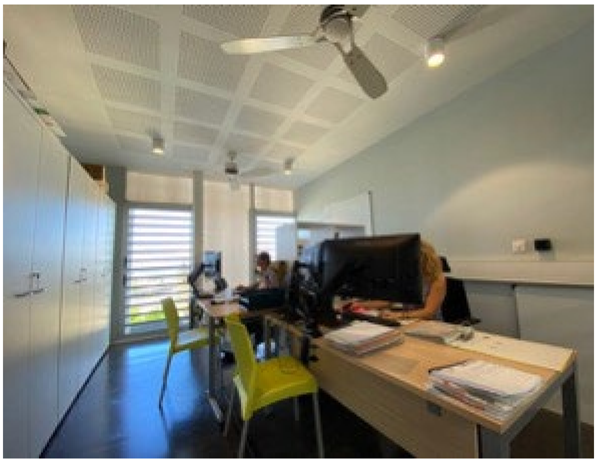


Figure 64 : Interior view of a typical office equipped with efficient ceiling fans and full-height glass louvers.

RENEWABLE ENERGY

PV

Brand: TRINASOLAR VERTEX S 395Wp - 253 PV modules

Technology: Monocrystalline silicon cells

Total area: 486.36 m²

Nominal power: 100 kWp

The slope of the PV cells is 15° for 2 roofs and 9° for the last one.

Solar thermal	Thermal solar panels are installed on rooftop of the building for the production of hot water. Total area: 10 m² of flat collectors
Wind	None
Geothermal	None
Biomass	None


Figure 65: Solar thermal and PV panels have been installed on the rooftop of the building.

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

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: **≥ 95%**
6. Percentage of time inside the Givoni comfort zone of 0m/s: **≥47%**
7. Number of hours within a certain temperature range:

1st March 2022 to 1st March 2023 Occupation time: 8:00am to 5:00pm	GROUND LEVEL				FIRST FLOOR LEVEL					
	Classroom A204		Classroom A207		Office A301		Classroom A313		Office A320	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
T<20°C	2	0%	4	0%	1	0%	1	0%	22	1%
20°C≤T<22°C	116	4%	249	8%	246	8%	153	5%	332	11%
22°C≤T<24°C	527	17%	572	19%	547	18%	676	22%	669	22%
24°C≤T<26°C	876	29%	835	28%	775	26%	787	26%	750	25%
26°C≤T<28°C	901	30%	1001	33%	896	30%	893	30%	746	25%
28°C≤T<30°C	536	18%	330	11%	510	17%	450	15%	454	15%
30°C≤T<32°C	61	2%	29	1%	45	1%	60	2%	44	1%
32°C≤T<34°C	1	0%	0	0%	0	0%	0	0%	3	0%
34°C≤T<36°C	0	0%	0	0%	0	0%	0	0%	0	0%
T≥36°C	0	0%	0	0%	0	0%	0	0%	0	0%

Energy performance indicators	1. Energy needs for heating (kWh/y/m2)
	2. Energy needs for cooling (kWh/y/m2)
	3. Energy use for lighting (kWh/y/m2)
	4. Energy needs for Sanitary Hot water (kWh/y/m2)
	5. Total Primary energy use: **178** [kWh/m²/year] for the ESIROI building only **244** [kWh/m²/year] for the whole building (ESIROI, the IUT (University and Technological Institute) the laboratories and kitchen). The total Primary Energy Factor (PEF) equal to **3.3** for electrical energy from the grid.
	6. Renewable Primary energy generated on-site: **52** [kWh/m²/year] from PV
	7. Renewable Primary energy generated on-site and self-consumed: **0** [kWh/m²/year]
	8. Renewable Primary energy exported to the grid: **52** [kWh/m²/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): **21%**
	10. Delivered energy = **54** [kWh/m²/year] for the ESIROI building only **74** [kWh/m²/year] for the whole building (ESIROI, the IUT (University and Technological Institute) the laboratories and kitchen).

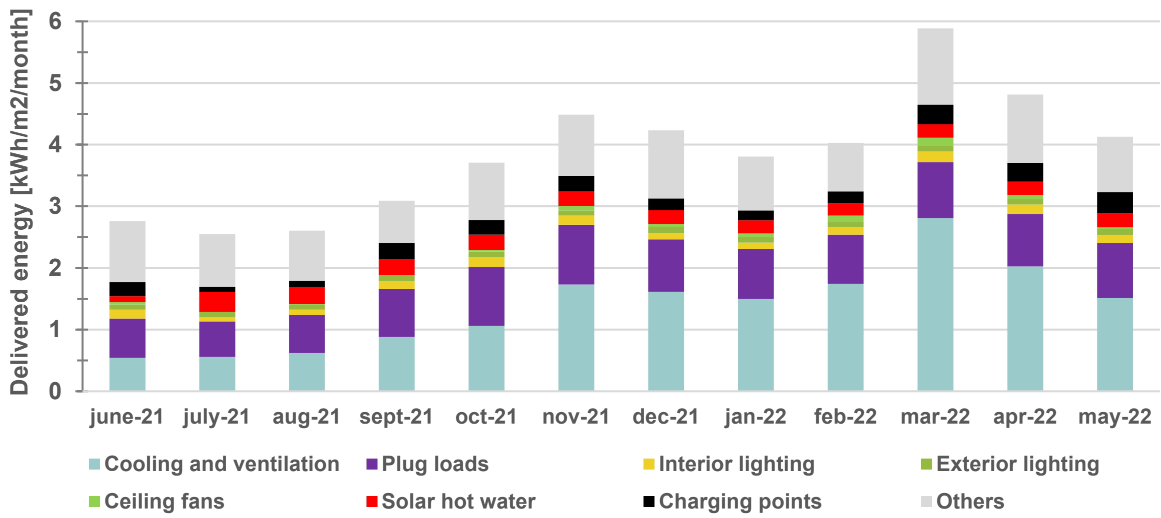


Figure 66: Monthly delivered energy by end-uses from June 2021 to May 2022 for the ESIROI building.

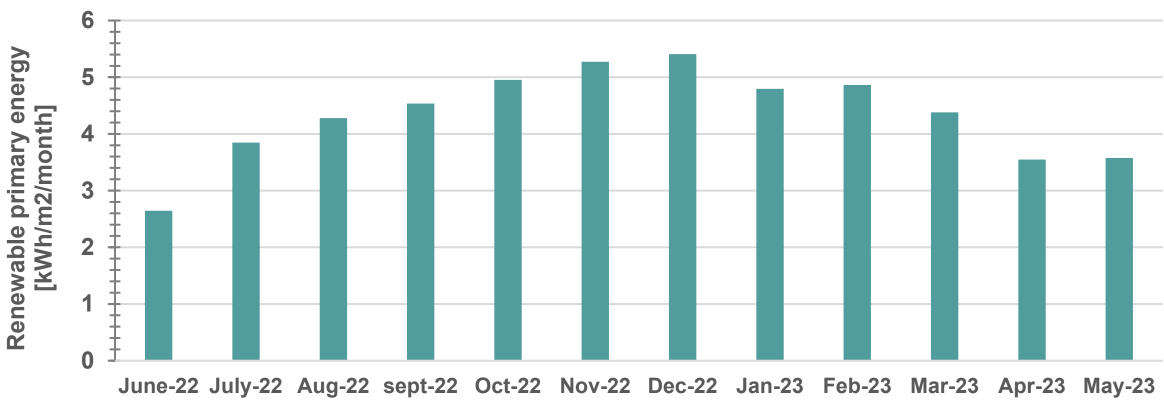


Figure 67 : Monthly primary energy generated on-site from PV for the years 2022-2023.

	1. Airborne sound insulation

ABC21 is funded by the EU's H2020 programme

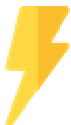
Acoustic comfort indicators	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	▪ Users are **overall satisfied** with the thermal comfort conditions in **summer** ▪ Users are **not satisfied** with the thermal comfort conditions in **winter,** which they consider **too windy and too cold.**

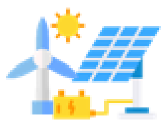
LESSONS LEARNED AND RECOMMENDATIONS

Lessons learned	▪ The management of comfort ventilation is as essential in summer as in winter. ▪ Ceiling fans play a pivotal role in summer comfort, especially for days without wind.
Recommendations	▪ To consider and optimise comfort ventilation both for summer and winter periods. ▪ To install efficient ceiling fans in all rooms and consider their maintenance. ▪ To draw inspiration from vernacular architecture.

BUILDING STRENGTHS AND WEAKNESSES

Strengths





Passive Design	Energy Efficiency	Renewable Energy

Weaknesses

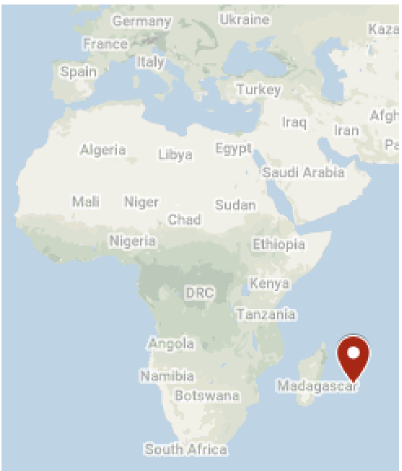
- Wind management in winter (lot of draughts)

REFERENCES

1. https://labreunion.fr/projets/esiroi/
2. https://www.construction21.org/france/case-studies/h/new-esiroi-premises-en.html

ABC21 is funded by the EU's H2020 programme

CASE STUDY 2-05: MALACCA FLORES | LA REUNION




© Hervé Douris

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Mail de l'Océan, Le Port, La Réunion
Latitude; Longitude	-20.938530579904032, 55.29597022970212
Climate zone (Köppen–Geiger classification)	Aw: Tropical savannah with dry winter
BUILDING INFORMATION [1][2]	
Building Type	Mixed – Residential, Offices and Shops
Project Type	New construction
Completion Date	2017
Number of buildings	Malacca: 3 Flores: 2
Number of storeys	7
Total Floor Area (m²)	-
Net Floor Area (m²)	8 780 (7 800 m^2 of housing areas and 980 m^2 of business premises surfaces)
Thermally conditioned space area (m²)	0
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	8 780
Total cost (€)	20 300 000
Cost /m² (€/m²)	2268.2
Performance Standards or Certification	The accommodations meet the recommendations of the local PERENE tool (acronym for Energy performance of buildings)
Awards	None
STAKEHOLDERS [2][3]	
Building Owner/ Representative	SIDR
Architect / Designer	AP architectures, 2APMR
Environmental consultancy	LEU Réunion
Structural Engineer, Civil Engineer	GECP

ABC21 is funded by the EU's H2020 programme

MEP consultancy	SOCETEM
PV engineering firm	TOP BIS

PROJECT DESCRIPTION [2][3]

Figure 68 : Exterior view of the Malacca Flores operation and the newly created axis towards the sea. (© Hervé DOURIS)

Figure 69 : Optimized solar shading devices, over-roofs and external passageways are architecturally integrated in the Malacca Flores project. (© Hervé DOURIS)

Delivered in late 2011, the two triangular islets Malacca and Flores belong to a large urban development project initiated by the city of Le Port for the requalification and the densification of its city centre. The compact programme induces a high density - 509 dwellings per hectare.
The five buildings of the operation are designed according to passive bioclimatic principles to provide 138 comfortable and energy efficient housing units (including 53 student apartments, 24 social rented housings and 61 intermediate rental housings).
On the ground floor services and businesses: tax office, post office and a restaurant.
In the North, 3 buildings make up the Malacca residence while in the South, Flores consists of two buildings, all crossed by vegetation. The whole operation is strictly drawn, with sharp base, dressed basalt stones, currents floors with varied treatments and a crowning of attics, types of houses in duplex overlooking. Fractionation of high volumes partially mitigates the perception of height. Both plots with diverse orientation raise the issue of the management of the sunshine on the directions east and west. The answers vary depending on the orientation and berries to protect: louvered verandas, corridors deported, caps, vertical blades. The car park is under the building for convenience of access and comfort reasons, allowing the building to be surrounded by green spaces.

SITE INTEGRATION [3]

Figure 70 : Aerial view of the building in its surrounding environment. (Source: Google Map)

The housing projects Malacca and Flores are designed as an urban complex and forms the entrance of the development zone Mail de l'Ocean, which aims to open the city to the port. It is located in a dense area of the city centre, on a rectangular plot split in half diagonally. The project therefore proposes a simple functional organisation with the creation of legible and identifiable entities, easily appropriable, distributed in two blocks facing each other: To the south, Flores is organised into two buildings linked by a break that integrates vertical movements. To the north, Malacca is divided into 3 buildings to meet the requirements of alignment and the breakthrough (public green space) towards the rue de Montpellier.

CLIMATE ANALYSIS

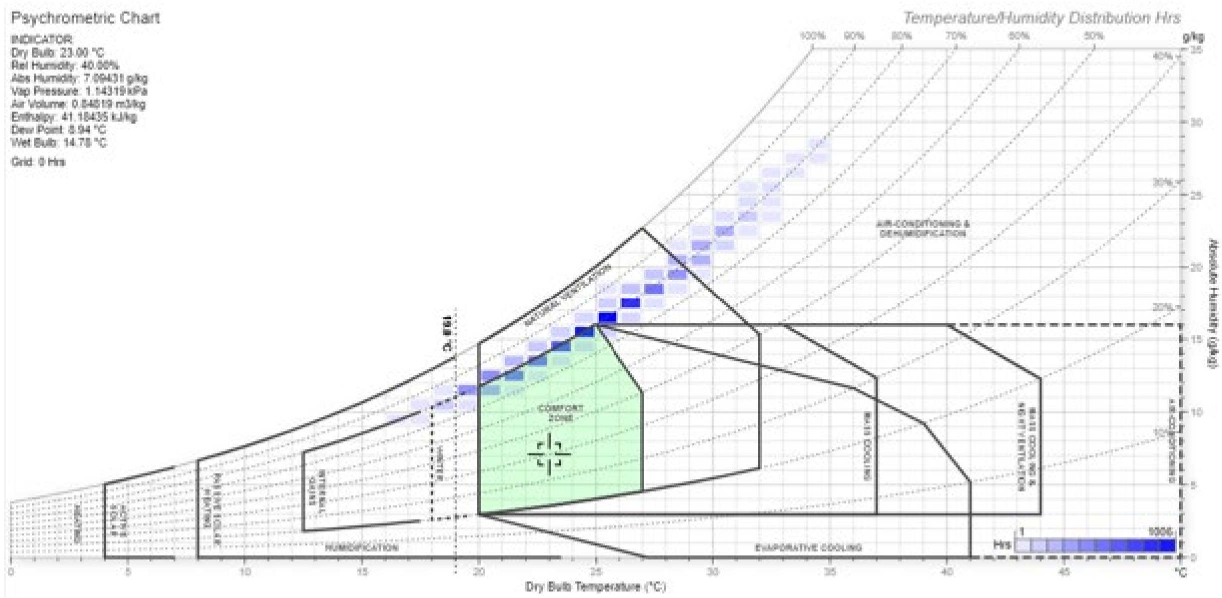


Figure 71: Givoni Bioclimatic chart for the climate of Le Port, La Reunion using Andrew Marsh online tool [2].

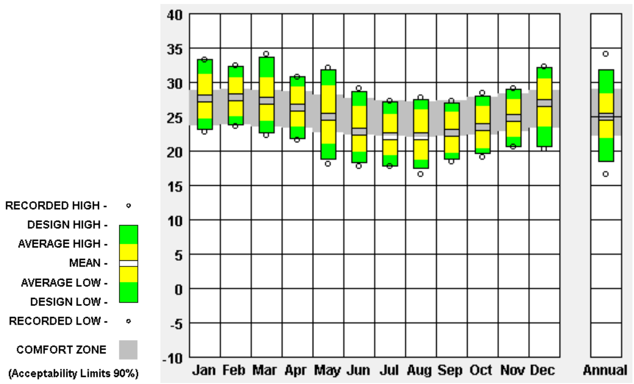


Figure 72: Temperature range by month for Le Port, La Reunion (Source: Climate consultant – Adaptative Comfort model).

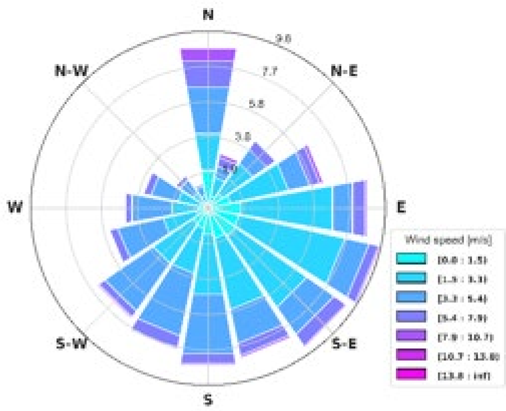


Figure 73: Wind rose for Le Port, La Reunion (Beaufort wind scale).

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **3 809** Wh/m² (Jun) Max: **6 133** Wh/m² (Dec) Mean: **5 048** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **0** CDD 10°C: **5 447**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **71** CDD: **25**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **1** CDD 26º: **294**

ABC21 is funded by the EU's H2020 programme

KEY BIOCLIMATIC DESIGN PRINCIPLES [2][3]	
Passive cooling strategy	**Comfort ventilation** (natural cross ventilation) Cooling is performed by natural ventilation combined with the evapotranspiration induced by the omnipresent native vegetation: all housing units are cross naturally ventilated and equipped with louvered windows; offices and shops are equipped with fans and the breakdown of the buildings facilitates the air flow at the scale of the building block.
Passive heating strategy	None
Solar protection	Solar shading is achieved by various architecturally integrated features designed according to the orientation of the facades, the views and the openings to protect: louvered porches, shading external passageways; horizontal blinds, vertical fins, trellised screens, over-roofs with wide overhangs. The design and optimisation of the solar shading devices were performed thanks to dynamic solar simulation using the Sketchup tool. The design of the various solar shading devices is adapted according to the orientation of the façade and the room operation.
Building orientation	The buildings are orientated facing the dominant wind for natural cross ventilation.
Insulation	PV panels and solar thermal collectors are integrated to the over-roofs which are used for shading the roofs of the buildings and limiting the adverse thermal gains through material conduction. East and West facades are thermally protected with wooden cladding. A reflective cladding is also installed and allows reflects up to 90% of the solar radiation.

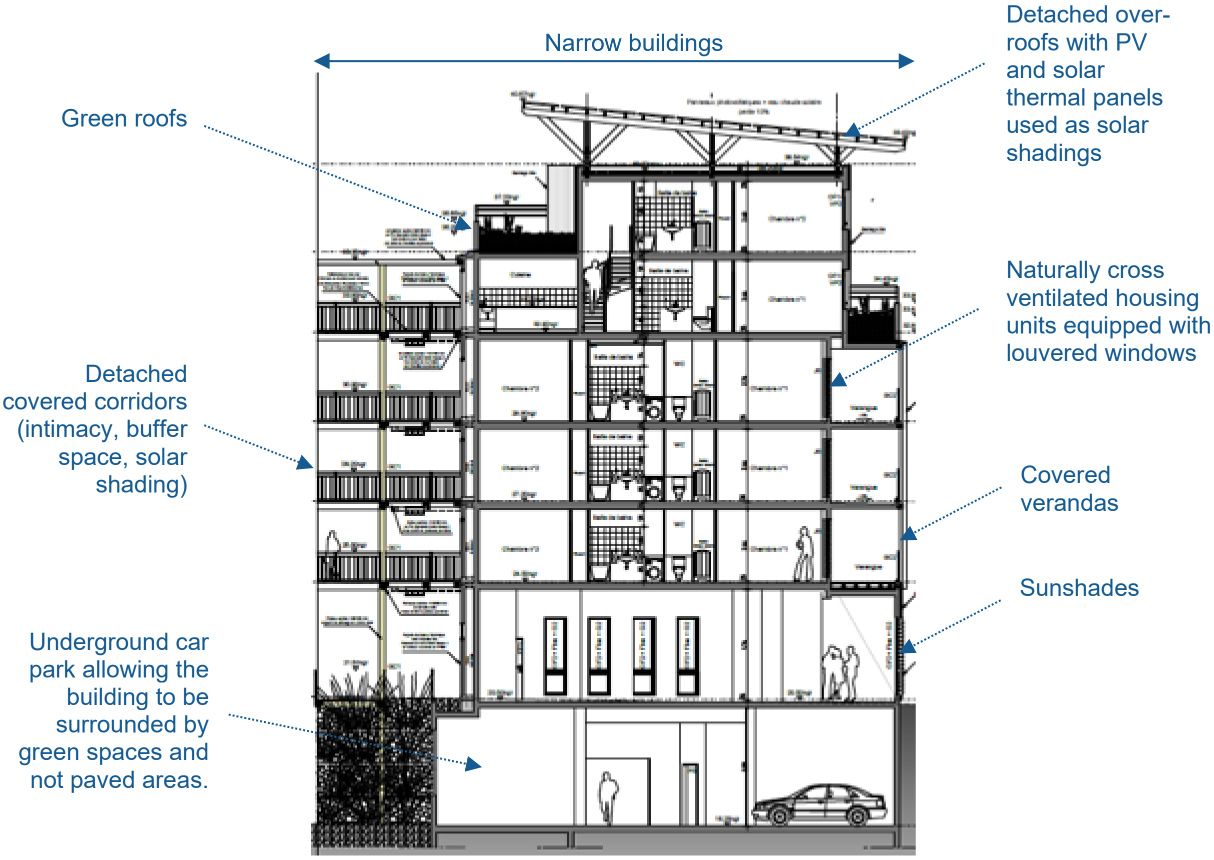
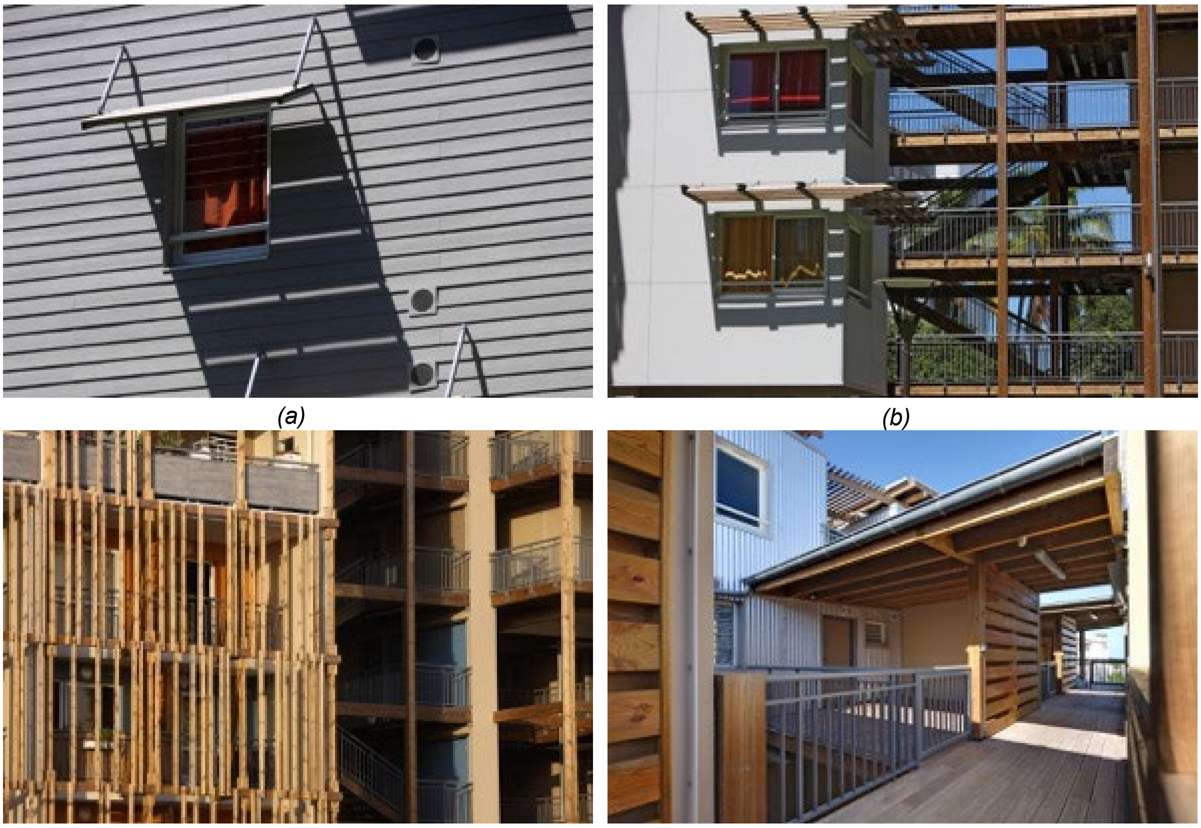


Figure 74: Cross-section of the main bioclimatic principles implemented. © Antoine Perrau Architectures

Vegetation	The greening of buildings around is dense and based on a plant palette rich in endemic dry area. Indeed, the permeable spaces in the centre of the operation and on the periphery represent 24% of the land area (650 m^2) that are planted with trees and shrubs. The building also includes flat roofs and some green walls. As far as possible, the feet of the facades are planted with species adapted to the environment, requiring little watering and maintenance.
Natural daylighting	Natural lighting is favoured in all spaces (housing and external traffic). The dwellings all benefit from large bay windows necessary for good natural ventilation, and these large windows also contribute to the comfortable lighting of the living areas.
Use of local and embedded materials	Perennial materials were chosen for their intrinsic qualities in a setting simple and consistent work. The choice was also focused on safe building products for health, benefiting labels. This includes wood (pine class IV), ONDULIT sheet panels and fibre cement siding. To reduce the green gas emissions related to construction materials, wood is widely used and integrated in the project: structure, over-roofs, pergolas, passageways, decks, solar shadings, façade cladding.
Water saving and flood management	Rainwater harvesting and temporisation by infiltration and overflow to the network; Recovery of grey water from the communal laundry room and part of the dwellings for watering the adjoining public gardens by means of a pit and a landfill.
Waste management	Building waste was sorted in order to reduce the environmental impact of the construction of the buildings. The buildings are equipped with specific bins for recyclable waste (paper, cardboard, plastic and metal).

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** If yes, Ratio with number of users: -
Ceiling fans	In every room, even those conditioned: **No, only in offices and shops located at the ground level.**
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: **Yes**
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.: **Unknown**



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

Figure 75: Different solar protection strategies have been implemented depending on the orientation and the type of openings to protect such as concrete caps (a), vertical and horizontal wooden blades(b) (c) and deported covered corridors (d). © Hervé DOURIS

BUILDING FABRIC AND MATERIALS

Roof

The main roof structure is composed of PV and solar thermal panels integrated to a detached over roof structure made of wooden frame.

Different types of green roofs have also been set up.

The **green roofs created as private gardens** are composed of (from top to bottom):

- Vegetal earth [0.42 m],
- Draining gravel [0.15 m],
- Geotextile,
- Expanded polystyrene drainage sheet for terraces (SOPRADRAIN ®) [0.055 m],
- Two-layer elastomer waterproofing
- Concrete slab [0.18 m]

U-value= **0.488** [W / m²K]

Overall R-value: **2.05** [m^{2}K/W]

Windows

- Louvered windows of different dimensions [0.9×1.10 m] [1.8×1.10 m]
- 3-leaf sliding aluminium door [2.4×2.10 m]

Type of materials: Clear glass - thickness of 0.006 m

Window-to-wall ratio (WWR): **20 %** of glazed area in the bedrooms and **46%** in the living rooms.

ABC21 is funded by the EU's H2020 programme

Walls

Different types of siding materials have been used to protect the facades exposed to solar radiation.

Part of the **exterior walls** are composed of (from outside to inside):

- ONDULIT metal siding [-m] or fibre cement cladding [0.01m]
- Air gap [0.03 m]
- Reinforced concrete wall [0.16 m]

	ONDULIT metal siding	Fibre cement cladding
U-value [W/m²K]	2.268	3.125
Overall R-value [m2K/W]	0.441	0.320

The **most exposed exterior walls** are composed of (from outside to inside):

- Plasterboard and mineral insulation composite panel [-m]
- Reinforced concrete wall [0.16 m]

U-value= **1.01** [W / m²K]

Overall R-value: **0.991** [m^{2}K/W]

Figure 76: Exterior view of the facades showing the different types of finishing materials used for the exterior walls, i.e., ONDULIT sheet panels and fibre cement siding. © Hervé Douris.

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	None
Low-energy heating systems	None
Ceiling fans	No ceiling fans in the apartments. Only the offices and shops at the ground level are equipped with ceiling fans.
Mechanical ventilation / air renewal	Limited use of mechanical systems for the ventilation of the bathrooms and toilets of some apartments. Wet rooms are preferably located on the facades and naturally ventilated throughout louvered windows.
Domestic Hot Water	Solar hot water production system.
Artificial lighting	All the dwellings are equipped with low-energy compact fluorescent lamps. All the corridors are outside and therefore do not require artificial lighting during the day. The lighting in the communal areas (external walkways, car park, corridors, halls) is of the fluorescent type controlled by motion detectors with integrated timers and photocells.
Control and energy management	None

RENEWABLE ENERGY	
PV	Integrated photovoltaic plant in overlaid roofs consists of 420 m^2 of PV panels Sharp, an 88 kWp power fed back into the network.
Solar thermal	Domestic hot water for all the buildings is produced thanks to 219 m² of solar thermal collectors. Individual water tanks are installed in each apartment. An electric backup power supply is installed and can be used in case of low solar availability during the winter period.
Wind	None
Geothermal	None
Biomass	None

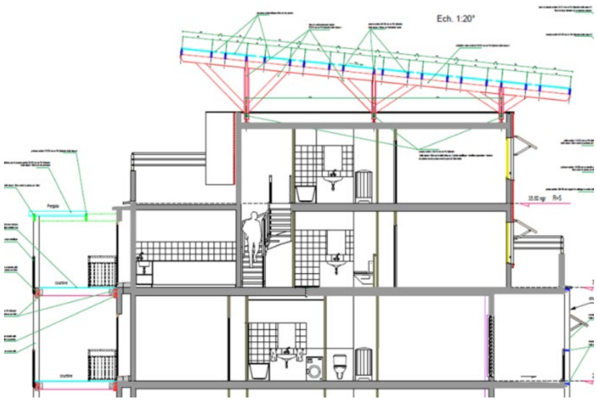


Figure 77 : Detached building integrated PV roof principle. This architectural feature enhances the efficiency of the panels by avoiding potential overheating and limits solar radiation on the roofs (© LEU Reunion)

Figure 78 :Aerial view of the PV system and solar thermal panels. (© Hervé Douris)

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating= **-** [kWh/m^2/year]
	2. Energy needs for cooling = **-** [kWh/m^2/year]
	3. Energy use for lighting = **-** [kWh/m^2/year]
	4. Energy needs for Sanitary Hot water = **-** [kWh/m^2/year]
	5. Total Primary energy use = **60** [kWh/m^2/year] (total Primary Energy Factor (PEF) equal to 3.00 for electrical energy from the grid)
	6. Renewable Primary energy generated on-site= **16** [kWh/m^2/year]
	7. Renewable Primary energy generated on-site and self-consumed= **0** [kWh/m^2/year]
	8. Renewable Primary energy exported to the grid= **16** [kWh/m^2/year]
	9. Ratio of renewable primary energy over the total primary energy use = **27** %

ABC21 is funded by the EU's H2020 programme

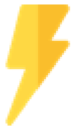
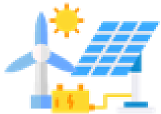
	10. Delivered energy (from electricity bills) = **20** [kWh/m²/year]
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	People are overall satisfied about the comfort conditions. The building works so well that people from the surroundings come to look for fresh air. The consequence is that people who lives in the building complain about safety issues.

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	▪ The breakdown of the operation into two islets (islands, parts) and five narrow buildings enhances comfort ventilation throughout both islets. ▪ The mix managed strata has led to tensions within the residences. This solution requires a prior tenant awareness and a learning among people for living together. ▪ The common areas and corridors designed as real meeting places have attracted the presence of external persons not necessarily desired. The multiplication operations offering qualities similar spaces should overcome this inconvenience.
Recommendations	▪ A large part of the heat input comes through the roof in this climate. Consequently, this element of the design should be treated with the utmost consideration and care. Detached roofs are a very efficient feature mutualizing energy generation and solar protection. ▪ A high level of porosity of the facades combined with optimized solar shading devices and vegetated surroundings is recommended since these measures ensure good visual and thermal comfort even in harsh tropical conditions. ▪ Noise and safety issues as well as visual intimacy should be considered when designing a building since these aspects can have a negative impact on the proper functioning of the bioclimatic strategies set up, especially on comfort ventilation.

ABC21 is funded by the EU's H2020 programme

BUILDING STRENGTHS AND WEAKNESSES

Strengths

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

Weaknesses

- Concrete caps over windows, serving as sun protection, store and release their heat through the openings.
- Lack of safety and visual intimacy because of windows of some living spaces that open onto the corridor pathways. This has a negative impact on the comfort ventilation operation since people do not open these windows.

REFERENCES

1. https://labreunion.fr/projets/malacca-flores/
2. https://www.construction21.org/france/case-studies/h/flores-malacca-en.html
3. SHC Task51 - Subtask C: Case studies and action research - Illustrative Prospective of Solar Energy in Urban Planning. Collection of International Case Studies. June 2017. Accessible at https://task51.iea-shc.org/Data/Sites/1/publications/Task51-Report-C1-1805031.pdf
4. https://www.envirobat-reunion.com/SPASSDATA/ALGEDIM/QOKQWR/D720/D72046.pdf

CASE STUDY 2-06: BURKINA INSTITUTE OF TECHNOLOGY | BURKINA FASO

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	B.P. 322, Koudougou, Burkina Faso
Latitude; Longitude	12.218139628590144, -2.378258705093982
Climate zone (Köppen–Geiger classification)	BSh: Hot semi-arid steppe
BUILDING INFORMATION	
Building Type	Educational
Project Type	New construction
Completion Date	2020
Number of buildings	1 (6 modules)
Number of storeys	1
Total Floor Area (m^2)	1000
Usable Area (m^2)	54 per classroom / 378 in total
Thermally conditioned space area (m^2)	0 m^2
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m^2 of usable area)	378
Total cost (€)	Unknown
Cost /m^2 (€/m^2)	Unknown
Performance Standards or Certification	None
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	Stern Stewart Institute & Friends
Architect / Designer	Kéré Architecture - Diébédo Francis Kéré
Construction supervisors	Diébédo Francis Kéré, Nataniel Sawadogo, Jaime Herraiz Martínez
Landscape design	Kéré Architecture
Structural Engineer, Civil Engineer	-

ABC21 is funded by the EU's H2020 programme

PROJECT DESCRIPTION

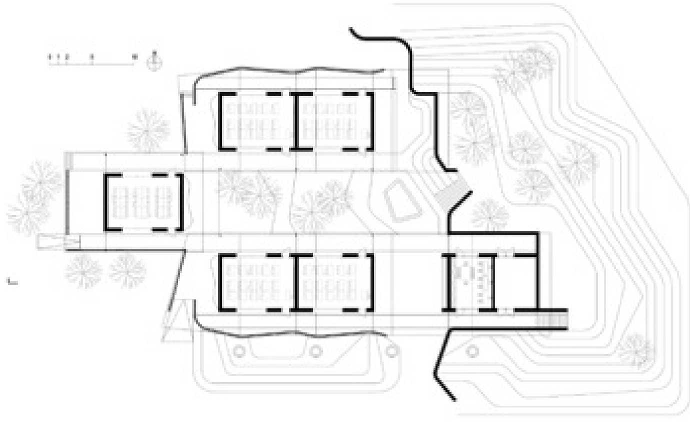


Figure 79 : Ground floor plan of the Burkina Institute of Technology. The modular structures are arranged to form a central courtyard. © Kéré Architecture

The architecture of the Burkina Institute of Technology is composed of a series of repeated and easily replicable rectangular elements, that house classrooms, lecture halls and auxiliary spaces. The modules are orthogonally aligned to zigzag, to create courtyards This arrangement allows the campus to expand incrementally according to its needs. Each module of the building has been poured and cast in-situ into large formworks.
Two conference rooms were created later but these are not part of the study.

Figure 80 Section of the Burkina Institute of Technology. © Kéré Architecture

SITE INTEGRATION

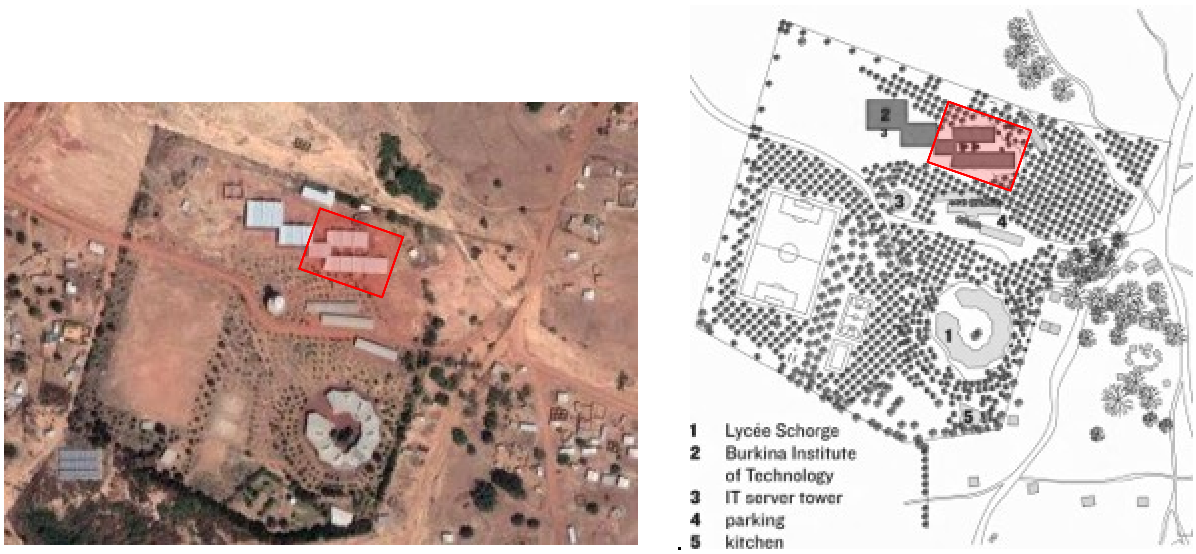


Figure 81 : (a) Aerial view (Source: Google Map) and and (b) site plan of the BIT.

The building is located on a desert flood plain of the city of Koudougou, in Burkina Faso. The site is characterized by a low building density and very little vegetation. The facility is an extension of the Schorge High School campus designed by the same architectural firm during a previous collaboration with the Stern Stewart Institute.

CLIMATE ANALYSIS

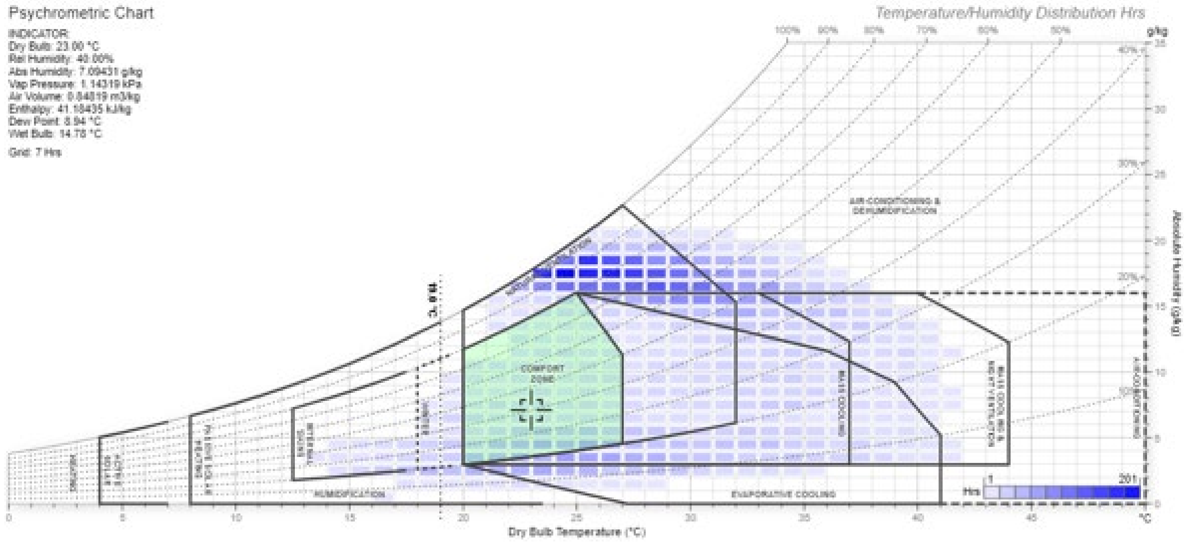


Figure 82: Givoni Bioclimatic chart for the climate of Koudougou using Andrew Marsh online tool [2]. Weather data are extracted from the PVGIS tool of the jrc for the 2007 – 2016 period.

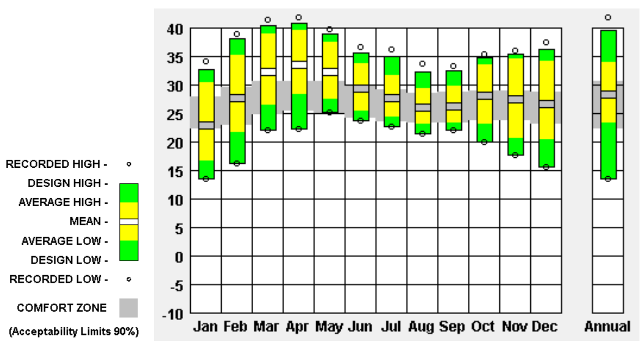


Figure 83: Temperature range by month for Koudougou, Burkina Faso (Source: Climate consultant – Adaptative Comfort model).

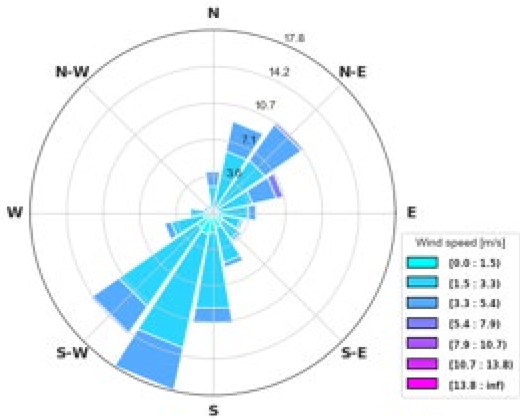


Figure 84: Wind rose for Koudougou, Burkina Faso

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **5 685** Wh/m² (July) Max: **6 844** Wh/m² (May) Mean: **6 228,2** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **8** CDD 10°C: **6 698**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **72** CDD: **387**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **13** CDD 26º: **1 197**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	Comfort ventilation Nocturnal convective cooling Thermal mass The modules are placed in a staggered formation to enhance airflow in and around the building. The large and adjustable wood louvers present on the walls allow the buildings to be naturally ventilated. In addition, the repetitive profiles on the roof allow for openings at the back of each module to naturally release warm air from the top through stack effect.

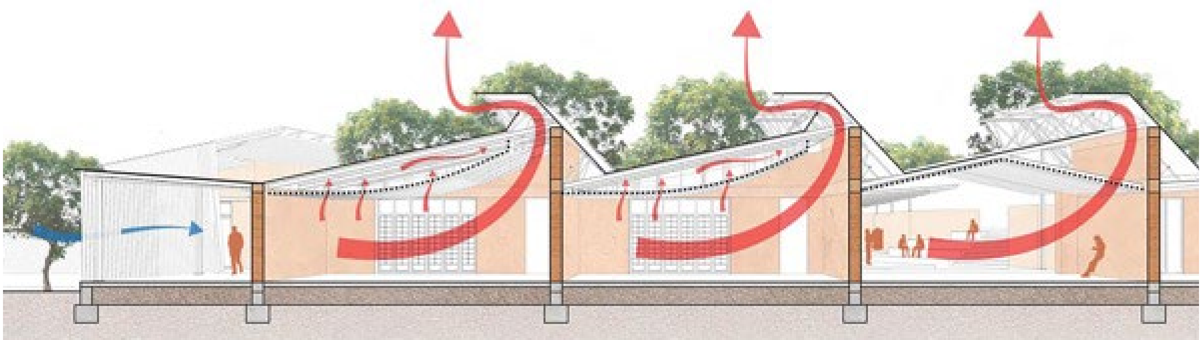


Figure 85: Section of the building showing the ventilation strategy.

Passive heating strategy	High thermal mass of the walls
Solar protection	Around each classroom are shaded corridors and walkways, framed by screens of locally sourced eucalyptus wood.
Building orientation	The lamella façades of the modules are North / South oriented.
Insulation	The massive clay walls of 35 cm contribute significantly to stabilize temperature in the interior spaces.
Vegetation	The building is surrounded by a vegetable garden and trees such as mango, kapok, banana, papaya and baobab. Over 2 000 tree seedlings, planted by pupils and students as part of the institution's ecological commitment, will create a forest around the campus in a few years. This varied and rich landscape helps prevent flooding. A bench surrounds each seedling to protect it, and will create a comfortable spot in the shade.
Natural daylighting	Hung ceilings, made of local eucalyptus wood, brighten the interior spaces and the large openings with adjustable wood louvers allow enough light to enter the interior.
Use of local and embedded materials	The main structure of the building is made from poured local clay, cast in-situ, combined with concrete. Local eucalyptus wood has been used to cover the hung ceilings inside the rooms and to create the exterior "screens" that protect the classroom, the corridors and the walkways from direct solar radiation.
Water saving and flood management	An extensive landscape design has been planned in order to protect the building during the rainy season, since the site is located on a flood plain. The principle is based on channelling and storing water into a large underground tank, that is later used for the irrigation of the mango plantations present on the campus.

Waste management	Unknown

Figure 86: View of a corridor between the classroom and porous skin in eucalyptus wood © Kéré Architecture

Figure 87 : View of the classroom through the louvered openings © Kéré Architecture

Figure 88 : View of the interior ceilings made of local Eucalyptus wood.

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** Ratio with number of users: -
Ceiling fans	In every room, even those conditioned: **No**
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**

ABC21 is funded by the EU's H2020 programme

BUILDING FABRIC AND MATERIALS		
Roof	The roof is composed of (from outside to inside): ▪ Metal sheet ▪ Air gap ▪ Eucalyptus wood (hung ceiling)	
Windows	Unglazed windows Wood louvers	
	Window-to-wall ratio (WWR): -	
Walls	The **exterior and interior walls** are both composed of local **clay combined with concrete** and then poured and cast in-situ into large formworks of **35 cm.**	

Figure 89: Roof openings allow warm air to be released. © Kéré Architecture

Figure 90: The modular structures are arranged to form a central courtyard. © Kéré Architecture

Figure 91: Eucalyptus wood was used to create a porous skin around the building to create a sense of unity with the rest of the campus. © Kéré Architecture

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	None
Low-energy heating systems	None
Ceiling fans	None
Mechanical ventilation / air renewal	None
Domestic Hot Water	None
Artificial lighting	Fluorescent tubes
Control and energy management	None

ABC21 is funded by the EU's H2020 programme

RENEWABLE ENERGY	
PV	Type of technology: polycrystalline (Poly-Si) Efficiency: about 1kWp/m^2 Surface: 895,75 m^2 Azimuth (degrees from south tilt angle):10°
Solar thermal	None
Wind	None
Geothermal	None
Biomass	None

Figure 92: Ground mounted solar PV system of the BIT.

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating (kWh/y/m2)
	2. Energy needs for cooling (kWh/y/m2)
	3. Energy use for lighting (kWh/y/m2)
	4. Energy needs for Sanitary Hot water (kWh/y/m2)
	5. Total Primary energy use (kWh/y/m2)
	6. Renewable Primary energy generated on-site (kWh/y/m2)
	7. Renewable Primary energy generated on-site and self-consumed (kWh/y/m2)
	8. Renewable Primary energy exported to the grid (kWh/y/m2)
	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)
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level

	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	-

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	The Kéré's team was able to take advantage of the experience gained during the construction of the "Naaba Belem Goumma" secondary school. The walls of the different modules were made of local clay cast on-site in large formworks. This innovative construction method offers the advantage of being faster and more flexible than traditional clay brick construction. As a result, the construction was completed in a very short time. Measurement of physical variables and occupants' surveys have been performed during the months (March to June) which present high maximum daily temperatures and medium humidity, hence challenging conditions. This should be kept in mind while considering the results of the Post Occupancy Survey. Across the various dates of the survey, a considerable proportion of responses expressed a neutral opinion regarding thermal sensation (about 227), while the widest portion of responses (360), reported feeling slightly warm, 294 felt warm and 146 felt hot. Hence, in terms of vote on the -3 to + 3 ASHRAE scale, the range -1 to +1 (slightly cool to slightly warm), which is assumed by e.g. Fanger to be a comfortable range, was voted in 59% of responses. If air velocity had been higher this percentage would have substantially increased, as it appears from the responses to the questions about air velocity, where a preference for more air movement was expressed in over 75% of responses. In terms of thermal comfort judgement, the 254 responses reported to be comfortable, 374 slightly uncomfortable, 374 uncomfortable, 78 very uncomfortable and 37 extremely uncomfortable. Majority of responses (835 out of 1117) expressed a preference for being cooler. The measured indoor air velocity is modest, predominantly in the range 0,1 to 0,3 m/s, where 0,1 practically corresponds to no air movement. The designers' expectation of achieving comfort ventilation (air velocity on people during occupied hours) thanks to the ample openings in the walls and roof, does not appear to have materialized. The actual reason for a scarce effect of cross and stack ventilation should be investigated and corrected. A possible problem might come from the dense configuration of the structures that shade the hallways surrounding the classrooms on one side (Figure 93 (a-b-c) made of local eucalyptus wood. On the other side (d) there are movable horizontal louvers which might prove more permeable to air.

Recommendations

Possible improvements, subject to further analysis, might be achieved by:

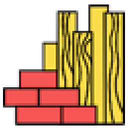
- Creating interruptions in the eucalyptus shading structure in order to reduce the resistance to the air flow
- Adding solar chimneys in order to enhance the stack effect
- Installing ceiling fans appropriately sized and positioned to guarantee the desired air velocity (in the order of 1 m/s) when the wind and stack driving forces are insufficient.

Given the fact that in some months (e.g. March, April and part of May) air humidity is quite low, and correspondingly the day night temperature swing is considerable, indoor air and operative temperatures might be reduced significantly by:

- Performing night ventilative cooling to cool down the masses by fully opening the louvers at night. The louvers seem to already have a robust structure and hence prevent intrusions also when open. During the day, depending on the conditions, louvers might be kept partially closed to reduce the flow of warm air, and air velocity might be obtained by the action of the ceiling fans
- Sustained air flow of external air might be kept also during the day if, taking profit of the low humidity, evaporative cooling systems could be installed at the windows. In the months when humidity is low, simple, direct evaporative cooling (rather than more complex indirect double stage) might be appropriate.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

			
Passive Design	**Local Materials**	**Replicability**	**Affordability**

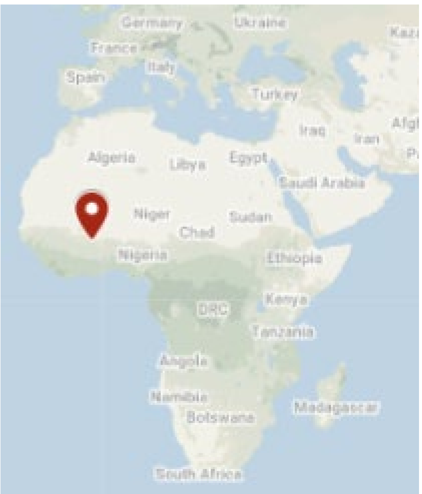
Weaknesses

\-

REFERENCES

1. https://www.kerearchitecture.com/work/building/burkina-institute-of-technology-bit
2. https://www.dezeen.com/2021/06/29/kere-architecture-burkina-institute-of-technology-architecture/
3. https://www.architectural-review.com/buildings/laying-down-roots-burkina-institute-of-technology-in-koudougou-burkina-faso-by-kere-architecture

CASE STUDY 2-07: LYCEE SCHORGE | BURKINA FASO



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	B.P. 322, Koudougou, Burkina Faso
Latitude; Longitude	12.216743389817205, -2.3780847033262478
Climate zone (Köppen–Geiger classification)	BSh: Hot semi-arid steppe
BUILDING INFORMATION	
Building Type	Educational
Project Type	New construction
Completion Date	2016
Number of buildings	1
Number of storeys	1
Covered Area (m²)	1660
Usable area (m²)	83.6 per module / 752.4 in total
Thermally conditioned space area (m²)	**0**
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m² of usable area)	752.4
Total cost (€)	Unknown
Cost /m² (€/m²)	Unknown
Performance Standards or Certification	None
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	Stern Stewart Institute & Friends
Architect	Kéré Architecture - Diébédo Francis Kéré
Design team	Jin-Gul David Jun, Pedro Montero Gosalbez, Dominique Mayer, Diego Sologuren Martin, Marta Migliorini, Jaime Herraiz Martínez, Adriana Arteaga
Construction management and Supervision	Association Dolai, Diébédo Francis Kéré, Marta Migliorini, Nataniel Sawadogo, Wéneyida Kéré

PROJECT DESCRIPTION

The school is formed by nine rectangular modules arranged radially around a courtyard, which prevents wind and dust from entering in the central space. The different modules accommodate classrooms and administration rooms. Besides, a series of steps creates a loosely defined amphitheatre, where informal gatherings and assemblies' celebrations for the school and wider community take place.

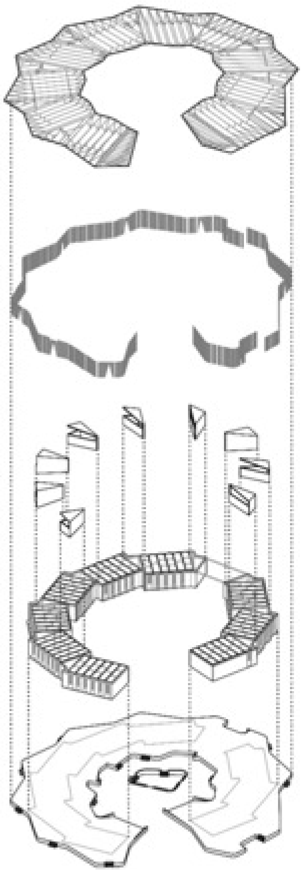


Figure 94 : Exploded axonometry of the ring-shaped Lycée Schorge. © Kéré Architecture

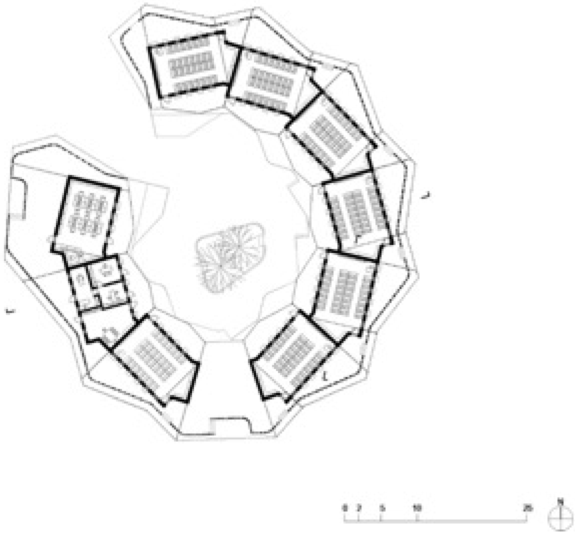


Figure 95 : Floor plan of the Lycée Schorge. The modular structures are arranged radially around a courtyard. © Kéré Architecture

SITE INTEGRATION

Figure 96 : Bird's-eye views of Lycée Schorge in its surrounding environment. © Iwan Baan

The building is located on a flat swath of semi-arid land and floodplain of the city of Koudougou, in Burkina Faso. The site is characterized by a low building density and sparse vegetation. The choice of the materials, with a mix of wood and stones, allows the building to fit into its natural environment.

CLIMATE ANALYSIS

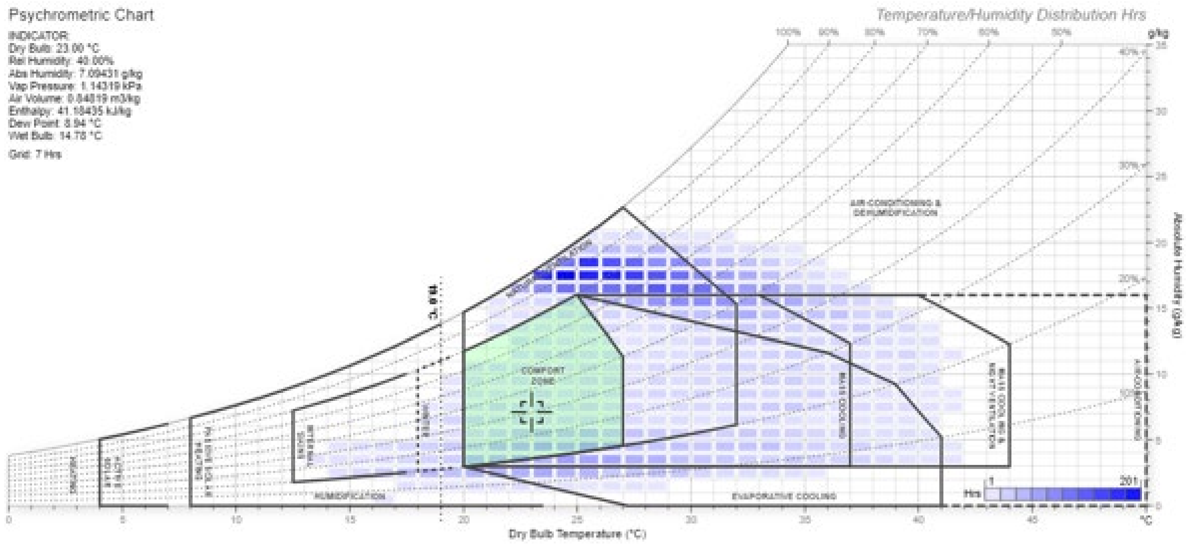


Figure 97: Givoni Bioclimatic chart for the climate of Koudougou using Andrew Marsh online tool [2]. Weather data are extracted from the PVGIS tool of the jrc for the 2007 – 2016 period.

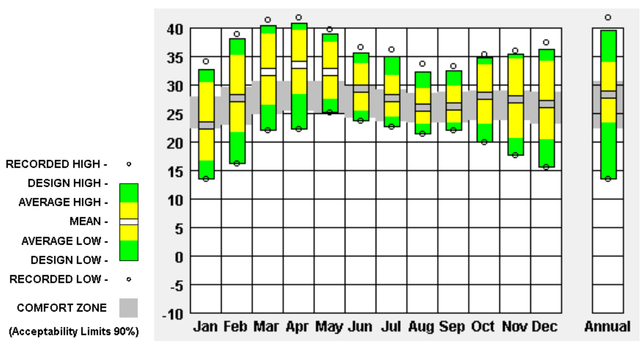


Figure 98: Temperature range by month for Koudougou, Burkina Faso (Source: Climate consultant – Adaptative Comfort model).

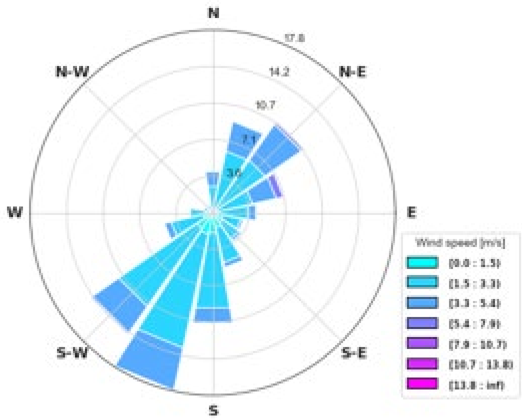


Figure 99: Wind rose for Koudougou, Burkina Faso

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **5 685** Wh/m² (July) Max: **6 844** Wh/m² (May) Mean: **6 228,2** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **8** CDD 10°C: **6 698**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **72** CDD: **387**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **13** CDD 26º: **1 197**

KEY BIOCLIMATIC DESIGN PRINCIPLES

Passive cooling strategy

Comfort ventilation: Natural cross-ventilation and stack effect.

Different passive features have been implemented in order to ensure that the interior spaces would be cooled naturally. Firstly, the louvered shutters installed on opposite facades enhance natural cross ventilation. In addition, towers planted on top of the classrooms allow the air to flow in out of the rooms.

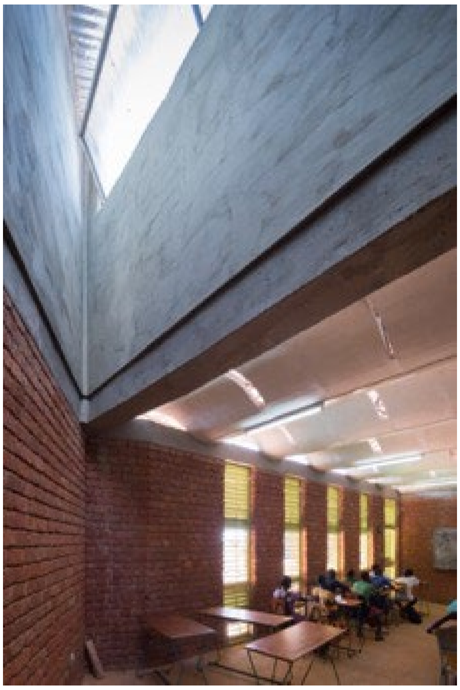


Figure 100: Interior view of the classroom with the ventilation openings in the roof © Iwan Baan.

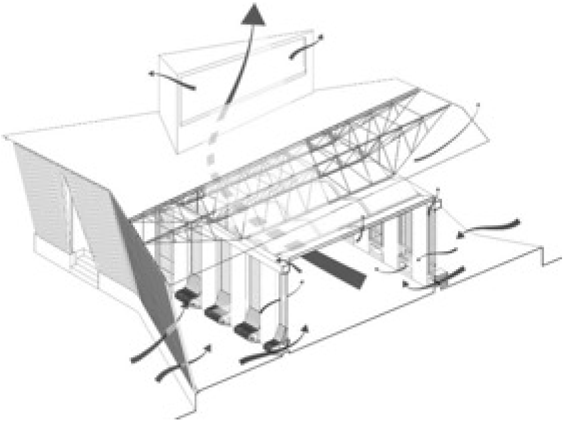


Figure 101: Climate diagram showing the comfort ventilation principle © Kéré Architecture

Passive heating strategy

High thermal mass of the walls, which are composed of laterite stones.

Solar protection

Large roof overhangs protect the louvered shutters and the main facades of the modules. The eucalyptus “screens” form a transparent fabric system all around the classrooms and create intermediary shaded spaces where students can gather. They also protect the classrooms from direct solar radiation, reducing heat gain.

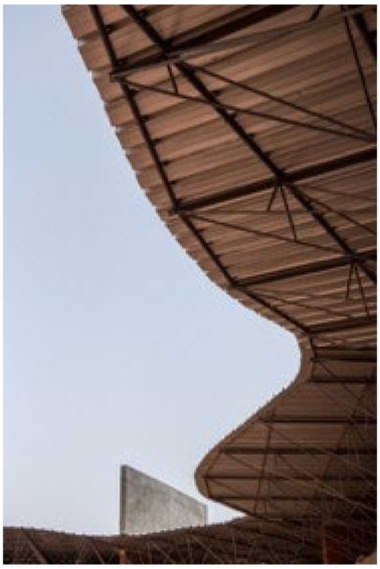


Figure 102 : Large roof overhangs provide shading spaces. © Andrea Maretto for Kéré Architecture.

Figure 103 : Wooden screens protect the building from wind, dust and direct solar radiation. © Iwan Baan

Building orientation

The modules are differently oriented due to the ring-like arrangement of the building.

Insulation	The laterite stones that composed the walls provide an excellent source of thermal mass, absorbing the heavy daytime heat and radiating it at night. The roof is composed of sheet metal which is separated by an air gap from the concrete ceiling to form a ventilation chamber that dissipates solar radiation.
Vegetation	Over 2 000 tree seedlings, such as mango trees, flamboyant trees, orange trees and so on, planted by pupils and students as part of the institution's ecological commitment, will create a forest around the campus in a few years. A bench surrounds each seedling to protect it, and will create a comfortable spot in the shade.
Natural daylighting	The massive undulating ceiling, made of perforated plaster vaults, diffuse indirect sunlight to improve daylight levels inside the rooms while avoiding the heat otherwise caused by direct radiation. Besides, the ceilings are painted white to optimize the diffusion of light in the spaces. The louvered shutters provide more natural light.
Use of local and embedded materials	The walls of each module are composed of locally sourced laterite stone. After extraction from the earth, the laterite is cut and shaped into bricks, which are then exposed to the sun to harden. The "screens" that wrap around the modules are made of locally available eucalyptus wood.
Water saving	A watertank of $10m^3$ is installed on site. A rainwater catchment basin and a well ensure the campus to be self-sufficient.
Waste management	In order to minimise costs and reduce material waste, the school's furniture is made from local hardwoods and steel offcuts from the roof construction.

Figure 104: View of the courtyard of the Lycée Schorge © Andrea Maretto for Kéré Architecture.

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** Ratio with number of users: -
Ceiling fans	In every room, even those conditioned: **In some classrooms only, not in all spaces.**
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.: **No**

Figure 105 : Exterior view of the building.

BUILDING FABRIC AND MATERIALS	
Roof	The roof is composed of (from the outside to the inside): ▪ metal sheet ▪ iron structure with air gap ▪ concrete ceiling ▪ perforated plaster vaults
Windows	Unglazed windows Metal louvers
	Window-to-wall ratio (WWR): -
Walls	The **walls** are composed of **20 cm** of local **laterite stones** (*BLT- Le Bloc de Laterite Taillé in French)*

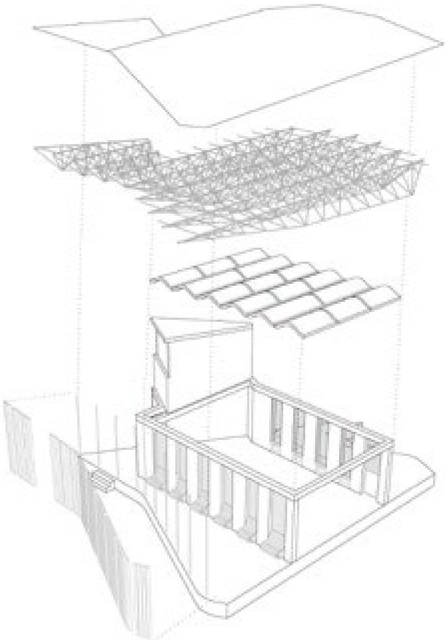


Figure 106: Exploded view of a typical classroom, showing the roof structure. © Kéré Architecture

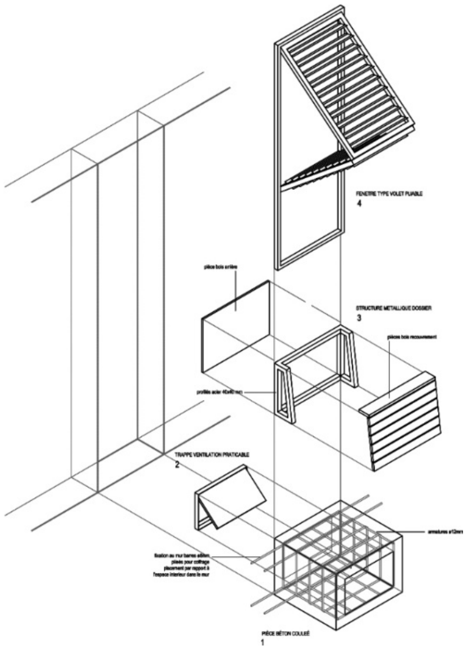


Figure 107: Details of the louvered shutter systems installed in Lycee Schorge © Kéré Architecture

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	None
Low-energy heating systems	None
Ceiling fans	None
Mechanical ventilation / air renewal	None
Domestic Hot Water	None
Artificial lighting	Fluorescent tubes
Control and energy management	None

Figure 108: Interior view of a classroom. The undulating ceiling pattern allows to diffuse natural light. © Andrea Maretto for Kéré Architecture

Figure 109 : View of one of the openings at the top of the building ©

RENEWABLE ENERGY	
PV	None
Solar thermal	None
Wind	None
Geothermal	None
Biomass	None

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating (kWh/y/m2)
	2. Energy needs for cooling (kWh/y/m2)
	3. Energy use for lighting (kWh/y/m2)
	4. Energy needs for Sanitary Hot water (kWh/y/m2)
	5. Total Primary energy use (kWh/y/m2)
	6. Renewable Primary energy generated on-site = **0** [kWh/m^2/year]
	7. Renewable Primary energy generated on-site and self-consumed = **0** [kWh/m^2/year]
	8. Renewable Primary energy exported to the grid = **0** [kWh/m^2/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation) = **0 %**
	10. Delivered energy (from electricity bills) = - [kWh/m^2/year]
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)

	7. Hazard material
Users' feedback	-

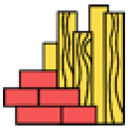
LESSONS LEARNED AND RECOMMENDATIONS

Lessons learned	The architect showed that local materials can be successfully used within contemporary structures.
Recommendations	-

BUILDING STRENGTHS AND WEAKNESSES

Strengths

Passive Design



Local Materials

Replicability

Affordability

The Lycée Schorge was designed with bioclimatic considerations in terms of cooling, ventilation, daylighting and the use of locally available materials.

Weaknesses

-

REFERENCES

1. https://www.kerearchitecture.com/work/building/burkina-institute-of-technology-bit
2. https://arquitecturaviva.com/works/escuela-secundaria-lycee-schorge-1

CASE STUDY 2-08: Centre de Formation Professionnelle de Nioro | SENEGAL

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	P6VM+M9P, Nioro du Rip, Sénégal
Latitude; Longitude	13.744376437735298, -15.76656745830613
Climate zone (Köppen–Geiger classification)	BSh: Hot semi-arid steppe
BUILDING INFORMATION	
Building Type	Educational
Project Type	New construction
Completion Date	2018
Number of buildings	14
Number of storeys	1
Total Floor Area (m²)	-
Net Floor Area (m²)	2100
Thermally conditioned space area (m²)	400
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	1560
Total cost (€)	2 134 286
Cost /m² (€/m²)	1 707
Performance Standards or Certification	None
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	LuxDev (agence luxembourgeoise pour la Coopération au Développement)
Architect / Designer	KHôZé architecture
Mechanical engineering and environmental consultancy	TERRANERGIE
Structural Engineer, Civil Engineer	LUXCONSULT
Construction company	ELEMENTERRE

ABC21 is funded by the EU's H2020 programme

PROJECT DESCRIPTION [1][2]

Figure 110 : Exterior view of the CFP Nioro buildings.

Figure 111: Site plan of the CFP Nioro buildings.

The professional training centre of Nioro (CFP of Nioro) combines several uses into one place, such as food production, hairdressing trade as well as dyeing, cutting, and sewing activities; catering area; accommodation area; classrooms and conference rooms; technical rooms and lavatories. Based on a pavilion type architecture; the different elements are linked by exterior walkways, forming a compact unit, with a shape close to that of the square. This allows it to be easily adapted to any plot of similar size which could be the subject of a similar program in the future, as requested by the project owner. The project relies on a bioclimatic concept and a sustainable approach in terms of energy and comfort based on the optimization of the physical characteristics of the building. In some spaces, air conditioning is combined with the adiabatic cooling system (evaporative cooling) and with ceiling fans.

SITE INTEGRATION

Figure 112 : Aerial views of the building in its surrounding environment. (Source: Google Map)

The CFP of Nioro is located in the urbanised area of the city of Nioro du Rip.

CLIMATE ANALYSIS

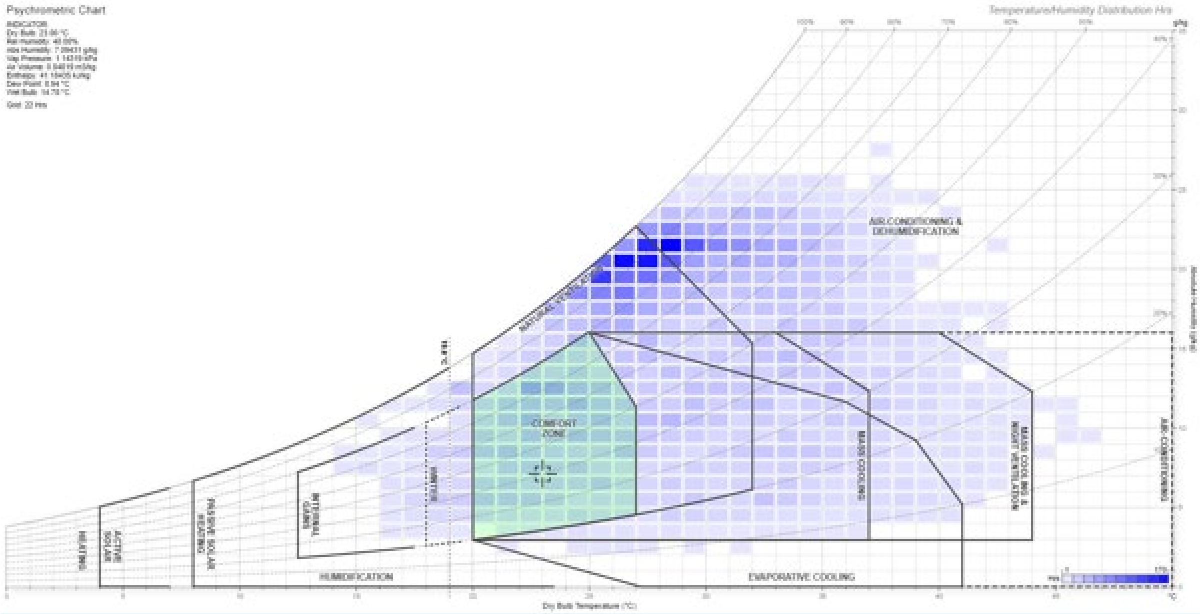


Figure 113: Givoni Bioclimatic chart for the region of Kaolack, Senegal using Andrew Marsh online tool [2]. Climate data are extracted from the database of the climate.onebuilding.org website.

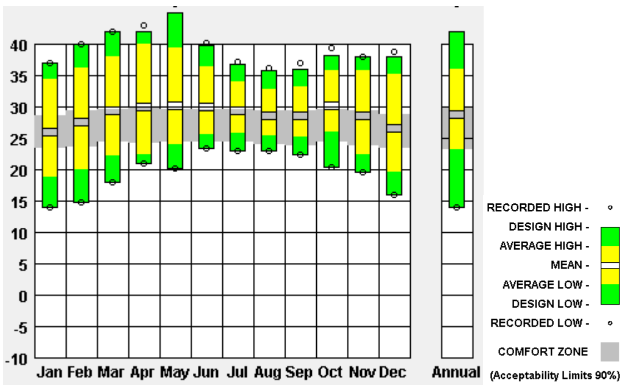


Figure 114: Temperature range by month for the region of Kaolack, Senegal (Source: Climate consultant – Adaptative Comfort model).

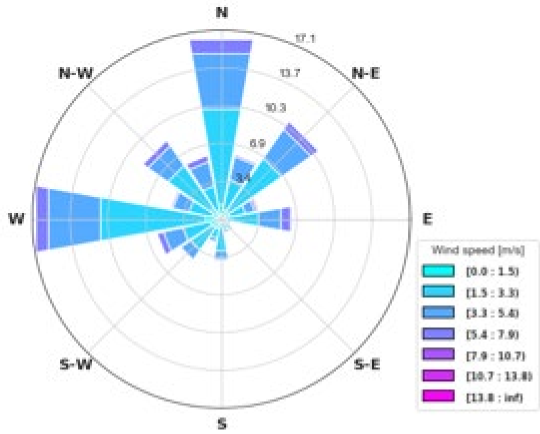


Figure 115: Wind rose for Kaolack, Senegal (Beaufort wind scale).

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **5091** Wh/m² (Sep.) Max: **7453** Wh/m² (Apr.) Mean: **6174** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **3** CDD 10°C: **6 845**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **90** CDD: **514**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **6** CDD 26º: **1 321**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	Comfort ventilation (natural cross ventilation) Evaporative cooling, Mass cooling Radiant cooling The large openings present on the two opposite sides of the facades allow the buildings to be naturally ventilated.
Passive heating strategy	N/A
Solar protection	Detached overhanging roofs protect the interiors from excessive heat while sheltering them from rain and sun.
Building orientation	The main facades of the buildings are facing North-East / South-West
Insulation	None
Vegetation	Vegetated patios allow to cool the air before entering the buildings.
Natural daylighting	Large openings allow enough light to enter the interior.
Use of local and embedded materials	The main structure of the building is made from compressed earth blocks.
Water saving and flood management	None
Waste management	None
Others features	-

Figure 116: Interior view of the rooms equipped with ceiling fans and fluorescent tubes.

Figure 117: Outdoor pathways.

Figure 118 : Interior view of the meeting room.

Figure 119: The planted patios create a comfortable microclimate between the buildings.

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** *Students are dressed in gowns or T-shirts in addition to their usual clothing.*
Protected bike parking and showers	**No** If yes, Ratio with number of users: **0**
Ceiling fans	In every room, even those conditioned: **Yes**
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: **No**
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.: **No**

BUILDING FABRIC AND MATERIALS	
Roof	The roof structure is composed of (from outside to inside): ▪ Over-roof made of aluminium sheet ▪ Aluminium trays ▪ Waterproofing layer ▪ Cement mortar [0.04m] ▪ Vaulted under roof in compressed earth bricks [0.30 ×0.14 ×0.10 m] ▪ (Coating and painting or tiles for some rooms)
Windows	Single-glazed with clear glass. Some openings are protected with iron grills. Dimension of the main openings: 0.90 ×0.75 ×0.60 m
Walls	The **Exterior walls of the classrooms, offices and accomodations** are mainly composed of compressed earth bricks with a thickness of 0.30m. Some other walls (for instance in buildings C, D and E) are made of (from outside to inside): ▪ Compressed earth bricks [0.14m] ▪ Cement filling [0.04m] ▪ Concrete block [0.10m] ▪ Tile [0.02m]
	The **Interior Walls** are structured as the exterior walls for the classrooms, offices and accommodations buildings, i.e, compressed earth bricks with a thickness of 0.30m. In the sanitary rooms and kitchens, interior walls are made of concrete wall tiled on both sides, with a thickness of 0.14m.

Figure 120: Exterior view of the walls and openings

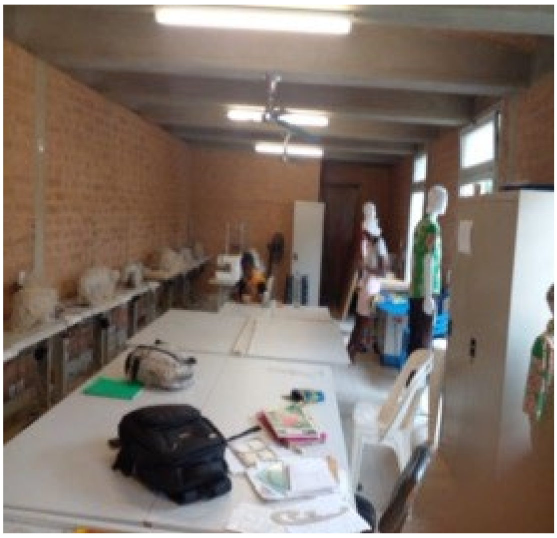


Figure 121: Interior view of the sewing room.

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	**Adiabatic cooling systems and split systems** For all the rooms located in the accommodation area, air conditioning is combined with the adiabatic cooling system (evaporative cooling) and with ceiling fans. The other rooms of the centre are either equipped with ceiling fans only or with ceiling fans and adiabatic cooling systems.
Low-energy heating systems	None
Ceiling fans	All rooms are equipped with ceiling fans.
Mechanical ventilation / air renewal	None
Domestic Hot Water	Solar thermal for the sanitary rooms.
Artificial lighting	Fluorescent tubes
Control and energy management	None

Figure 122: Interior view of the ceiling and lighting tubes.

Figure 123 : Floor standing air conditioner have been installed in some rooms.

RENEWABLE ENERGY	
PV	None
Solar thermal	Solar thermal panels have been installed for the production of hot water.
Wind	None
Geothermal	None
Biomass	None

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

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
   Seewing classrooms : 86% | Conference room : 38% | Bedroom : 58% | Office : 59%
6. Percentage of time inside the Givoni comfort zone of 0m/s
   Seewing classrooms : 34% | Conference room : 0% | Bedroom : 1% | Office : 1%
7. Number of hours within a certain temperature range

Oct 22 to Feb 2023	Seewing classroom 2		Seewing classroom 1		Office		Bedroom 1		Conf room		Weather Station	
	Nb of Hours	Fq.	Nb of Hours	Fq.	Nb of Hours	Fq..	Nb of Hours	Fq..	Nb of Hours	Fq..	Nb of Hours	Fq.
Ta<16°C	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%
16°C≤Ta<18°C	0	0%	0	0%	0	0%	0	0%	0	0%	8	2%
18°C≤Ta<20°C	0	0%	1	0%	0	0%	0	0%	0	0%	10	2%
20°C≤Ta<22°C	13	3%	2	0%	0	0%	0	0%	0	0%	20	5%
22°C≤Ta<24°C	17	4%	19	4%	0	0%	0	0%	0	0%	20	5%
24°C≤Ta<26°C	114	26%	88	20%	0	0%	0	0%	0	0%	26	6%
26°C≤Ta<28°C	194	44%	209	48%	114	26%	114	26%	9	2%	32	7%
28°C≤Ta<30°C	85	19%	110	25%	224	51%	223	51%	214	49%	27	6%
30°C≤Ta<32°C	14	3%	8	2%	92	21%	97	22%	152	35%	42	10%
32°C≤Ta<34°C	0	0%	0	0%	7	2%	3	1%	54	12%	75	17%

Energy performance indicators

1. Energy needs for heating (kWh/y/m2)
2. Energy needs for cooling (kWh/y/m2)
3. Energy use for lighting (kWh/y/m2)
4. Energy needs for Sanitary Hot water (kWh/y/m2)
5. Total Primary energy use (kWh/y/m2)
6. Renewable Primary energy generated on-site (kWh/y/m2)
7. Renewable Primary energy generated on-site and self-consumed (kWh/y/m2)
8. Renewable Primary energy exported to the grid (kWh/y/m2)
9. Ratio of renewable primary energy over the total primary energy use (with and without compensation) (%)

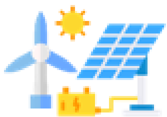
	10. Delivered energy (kWh/y/m2) (from electricity bills) : **26,5 [kWh/m²/year]**
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	The users are happy with their working environment and appreciate the architectural design (based on a pavilion type architecture) and the presence of vegetation in the outdoor spaces. The feedback from users is reserved about the comfort conditions of the building.

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	- Some spaces remain hot, dry and uncomfortable and must be improved in terms of thermal comfort - There is a lack of information about how to use the building properly.
Recommendations	- Teach the occupants and the staff how to use properly the building (nocturnal convective cooling, adiabatic cooling system); - Check if the adiabatic cooling system works well; - Improve the management of passing cooling strategies (nocturnal convective cooling, evaporative cooling, natural cross ventilation); - Check if the density of ceiling fans is correct (1 CF/10 m^2), e.g. using the CBE ceiling design tool (online, from Berkeley University); - Extend the adiabatic cooling system to the sewing classrooms and other classrooms.

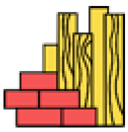
BUILDING STRENGTHS AND WEAKNESSES

Strengths

Passive Design



Renewable Energy



Local Materials

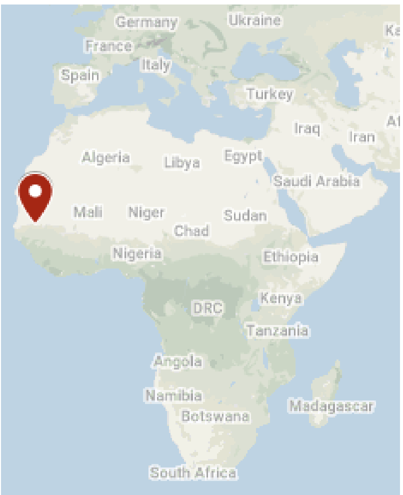
Replicability

Weaknesses

-

REFERENCES

CASE STUDY 2-09: LYCEE JEAN MERMOZ | SENEGAL



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Avenue Cheikh Anta Diop - BP 3222 - Dakar, SÉNÉGAL
Latitude; Longitude	14.718193231710131, -17.484476683878636
Climate zone (Köppen–Geiger classification)	BSh: Hot semi-arid steppe

BUILDING INFORMATION	
Building Type	Educational (Kindergarten, primary, high school, CDI, administrative centre and sports platform)
Project Type	New construction
Completion Date	2010: Classrooms 2012: Sports infrastructure
Number of buildings	19
Number of storeys	2 for the kindergarten and primary school 3 for the high school
Total Floor Area (m²)	Unknown
Net Floor Area (m²)	17 000m^2
Thermally conditioned space area (m²)	Unknown
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	Unknown
Total cost (€)	15,7 M€ excluding taxes (10 102 MFCFA)
Cost /m² (€/m²)	923,5
Performance Standards or Certification	None
Awards	Winner of the 2012 AFEX Grand Prize Nominated for the Aga Khan Award for Architecture 2013

STAKEHOLDERS	
Building Owner/ Representative	A.E.F.E (The Agency for French Education Abroad), Paris / The embassy of France in Dakar

Assistance to the contracting authority	SCO Afrique (Société de Coordination et d'Ordonnancement)
Architect / Designer	TERRENEUVE architects (lead architect), Adam Yedid Architect (associate architect), Architecture and Climate (Architects and Construction Economics)
Building control expert	SCAT Internationale
Construction Manager	POLYPROGRAMME
Mechanical engineering and environmental consultancy	ALTO Ingenierie
Structural Engineer, Civil Engineer	SATOBA Ingenierie
Acoustical consultant	AYDA Yves Dekeyrel
Landscape design	Armelle Claude
Others	GETRAP, GENERALE D'ENTREPRISES (GE), Miquel Mont

PROJECT DESCRIPTION [1][2]

Figure 124 : Exterior view of the building. ©Daniel Rousselot

The program includes new construction on what were formerly the sports grounds of an existing school complex. It houses the preschool, elementary, middle, and high schools for a total of 2 500 students.

This project shows a radically contemporary architectural approach but at the same time it uses the savoir-faire of local businesses, with savings on technical resources, limiting the import of manufactured products.

The type of construction used for each portion incorporates several passive solutions for cooling and protection from the sun - exterior covered walkways, ventilated cavity walls, awnings, and roofing with high thermal inertia. These systems were planned to provide comfortable temperatures for most of the school year and reduce air conditioning use to one or two months per year, during the monsoon period. This first monitoring campaign points out that the building does not work as well as planned in terms of thermal and energy performance. A number of recommendations are provided in the report.

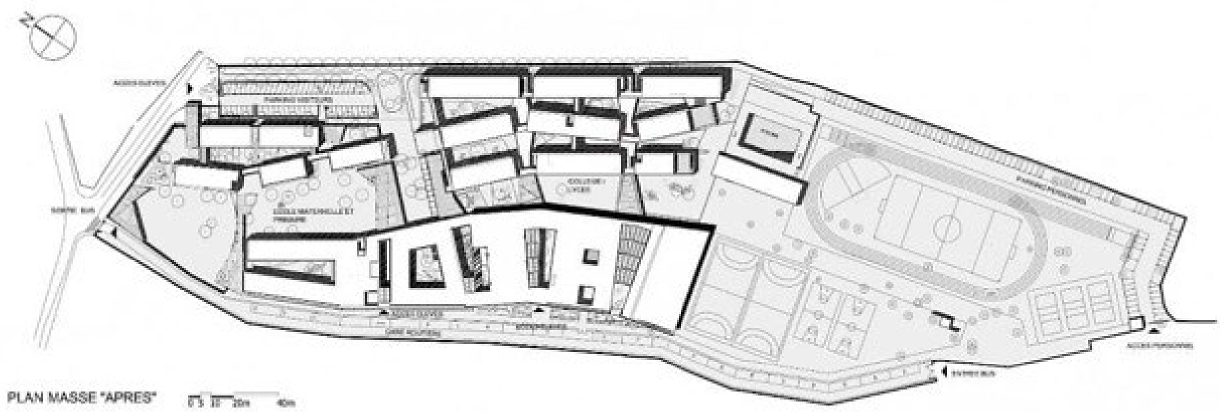


Figure 2: Site plan of the "Lycée Mermoz" ©TERRENEUVE

SITE INTEGRATION

(a) (b)

Figure 125 : Aerial views of the building in its surrounding environment. (Source: (a) Google Map and (b) ©Daniel Rousselot)

The Mermoz high school is located in the densely built-up Ouakam district, along the western coastline of the Dakar peninsula. The new buildings replace the old high school built temporarily in 1994 and made up of prefabricated modular constructions but benefiting from a very appreciated vegetal environment. The French high school has a special relationship with the surrounding neighbourhood, since the configuration of the site offers only two points of contact with the city. Almost totally enclosed, the lycée is hardly visible from the urban space. The project tends to minimize its impact on the immediate environment, and in particular on the existing urban networks. The traffic and parking of school buses and private vehicles has been taken care of within the plot, as well as all water treatment.

CLIMATE ANALYSIS

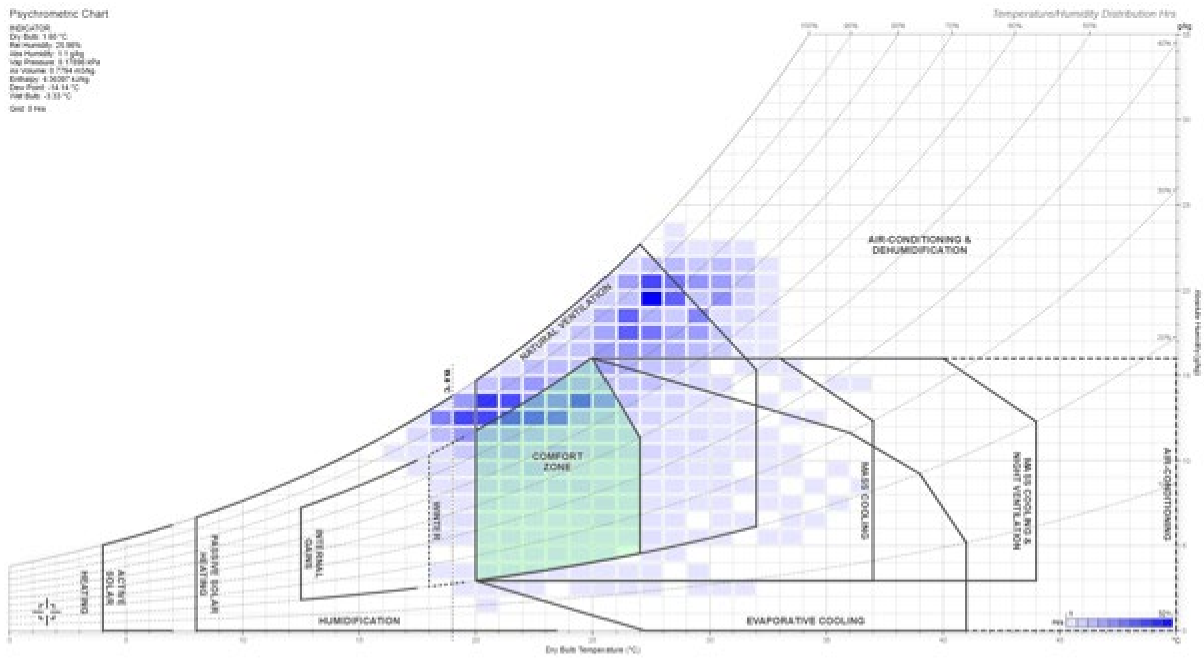


Figure 126: Givoni Bioclimatic chart for the climate of Dakar, Senegal using Andrew Marsh online tool [2]. Climate data are extracted from the database of the climate.onebuilding.org website.

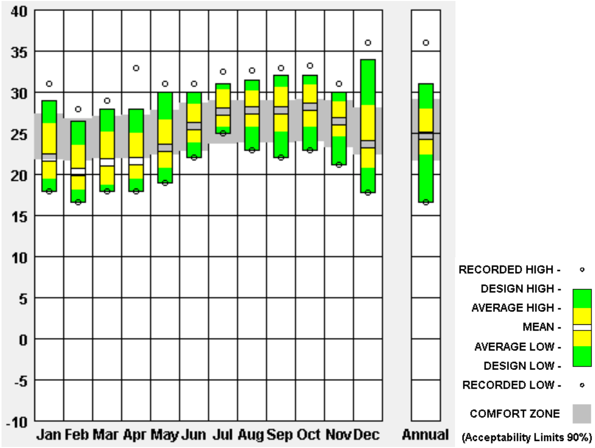


Figure 127: Temperature range by month for Dakar, Senegal (Source: Climate consultant – Adaptative Comfort model).

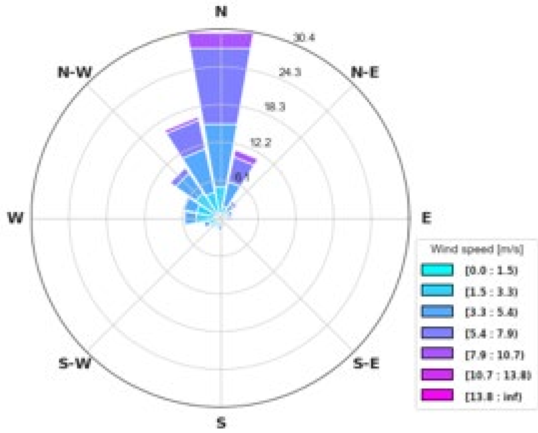


Figure 128: Wind rose for Dakar, Senegal (Beaufort wind scale).

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **5 243** Wh/m² (Dec.) Max: **6 937** Wh/m² (May) Mean: **5 964** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **0** CDD 10°C: **5 364**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **97** CDD: **20**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **5** CDD 26º: **321**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	**Comfort ventilation** (natural cross ventilation) The arrangement of the buildings in relation to each other generates micro-climates in the patios that enhance the natural cooling of the interior spaces. The trade winds, which benefit the oceanic climate of Dakar, justify the linear and tight organization of the buildings which amplifies the effect of the air movements and increases the impression of freshness. The rooms are equipped with so called French windows in the double-walled facades and louvers on the corridor side, which can be used for night-time cooling and also act as an anti-intrusion strategy. High thermal mass of the roofs and ventilated double walls
Passive heating strategy	-
Solar protection	The shading provided by the arrangement of the buildings allows to limit not only the heating of the walls but also of the exterior ground. On the front facade of the teaching spaces, galleries and awnings prevent the sun from impacting the facades during the hottest hours. On the rear facade, ventilated double walls

	prevent the interior walls from heating up, and form thick walls and window panels that limit direct sunlight. All exterior corridors and common pathways are at the same time places of life, architectural walks, and solar protection. Pergolas planted with Bougainvillea and other tropical species also provide shaded spaces.
Building orientation	The main facades of the different buildings are facing the North-East / South-West.
Insulation	Ventilated double walls
Vegetation	The different buildings are surrounded by vegetation (shrubs, trees and flowers). The planted patios create a comfortable microclimate around the buildings and also bring conviviality. Pergolas are covered with Bougainvillea and other tropical species.
Natural daylighting	Large openings on opposite facades allow natural light to enter in the rooms in relation to the constraints of solar protection, also favoured by high ceilings.
Use of local and embedded materials	Unknow
Water saving and flood management	Particular attention was paid to the rainwater management including the infiltration of a large part of the rainwater to limit the discharge to urban networks that are undersized and inefficient. The roofs are designed to allow for delayed runoff during heavy winter rains, with a flow limitation system allowing for temporary storage on the terraces. At the foot of the buildings, the water is channelled into large open vertical gutters and discharged into drainage basins made of several layers of basalt and laterite aggregates associated with drains.
Waste management	An autonomous wastewater treatment plant has been set up to recycle all wastewater. The recycled water is used for watering the green spaces. The plants were chosen from local species that consume little water, so that it is not necessary to use additional water resource.
Others features	-

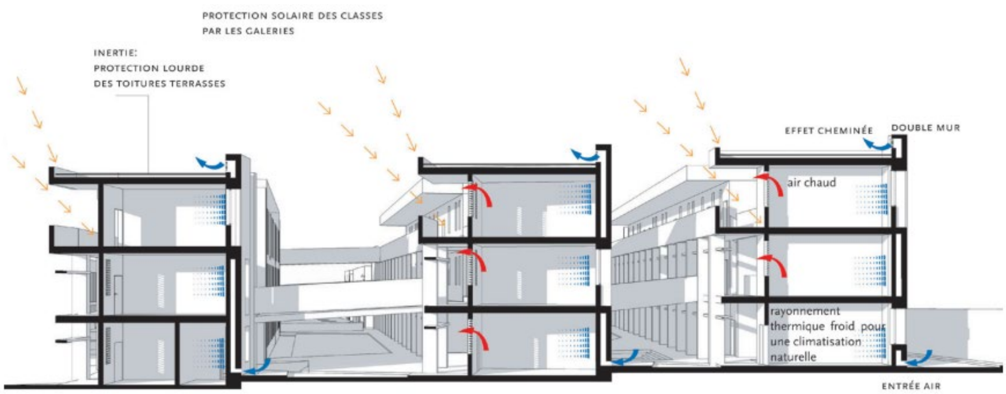


Figure 129: Cross section of the passive solutions set up for the high school buildings. ©TERRENEUVE.

Figure 130: The buildings are connected by exterior corridors. ©Daniel Rousselot

Figure 131: Different solar protection solutions have been set up, such as canopies. ©Daniel Rousselot

Figure 132 : Solar protection strategies also include vertical blade sunshades and pergolas recovered by climbing plants. ©Daniel Rousselot

Figure 133: The planted courtyards create a comfortable microclimate around the buildings and also bring conviviality ©Daniel Rousselot

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): **Unknown**
Protected bike parking and showers	**Unknown** If yes, Ratio with number of users: **-**
Ceiling fans	In every room, even those conditioned: **No**
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: **N/A**
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	In every room, even those conditioned: **N/A**
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.: **No**

BUILDING FABRIC AND MATERIALS	
Roof	**Unknown**

Windows	Type of materials: clear glass
Walls	The **Exterior double walls** are composed of (from outside to inside): ▪ Plaster and paint (1 cm) ▪ Concrete blocks (20cm) ▪ Air gap (35cm) ▪ Concrete blocks (20cm)
	The **Interior Walls** composition is unknown

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	**The building is air-conditioned.**
Low-energy heating systems	None
Ceiling fans	**No ceiling fans**
Mechanical ventilation / air renewal	**Unknown**
Domestic Hot Water	Solar thermal
Artificial lighting	**Unknown**
Control and energy management	None

RENEWABLE ENERGY	
PV	**Unknown**
Solar thermal	**Unknown**
Wind	None
Geothermal	None
Biomass	None

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating (kWh/y/m2)
	2. Energy needs for cooling (kWh/y/m2)
	3. Energy use for lighting (kWh/y/m2)
	4. Energy needs for Sanitary Hot water (kWh/y/m2)
	5. Total Primary energy use (kWh/y/m2)
	6. Renewable Primary energy generated on-site (kWh/y/m2)
	7. Renewable Primary energy generated on-site and self-consumed (kWh/y/m2)
	8. Renewable Primary energy exported to the grid (kWh/y/m2)

	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) : **64 kWh/m²^2.year**
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	Green spaces are appreciated a lot by the users.

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	This first monitoring campaign points out that the building does not work well in terms of thermal and energy performance. Despite favourable outdoor conditions, the indoor air temperature remains above the outdoor conditions in all the monitored spaces. All the spaces are air conditioned. The absence of ceiling fans does not allow to use them to balance the hot conditions or to reduce the period of air-conditioning. The delivered energy (in form of electricity) is equal to 64 kWh/m^2/year, which is quite high for a building that is supposed to be bioclimatic. It is reported that there is not an energy management strategy. Users and staff are not concerned and trained to demand side management. Air conditioning and artificial lighting are used all day long with sometimes the doors opened to the outside.
Recommendations	- Information and training of the staff and the users to demand side management; - Install ceiling fans in all the working spaces (1 CF/10 m^2); - Carry out an in-depth analysis of the electric consumption; - Launch a new measurement campaign and a POE; - Hire an energy manager.

ABC21 is funded by the EU's H2020 programme

BUILDING STRENGTHS AND WEAKNESSES

Strengths

Passive Design

Weaknesses

The building consumes too much energy due to the use of air-conditioning and there is a lack of energy management strategy.

We are doubtful about the efficiency of the double wall used for night time cooling. Due to the weather conditions that are close to a tropical climate, this passive solution may not work properly. Also, the position of the different buildings parallel to each other does not facilitate natural cross ventilation. The window to wall ratio seems to be not sufficient for an effective natural cross ventilation.

REFERENCES

1. https://www.terreneuve.fr/projets/lycee-mermoz-dakar/

CASE STUDY 2-10: MAISON DES YVELINES | SENEGAL

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Route Nationale 2, Ourossogui, Senegal
Latitude; Longitude	15.593247890123722, -13.311984869213356
Climate zone (Köppen–Geiger classification)	BWh : Hot desert
BUILDING INFORMATION	
Building Type	Other: Mixed-use residential and office building
Project Type	New construction
Completion Date	2016
Number of buildings	3
Number of storeys	2
Total Floor Area (m²)	479
Net Floor Area (m²)	367
Thermally conditioned space area (m²)	212 (offices, conference room and bedrooms)
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	267
Total cost (€)	109 000,0
Cost /m² (€/m²)	297,0
Performance Standards or Certification	None
Awards	Low-carbon building prize from the Green Solutions Awards / Construction21 at the COP23 meeting in Bonn Terra Award Sahel+ 2019 winning project
STAKEHOLDERS	
Building Owner/ Representative	Conseil Départemental des Yvelines
Architect / Designer	AL-MIZAN Architecture & développement au Sahel – Mathieu Hardy
Construction manager	ONG Le Partenariat
Structural Engineer, Civil Engineer	Habitat Moderne

Technical expertise	The Nubian Vault Association (AVN)
Others	Regional Development Agency of Matam - Technical Partner Regional Urbanism Service - Technical Partner

PROJECT DESCRIPTION

Figure 134 : Exterior view of the 'Maison des Yvelines'.

The 'Maison des Yvelines' is a mixed-use building combining administrative and reception spaces, as well as accommodation spaces. It consists of three independent two-storey blocks, separated by inner courtyards offering ventilated and shaded spaces as additional quality spaces. The building is made of mud bricks and earth-based mortars, that are locally available and provide thermal inertia.

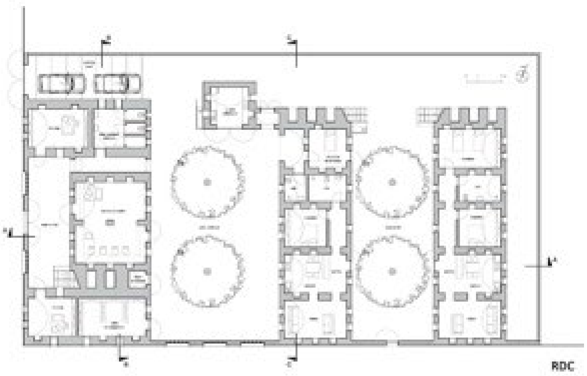


Figure 135: Floor plan of the first floor (©Al-Mizan Architecture)

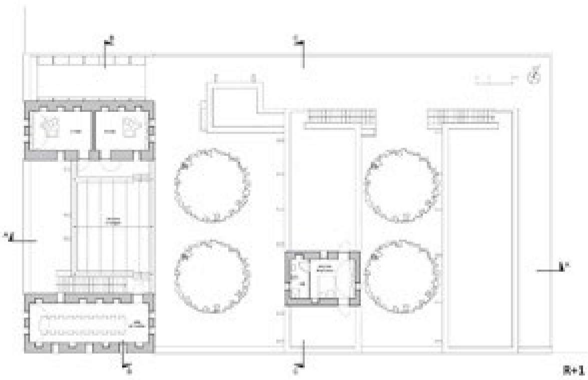


Figure 136: Floor plan of the second floor (©Al-Mizan Architecture)

SITE INTEGRATION

Figure 137 : Aerial view of the building in its surrounding environment

The Maison des Yvelines is located in Ourossogui, in the region of Matam, in eastern Senegal. It is a low-density area with some sparse vegetation.

The building is located along a highway and benefits from its high visibility. The three wings of the building are arranged parallel to the main road. The administrative and reception block is aligned with the main road and offers a welcoming facade while the accommodation blocks are more discreetly positioned behind.

CLIMATE ANALYSIS

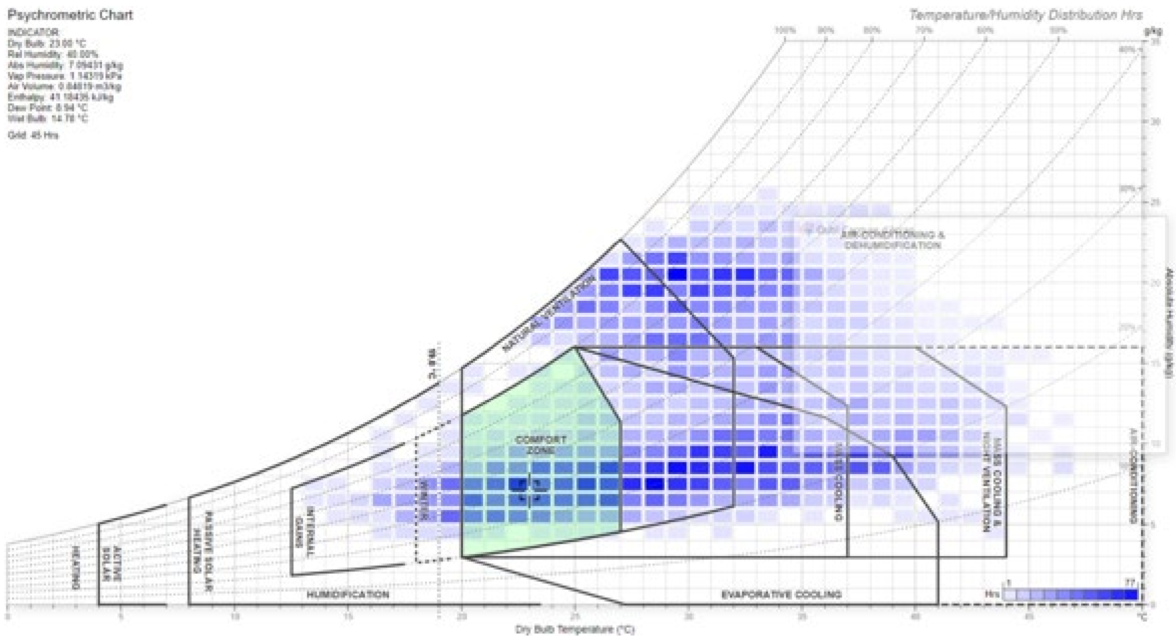


Figure 138: Givoni Bioclimatic chart for the climate of Matam using Andrew Marsh online tool [2]. Climate data are extracted from http://climate.onebuilding.org/WMO_Region_1_Africa/SEN_Senegal/SEN_MT_Matam.616300_TMYx.2004-2018.zip

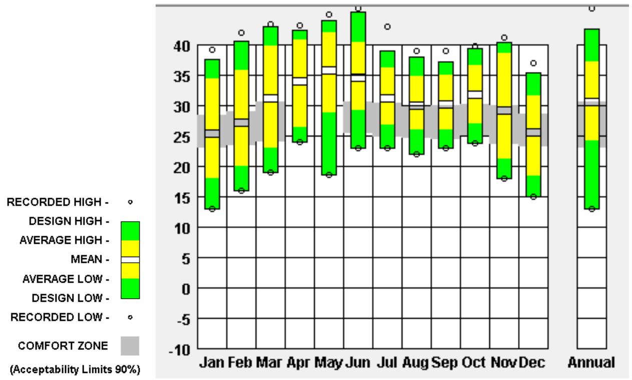


Figure 139: Temperature range by month for the region of Matam, Senegal. (Source: Climate consultant – Adaptative Comfort model).

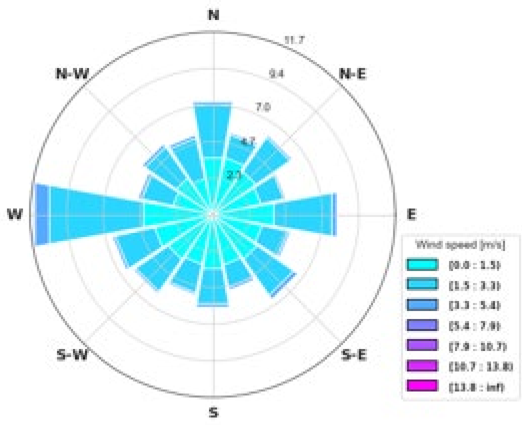


Figure 140: Wind rose for Matam, Senegal.

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **5422** Wh/m² (Dec) Max: **7550** Wh/m² (Apr) Mean: **6421,25** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **6** CDD 10°C: **7500**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **92** CDD: **783**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **10** CDD 26º: **1940**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	Comfort ventilation: Cross natural ventilation High thermal mass of the walls and roofs
Passive heating strategy	High thermal mass of the walls and roofs
Solar protection	The three building blocks are separated by inner courtyards offering ventilated and shaded spaces as additional quality spaces. A pergola built on a steel frame and covered by bamboos offers a protected space on the roof.
Building orientation	All the vaults are oriented East/West to take advantage of the wind.
Insulation	The walls are composed of 60 to 80 cm of mud bricks which provides a high level of "dynamic insulation".
Vegetation	Sparse vegetation and some trees are present around the building and in the courtyards.
Natural daylighting	All rooms are fairly well lit with natural light thanks to the different openings.
Use of local and embedded materials	The building is made of locally sourced raw materials (earth, rocks and water) for adobe bricks and mortar.
Water saving and flood management	Rainwater seeps into the ground through unbuilt spaces. There is no rainwater drainage system.
Waste management	There is no proper waste management system.

Figure 141: View of the patio shaded by the exterior wall

Figure 142 : The different facades present steel windows to allow natural ventilation

Figure 143:View of the inner courtyard and its vegetation

Figure 144: Metal and bamboo pergola provides shaded space on the 1st floor

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): **No**
Protected bike parking and showers	**No** Ratio with number of users: 0
Ceiling fans	In every room, even those conditioned: **Yes**
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: **No**
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	In every room, even those conditioned: **Yes** *Laundry drying facilities are located on the terrace and in the sun.*
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.: **No**

BUILDING FABRIC AND MATERIALS	
Roof	Waterproofing of the terraced roofs (from top to bottom): ▪ An anti-erosion plaster stabilised with tar of 3 cm ▪ A 6 cm layer of packed earth ▪ Plastic sheet ▪ A 2 cm layer of packed earth (at its lowest point) The roofs are buttressed to form flat roof terraces. The roof buttresses are made of mud bricks (banco) of 38 × 18 × 18 cm recovered from the inside by a fine clay plaster, lime and paint.
Windows	Single-glazed windows protected with steel grills
Walls	The **Exterior Walls** are composed of (from outside to inside): ▪ Cement render

- Mud bricks [dimension: 38 × 18 × 18 cm] with stony bricks (mud bricks with encrusted stones) on the outside layer
- A 2cm cement plaster and paint

The majority of the exterior walls are 60 cm or 80 cm thick.

The **Interior Walls** are made of mud bricks. The thickness of the walls can vary from about 20 cm (for some of the partition walls facing the interior corridors) to 60 cm (for the majority of the walls).

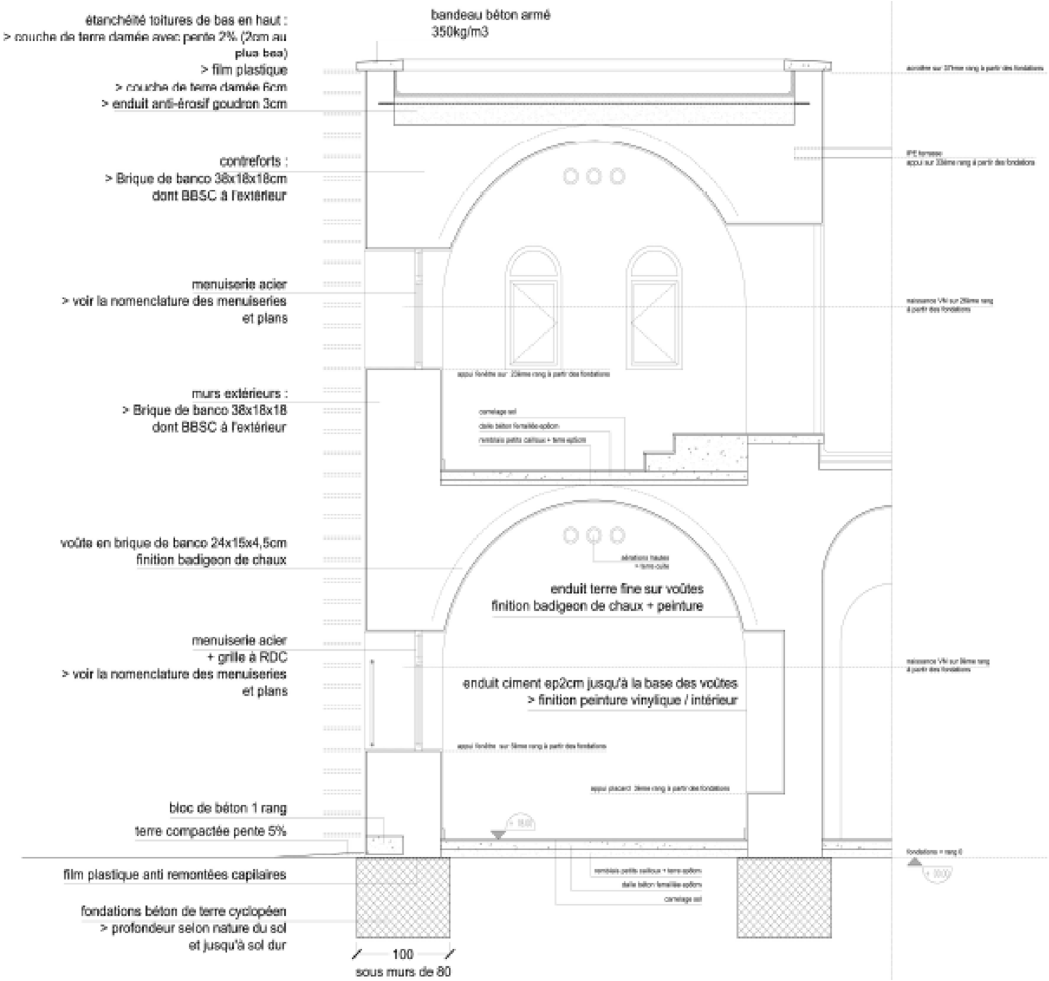


Figure 145:Cross-section of the vault principle

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	**Split system** **Sharp brand / cooling capacity of 3.5 kW**
Low-energy heating systems	None
Ceiling fans	**All offices, bedrooms and living rooms are equipped with ceiling fans (Evernal type)**
Mechanical ventilation / air renewal	None
Domestic Hot Water	**Electrical water heater (Ariston type / capacity of 49 l / power = 1500 W)**

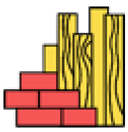
Artificial lighting	**LED's lamps (8W)**
Control and energy management	None
RENEWABLE ENERGY	
PV	Two solar lamps for outdoor lighting
Solar thermal	None
Wind	None
Geothermal	None
Biomass	None

Figure 146: Interior view of a typical (a) bedroom, (b) office and (c) of the meeting room. All rooms are equipped with a split system and ceiling fans.

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating (kWh/y/m2)
	2. Energy needs for cooling (kWh/y/m2)
	3. Energy use for lighting (kWh/y/m2)
	4. Energy needs for Sanitary Hot water (kWh/y/m2)
	5. Total Primary energy use (kWh/y/m2)
	6. Renewable Primary energy generated on-site (kWh/y/m2)
	7. Renewable Primary energy generated on-site and self-consumed (kWh/y/m2)
	8. Renewable Primary energy exported to the grid (kWh/y/m2)

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

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	The building was designed with the aim to disseminate an ancestral technical concept, perfectly adapted to the Sahel region: the Nubian Vault. The technical concept presents a simple, replicable and economical bioclimatic solution in hot climates. The technical method is **very easily taught,** with the **training of local workers on site**. A large range of architectural choices is possible, from housings to offices or health care buildings, and extensions can be easily added to the initial building.
Recommendations	-

BUILDING STRENGTHS AND WEAKNESSES			
Strengths			
			
Passive Design	**Local Materials**	**Replicability**	**Affordability**

The project is a bioclimatic design featuring **comfort ventilation**, **thermal inertia** and the use of **locally available material** for construction. A key factor in its design is the **affordability**, the **replicability** and the **modularity** of the Nubian Vault technique.

ABC21 is funded by the EU's H2020 programme

Weaknesses
-

REFERENCES

1. https://almizan-sahel.com/a-propos
2. https://www.construction21.org/case-studies/h/maison-des-yvelines-nubian-vault,es.html
3. https://www.lavoutenubienne.org/the-nv-maison-des-yvelines-winner-of-the-low-carbon-green-solutions-award

CASE STUDY 2-11: MBAKADOU PRIMARY SCHOOL – 3rd Classroom | SENEGAL

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Mbakadou village, Touba Merina rural community, Darou Mousty district, Kébémer department, Louga Region, Senegal
Latitude; Longitude	15°17'30.4"N 15°56'09.8"W
Climate zone (Köppen–Geiger classification)	BSh: Hot semi-arid steppe
BUILDING INFORMATION	
Building Type	Educational
Project Type	New construction
Completion Date	2019
Number of buildings	1
Number of storeys	1 (ground floor)
Total Floor Area (m^2)	Classroom: 74
Net Floor Area (m^2)	Classroom: 74
Thermally conditioned space area (m^2)	0
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m^2)	Classroom: 74
Total cost	~15 000 €

Cost /m²	~203 €/m^2
Performance Standards or Certification	-
Awards	-
STAKEHOLDERS	
Building Owner/ Representative	Public School Darou Diop 2
Architect / Designer	Architetti Senza Frontiere Italia
Construction manager	Touba Merina building company (construction) + GIE GANDIOL BATIMENT (thatch)
Others	Mbakadou village (beneficiaries and participants in the construction), Associazione Solidarietà Dimbalente and Associazione Insieme (promoters and facilitators)

PROJECT DESCRIPTION

ABC21 is funded by the EU's H2020 programme

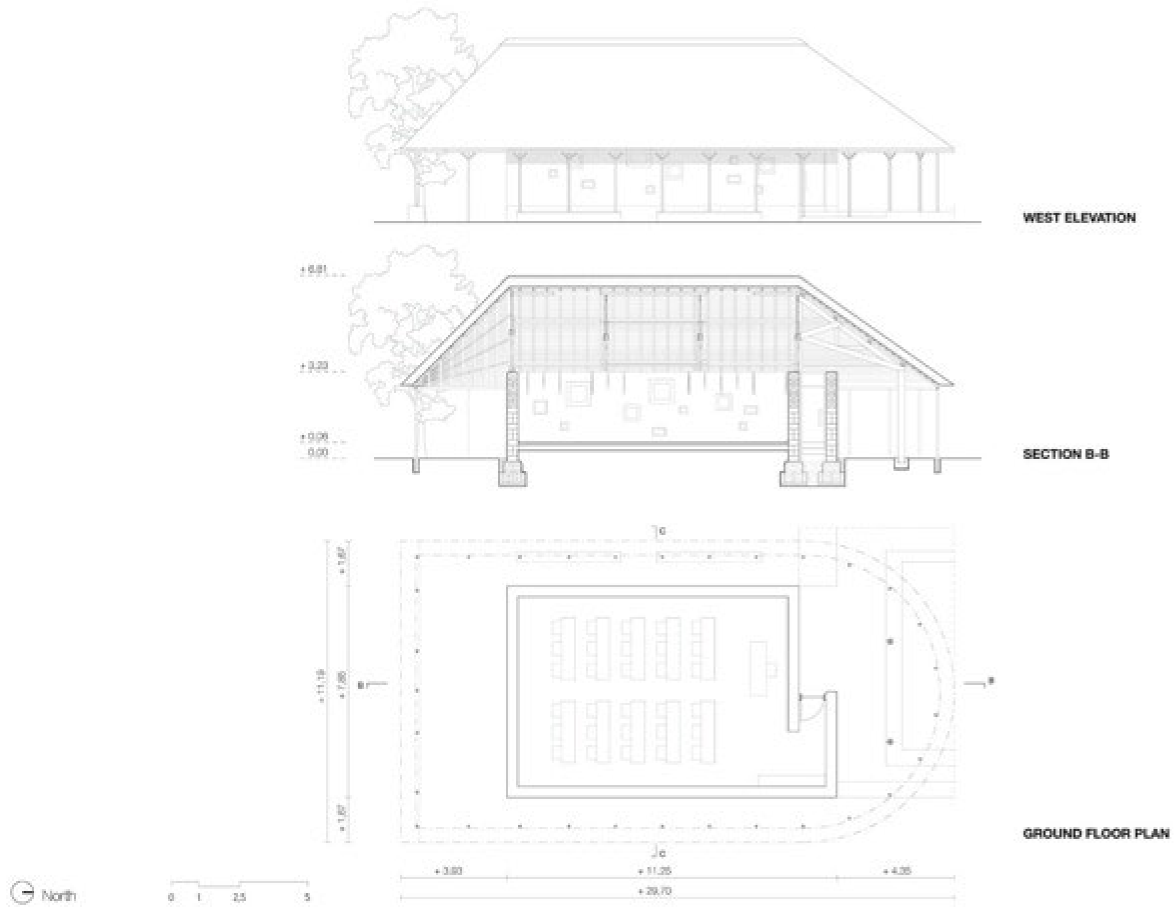


Figure 147 West elevation, longitudinal section, and ground floor plan of the third classroom

The Mbakadou school consists of three independent classrooms, a fence with 14 tanks for collecting rainwater, a cassava orchard, a kitchen with a bread oven, a toilet block, and an ablution area. Independent classrooms were built due to the bottom-up character of the project: a new classroom was built each time the necessary funds could be raised.

After the construction of the first classroom, Solidarietà Dimbalente, Insieme, and the community of Mbakadou called Architetti Senza Frontiere Italia to rethink and improve the general project of the school for the third classroom to come.

The new project was thus designed based on bioclimatic principles so as to enhance thermal comfort, valorise local natural materials and sustainable processes, as well as directly involve the participation of local people both in the design and building phases.

The school's newest classroom, built between 2018 and 2019, is characterised by a thatch roofing in Typha that shapes a porch all around the building and shelters the earthen walls from the rain; clusters of windows on the East, South, and West sides that allow natural free cooling; an entrance protected from winds.

The building combines low-tech technologies and local traditional knowledge: Foundations are made of on-site quarried sandbags, walls are of mudbricks and earth plaster, the thatched roof has a structure of wooden planks and bamboo.

SITE INTEGRATION

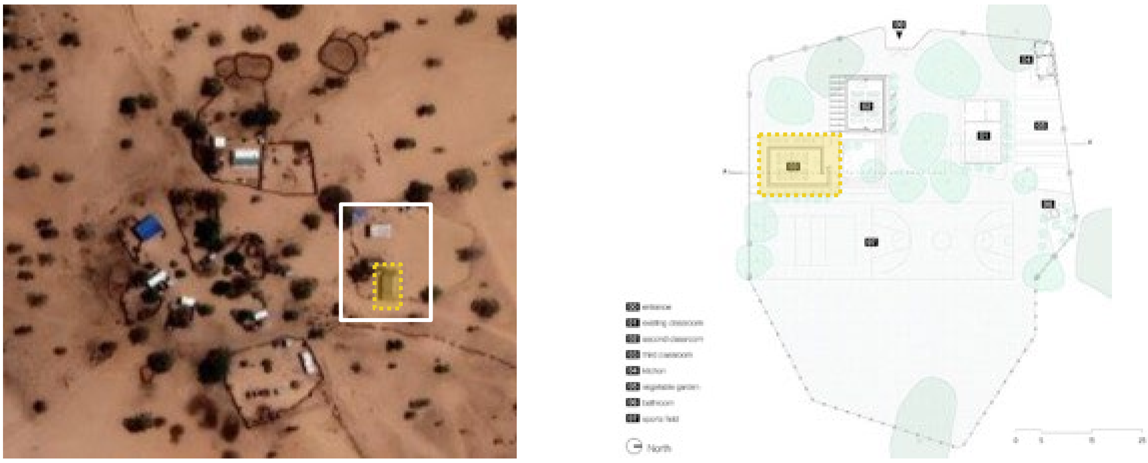


Figure 148 : (a) Aerial view and (b). ground plan of the Mbakadou primary school. (source: Google Earth and ASF Italia)

Mbakadou is a small rural village of about 600 inhabitants, located in the Louga region of Senegal, very close to the sub-Saharan area. The landscape is characterised by a mainly sandy soil dotted with baobab trees which provide shade and around which village life is concentrated during the hottest hours. The classrooms serve all the surrounding villages, which are sometimes dozens of kilometres away.

CLIMATE ANALYSIS

Mbakadou is very close to the pre-desert region, an area that is experiencing progressive desertification. The school borders the village's eastern side; thus, it is fully exposed to the prevailing desert winds, which blow from the northeast to the southwest. The climate is hot and dry, with little rainfall even during the rainy season.

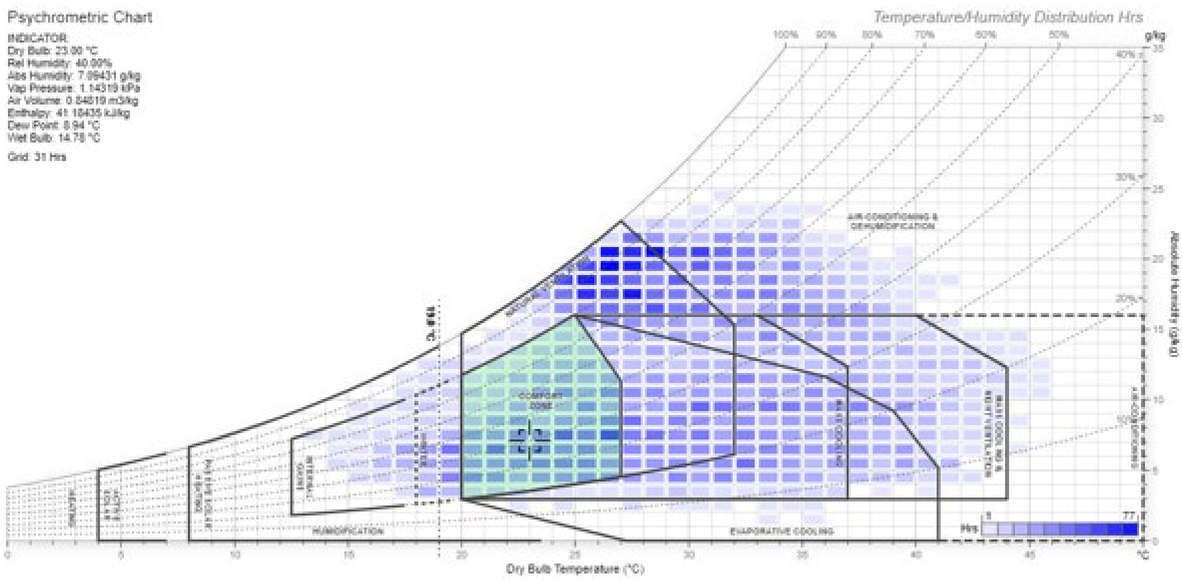


Figure 149: Givoni Bioclimatic chart for the climate of the Louga region using Andrew Marsh online tool [2]. Weather data are extracted from the PVGIS tool of the jrc for the 2007 – 2016 period.

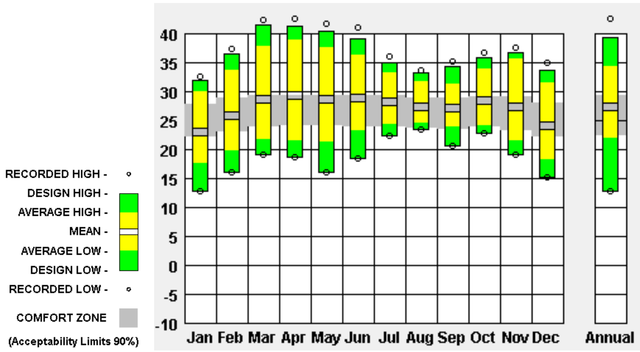


Figure 150: Temperature range by month for the Louga region, Senegal (Source: Climate consultant – Adaptative Comfort model).

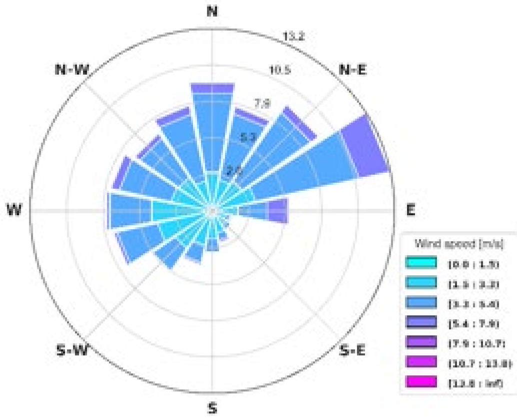


Figure 151: Wind rose for the Louga region, Senegal

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **5 208** Wh/m² (Dec.) Max: **7 722** Wh/m² (Apr.) Mean: **6 339** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **11** CDD 10°C: **6 311**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **121** CDD: **390**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **17** CDD 26º: **973**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	**Comfort ventilation: Natural cross-ventilation** **Nocturnal convective cooling** Windows of varying sizes and heights arranged on three sides of the building bring 24h natural cross-ventilation. The free space between the walls and the roof structure also contributes to cross-ventilation. Thick walls and thatch roofing provide high thermal inertia.
Passive heating strategy	High thermal mass of the walls.
Solar protection	The Typha roof overhang protrudes the building on all sides, shading windows and walls.
Building orientation	The main facades of the building are oriented East/West. .
Insulation	Thermal insulation is provided by the materials and thicknesses of the roof (Typha, 35cm) and walls (Mudbricks, 40cm), which give the building great thermal inertia.
Vegetation	Shrubs and trees have recently been planted close to the building. Indeed, between 2021 and 2022, the entire school area was planted with shrubs and trees, creating a cassava garden, and bougainvillaea has been installed along the fence. The aim is to cool the air temperature, counteract the action of the winds, and improve the environment quality.

Natural daylighting	Natural daylighting is generous and partially shielded by the roof overhang.
Use of local and embedded materials	The clay used for the bricks, plaster and floor was quarried about 100 metres from the school. The foundations are made with sand excavated from the same foundation pit. The Typha for the roof was collected about 90 km from the village.
Water saving	-.
Waste management	-.

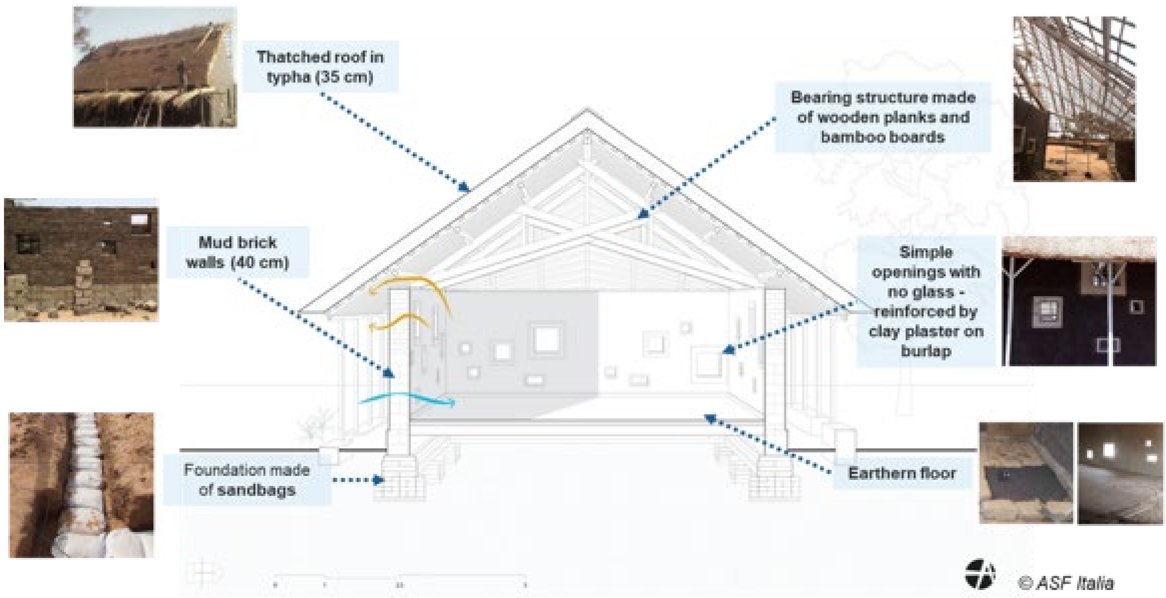


Figure 152: Cross section of the bioclimatic strategies implemented in the classroom. The main strategies include natural cross ventilation, high thermal mass of the walls and roofs, solar shading with the large roof overhangs and the use of local materials (mudbricks and Typha).

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): **No** *The school well accepts it, but there is no particular indication/promotion.*
Protected bike parking and showers	**No** Ratio with number of users: 0
Ceiling fans	In every room, even those conditioned: **No**
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: **No**
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	Available through leaflets and posters at relevant places, online, etc.: **Yes.**

savings) and active (lighting…) in order to promote sufficiency and efficiency actions	*An illustrated manual for the use and maintenance of the school (classrooms, kitchen, open spaces) will be completed in 2022.*

Figure 153 : Construction materials. Top, from left to right: bonded sandbags foundations, mudbrick walls, wooden plank truss. Bottom, from left to right: earth plaster, earth floor and Typha thatched roof.

BUILDING FABRIC AND MATERIALS	
Roof	▪ Thatched roof in typha [0.35m] ▪ Bearing structure made of wooden planks and bamboo boards
Windows	▪ Unglazed windows - simple openings with no glass nor brise-soleil. ▪ Each window frame is reinforced by clay plaster on burlap (clay is more water-resistant than earth plaster).
Walls	The **walls** are composed of (from outside to inside): ▪ Earth plaster [0.03 – 0.04m] ▪ Mudbrick [0.40m] ▪ Earth plaster [0.03 – 0.04m] The first courses of bricks (those closest to the foundations) are improved with approximately 8% cement for better water resistance (following CRAterre guidelines and on-site tests).
Basement floor	Earthen floor

Figure 154 : Exterior view of the East façade of the classroom during the rainy season.

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	None
Low-energy heating systems	None
Ceiling fans	None
Mechanical ventilation / air renewal	None
Domestic Hot Water	None
Artificial lighting	None The school operates during daylight hours, so no artificial lighting is needed. As the village sometimes uses the classrooms in the evening as a meeting place, (a few) light bulbs were installed in the classrooms in February 2022, powered by the photovoltaic panel in the school kitchen.
Control and energy management	None

RENEWABLE ENERGY	
PV	No PV systems for this classroom.
Solar thermal	None
Wind	None
Geothermal	None
Biomass	None

(a) (b) (c)

Figure 155 : Views of the bearing structure of the thatched roof under construction (a)(b) and interior view of the classroom with the Typha roof (c).

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

2. 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: **Building 1: 47.4 %** **Building 2: 48.6 %**

6. Percentage of time inside the Givoni comfort zone of 0m/s: **Building 1: 31.0 %** **Building 2: 33.4 %**

7. Number of hours within a certain temperature range:

Warm period: 15th Nov. 2022 to 10th March 2023 Occupation time: 8:00am to 4:00pm	Building 1 – M1		Building 2 – M2	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<20°C	28	3,7%	24	3,1%
20°C≤Ta<22°C	36	4,7%	64	8,3%
22°C≤Ta<24°C	82	10,7%	89	11,6%
24°C≤Ta<26°C	102	13,3%	122	15,9%
26°C≤Ta<28°C	125	16,3%	142	18,5%
28°C≤Ta<30°C	139	18,1%	139	18,1%
30°C≤Ta<32°C	126	16,4%	114	14,9%
32°C≤Ta<34°C	89	11,6%	61	8,0%
34°C≤Ta<36°C	21	2,7%	12	1,6%
Ta≥36°C	19	0,7%	0	0,0%

Energy performance indicators

11. Energy needs for heating (kWh/y/m2)

12. Energy needs for cooling (kWh/y/m2)

13. Energy use for lighting (kWh/y/m2)

14. Energy needs for Sanitary Hot water (kWh/y/m2)

15. Total Primary energy use (kWh/y/m2)

16. Renewable Primary energy generated on-site = **0** [kWh/m^2/year]

17. Renewable Primary energy generated on-site and self-consumed = **0** [kWh/m^2/year]

18. Renewable Primary energy exported to the grid = **0** [kWh/m^2/year]

19. Ratio of renewable primary energy over the total primary energy use (with and without compensation) = **0 %**

20. Delivered energy (from electricity bills) = 0 [kWh/m^2/year]

Acoustic comfort indicators

1. Airborne sound insulation

2. Equivalent continuous sound Level

3. HVAC noise level

4. Reverberation time

5. Masking/barriers

Visual comfort indicators

1. Light level (illuminance)

2. Useful Daylight Illuminance (UDI)

	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	-

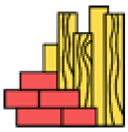
LESSONS LEARNED AND RECOMMENDATIONS

Lessons learned	▪ The different results obtained highlight the impact of the high thermal inertia of the materials used, with the mud brick walls of 40 cm and the typha roof of 35cm. ▪ Another important point to emphasise is that no thermal lag is observed in this case study while this phenomenon is generally observed in buildings with high thermal inertia. One of the assumptions made is that since the buildings are made of small openings with no glass (only simple holes in the walls), the air is continuously entering the buildings both during the day and at night and is counterbalancing the effect of thermal mass.
Recommendations	Given what can be seen on the Givoni diagram, it might be useful to do night ventilation and avoid ventilating during the day, but there are presently no windows to allow this. If the cost of glazing is not affordable, other type of closures (eg translucent plastic sheets) might be considered.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

Passive Design



Local Materials

Replicability

Affordability

The Mbakadou primary school was designed with bioclimatic considerations in terms of cooling, ventilation and use of locally available materials.

Weaknesses

-

REFERENCES

1. https://www.asfitalia.org/primary-school-mbakadou-senegal

CASE STUDY 2-12: CHILDREN'S SURGICAL HOSPITAL | UGANDA

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Plot 120-122 Bishop Dunstan Nsumbuga Road, Entebbe, Uganda
Latitude; Longitude	0.08378874306047031, 32.45785942464613
Climate zone (Köppen–Geiger classification)	Af: Equatorial rainforest
BUILDING INFORMATION	
Building Type	Health Facility | Hospital
Project Type	New construction
Completion Date	2020
Number of buildings	1
Number of storeys	2
Total Floor Area (m²)	**Unknown**
Net Floor Area (m²)	9 700
Thermally conditioned space area (m²)	9 700
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	**0**
Total cost	22 715 036 € (construction and equipment)
Cost /m² (€/m²)	**2 341.8**
Performance Standards or Certification	None
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	EMERGENCY
Architect / Designer	Renzo Piano Building Workshop & Studio Tam Associati
Design team	▪ RPBW - G.Grandi (partner in charge), P.Carrera, A.Peschiera, D.Piano, Z.Sawaya and D. Ardant; F.Cappellini, I.Corsaro, D.Lange, F.Terranova (models) ▪ TAMassociati -R.Pantaleo, M.Lepore, S.Sfriso, V.Milan, L.Candelpergher, M.Gerardi

	▪ EMERGENCY Field Operations Department, Building Division - Roberto Crestan, Carlo Maisano
Mechanical, Electrical and Plumbing (MEP) engineering	Prisma Engineering
Structural Engineer, Civil Engineer	Milan Ingegneria
Landscape design	Studio Giorgetta - Franco and Simona Giorgetta
Fire Consultants	GAE Engineering, J&A Consultants

PROJECT DESCRIPTION [1][2]

Figure 156 : Floor plan of the building © RPBW architects

The Children's Surgical Hospital is a project of medical, health, economic and environmental sustainability.
The challenge was to combine excellent paediatric surgery and excellent architecture, creating a "healing architecture". This concept is based on the fact that: "Beauty is not just an aesthetic choice; it is part of treatment" [3]. One of the guiding principles of the project was the idea of a hospital that was not just functional and efficient from a medical point of view, but also 'beautiful'. Every detail of the hospital was built with children in mind. The walls are covered in pictures, colour is everywhere and the garden offers a place to play. This modern building is also firmly linked to tradition, using the rammed earth technique. The same architectural principles used for traditional houses was implemented but in an innovative way.

Figure 2: Section of the building. © RPBW architects

SITE INTEGRATION

Figure 157 : Aerial view of the building in its surrounding environment. (Source: Google Map)

The Children's Surgical Hospital is located in Entebbe, Uganda, close to the Victoria Lake and to an urbanised area. The Children's Surgical Centre sits on the banks of Lake Victoria. It is a very green spot, almost 4000 feet (1,150 m) above sea level, chosen for its clean air and beautiful surroundings. "The building follows the curves that slope down to the lake. By following the course of the land, the hospital walls and the boundaries of its outdoor pathways will form terraces on which the hospital itself will stand, in a spatial continuum between interior and exterior, above and below. The stacked walls will break the distinction between the various zones, creating a unity between the lake, the park and the internal hospital environment" [1][2].

ABC21 is funded by the EU's H2020 programme

CLIMATE ANALYSIS

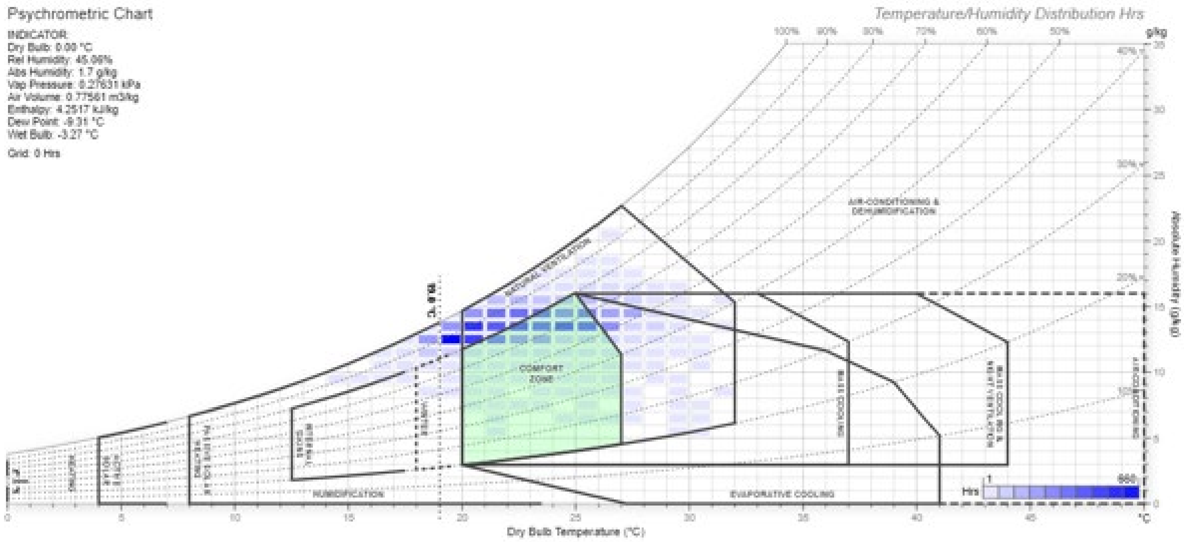


Figure 158: Givoni Bioclimatic chart for the climate of Entebbe, Uganda using Andrew Marsh online tool [2]. Climate data are extracted from the database of the climate.onebuilding.org website.

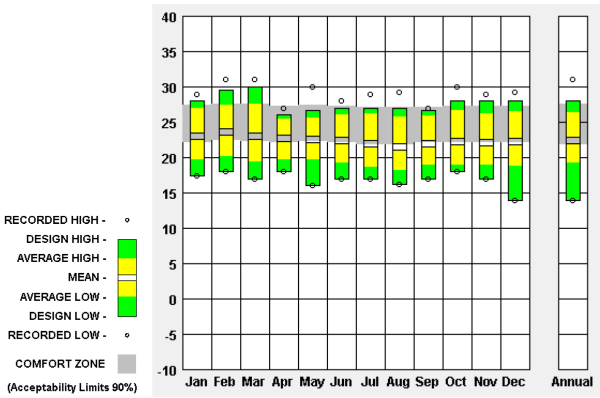


Figure 159: Temperature range by month for Entebbe, Uganda (Source: Climate consultant – Adaptative Comfort model).

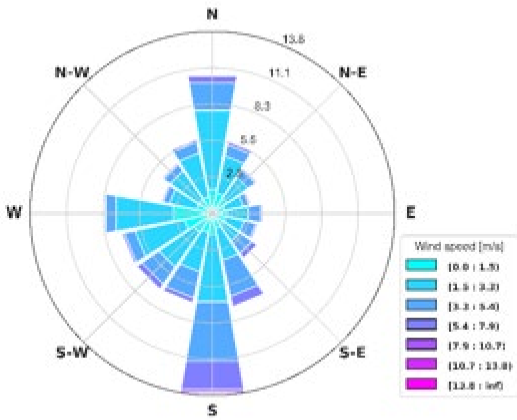


Figure 160: Wind rose for Entebbe, Uganda (Beaufort wind scale).

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **4 999** Wh/m² (May) Max: **6 249** Wh/m² (March) Mean: **5 662,7** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **2** CDD 10°C: **4 545**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017	HDD: **196** CDD: **3**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **9** CDD 26º: **40**

ABC21 is funded by the EU's H2020 programme

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	The rammed earth has a high level of thermal inertia, which makes it easy to control the temperature in the building and stop heat entering and cold escaping.
Passive heating strategy	High thermal mass of the load-bearing walls made of raw earth.
Solar protection	The roof canopy structure, "floating" above the building, will provide shade for the building and all the uncovered walkways.
Building orientation	The main façades of the two wings of the building are oriented North-East and South-West.
Insulation	The massive walls made of raw earth contribute significantly to cooling down the interior spaces.
Vegetation	Gardens are an essential feature of EMERGENCY's hospitals all over the world, and not just because they are natural air conditioners, but they are the basis of so-called 'healing architecture'. The heart of the Children's Surgical Centre is its garden which is full of plants grown during construction, using the technique of air pruning. The plants are grown above ground, in huge pots made of wire frames and jute. Over two years the plants have doubled in size, thanks in part to the favourable climate. A garden with 350 trees offers a place to play and to recover to children.
Natural daylighting	Large windows fill the rooms with natural light.
Use of local and embedded materials	The excavated land has been used to build the load-bearing walls with the rammed earth technique. The same architectural principles used for traditional houses were used in an innovative way.
Water saving and flood management	A gutter runs from the roof of the facility, collecting rainwater, filtering it and reusing it to water plants and clean outdoor areas, so as not to waste the water that comes from the mains.
Waste management	**Unknown**
Others features	-

Figure 162 : View of the shaded exterior walkways

Figure 161: The suspended canopy structure provides shade to the building and the walkways. © Emmanuel Museruka – Malaika Media

© Emmanuel Museruka – Malaika Media

Figure 163: View of the load-bearing walls made of raw earth. © Emmanuel Museruka – Malaika Media

Figure 164: View of the inner courtyard © Emmanuel Museruka – Malaika Media

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): **No for the staff**
Protected bike parking and showers	**Unknown** If yes, Ratio with number of users: **Unknown**
Ceiling fans	In every room, even those conditioned: **No** No ceiling fans, air is supplied and extracted by Ahus through ducts; exceptions are some small extractions fans from toiles not reachable by main ducting and in technical rooms in plant area.
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: **Yes** Lighting system is fractioned by areas (supply by means of lv electrical boards) and by service (normal and emergency lighting system).
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	In every room, even those conditioned: **Unknown**
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.: **Unknown**
BUILDING FABRIC AND MATERIALS	
Roof	Suspended canopy structure in galvanised steel. The solar energy system is linked to one of the hospital's most distinctive features: its pair of roofs. The higher of the two, used for cover, is made of corrugated sheet metal and supports the 2 500 panels, which have

ABC21 is funded by the EU's H2020 programme

	the twofold function of capturing energy and providing shade, thereby helping control the temperature in the building. The lower roof is made of Zintek, an alloy of zinc, titanium and copper. There is a space between the two varying from seven to 20 feet (two to seven metres), which is used for maintenance.
Windows	Clear glass
Walls	Load-bearing walls made of raw earth. The walls are approximately two feet (60 cm) wide and have a volume of 62,285 cubic feet (1,763.7 m3).

Figure 165: View of the canopy structure.
© Emmanuel Museruka – Malaika Media

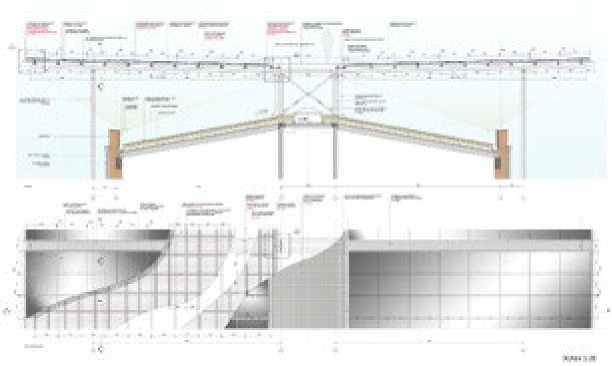


Figure 166: Details of the suspended canopy structure.
© RPBW architects

ENERGY EFFICIENT BUILDING SYSTEMS

Low-energy cooling systems Mechanical ventilation / air renewal	HVAC systems In order to protect patients, staff and visitors from germs, the hospital is served with a pass-through system without recirculation of the air (which could give an energy saving): air is filtered, thermal treated, used by relevant areas and then disposed to the outside, without reusing it. Air Handling Units (AHU) have been used to take air from outside then filtering the air thanks to various types of filters (depending upon the function of the area standards and finally, thermally treat the air by using Cool or Hot water produced by chiller (cold) or multipurpose machine (cold and hot) and boiler (hot). Cold water to 7/12°C is produced to lower air temperature, use economizers on AHUs to raise a bit the temperature of the air in order to dehumidify it, and give the desired temperature before releasing it in ambient by means of postheating batteries; in specific cases cold water was used to fan coils and VRF (pharmacy and kitchen stores, electrical rooms, corridors or areas exposed to direct sunlight) to mitigate the irradiation and convection effects during the exposure to the sun or emitted by the devices and boards). All the AHU are equipped with a water recovery system with a dedicated circulation pump that performs a free pre-cooling of the external air, through a battery system: the first one removes heat from the incoming air; the second transfers it to the cooled air by carrying out a first free post-heating. The system starts when the outside temperature is favourable. In

	this regard, a special thermostat is installed on the external air channel. A thermostat on the air delivery stops recovery if the air temperature is higher than the need for air conditioning. The air exhaust from Toilets is made by AHU (because there is no air recirculation and all the air collected is pulled outside) or by means of local exhaust fans.
Low-energy heating systems	None
Ceiling fans	None
Domestic Hot Water	The production of hot domestic water is made by solar panels combined with a diesel boiler. Both boiler and solar panels provide energy to the sanitary water going to the hospital (tanks are water to water heat exchangers); these tanks are filled by cold domestic water, with a dedicated line that starts from the stainless-steel manifold; hot domestic water circuit is built mainly by multilayer pipes (the underground portion is made by pre-insulated pipes)
Artificial lighting	All the lighting of the hospital was realized using **LED** lamps (to reduce power consumption). In the offices and all the spaces, where computers are often used, the lighting devices are UGR<19 in accordance to UNI EN 12464-1. Depending upon the installation location, different lighting commands (switches, buttons, **presence sensors**, etc.) have been installed. Total power for internal lighting= 32 kW Total power for external lighting= 5 kW
Control and energy management	The temperature control is made by zones. The system has post-heating coils. Each post-heating coil is for a zone made by more rooms. For each zone there is a panel RLU220, with a temperature sensor installed on the exhaust duct. The universal controllers RLU220 controls the temperature of the zone in relation to the temperature set point required. The post-heating coil circuit will be better described in next paragraphs. For each operating room, there are two set point adjusters: one is used to modify the temperature set-point on RLU220 adding or reducing the temperature up to a maximum 3 °C; the other one for the regulation of the VAV installed on the supply and exhaust ducts in order to modify the air change – 20 volumes per h during the operation, less (5 volumes /h) during the stand-by of the room.

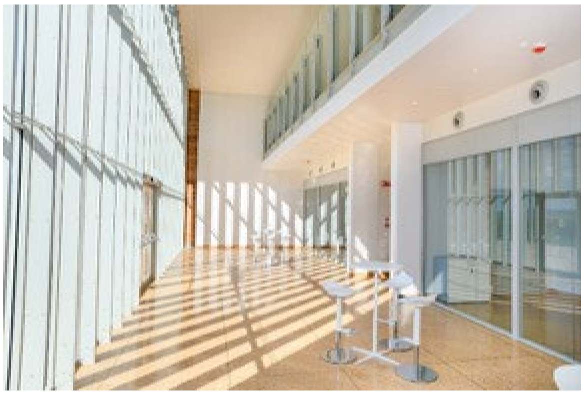


Figure 167: Large windows provide natural light inside the building. © Emmanuel Museruka – Malaika Media

Figure 168 : Interior view of the building. © Emmanuel Museruka – Malaika Media .

RENEWABLE ENERGY	
PV	The hospital is equipped with 3600 m2 of photovoltaic panels. This system will provide a portion of the electricity needed by the building, in order to reduce energy usage. The hospital's maximum demand is 750 kW, a third of which is provided by the panels in the daytime, enough to provide the necessary air conditioning. **Type:** Building integrated PV over-roof **Technology:** thin film **Number of panels:** 2352 **Surface covered:** 3600 m2 **Power at peak as per data sheets: 276,3 kWp** Average monthly downtime of national power from Feb. to May 2022: 62 hours/month
Solar thermal	Thermal solar system made by 28 panels on the roof of the Plant Area with horizontal installation with an angle of 15°, ideal inclination in relation to the latitude of the place, connected with a closed circuit made by copper pipes to the heat exchangers tanks.
Wind	None
Geothermal	None
Biomass	None

Figure 169: 3 600 m^2 of photovoltaic panels are installed on the rooftop of the building. © Emmanuel Museruka – Malaika Media

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating (kWh/y/m2)
	2. Energy needs for cooling (kWh/y/m2)
	3. Energy use for lighting (kWh/y/m2)
	4. Energy needs for Sanitary Hot water (kWh/y/m2)
	5. Total Primary energy use (kWh/y/m2)
	6. Renewable Primary energy generated on-site (kWh/y/m2)
	7. Renewable Primary energy generated on-site and self-consumed (kWh/y/m2)
	8. Renewable Primary energy exported to the grid (kWh/y/m2)
	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)
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	-

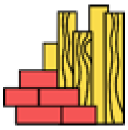
LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	-
Recommendations	-

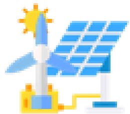
- There appear to be glazed surfaces , both vertical and skylights, which are missing external solar protections; this should be checked and in case , external solar protections provided
- a heat recovery heat exchanger might be applied to the air conditioning plant. It allows recovering energy without contact or mixing of exhaust air (potentially contaminated) with fresh outdoor air. See e.g. https://passivehouseaccelerator.com/articles/prof-wolfgang-feist-we-can-still-do-it

BUILDING STRENGTHS AND WEAKNESSES

Strengths


Passive Design


Local Materials


Renewable Energy

Weaknesses

-

REFERENCES

1. RPBW projects, Children’s Surgical Hospital, 2013 - 2020, Entebbe, Uganda. Accessed 12 May 2022. http://www.rpbw.com/project/emergency-childrens-surgery-center.
2. Children's Surgical Hospital / Renzo Piano Building Workshop + Studio TAMassociati " 27 Jul 2021. ArchDaily. Accessed 12 May 2022. https://www.archdaily.com/965709/childrens-surgical-hospital-renzo-piano-building-workshop-plus-studio-tamassociati . ISSN 0719-8884
3. Children’s surgical hospital in Entebbe. Accessed 12 May 2022. URL: https://en.emergency.it/projects/uganda-entebbe-paediatric-surgery-centre/

ANNEX B : Description of Case studies | PHASE 1

EUROPE

Case study 1-01 : Botticelli project, Italy

Case study 1-02 : CML Kindergarten, Portugal

Case study 1-03 : IZUBA Energy, France

LA REUNION

Case study 1-04 : Niama, La Reunion

Case study 1-05 : ENERPOS, La Réunion

Case study 1-06 : Moufia lecture theater, La Réunion

AFRICA

Case study 1-07 : Maison des énergies, Sénégal

Case study 1-08 : UNON Office Building, Kenya

Case study 1-09 : Villas des chercheurs, Morocco

Case study 1-10 : Dar Nassim project, Morocco

Case study 1-11 : Dar Amys villa, Morocco

Case study 1-12 : Salam cardiac surgery centre, Sudan

ABC21 is funded by the
EU's H2020 programme

CASE STUDY 1-01: BOTTICELLI PROJECT | ITALY

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Via Botticelli, Mascalucia (CT), Sicily, Italy
Latitude; Longitude	37.60422167605705, 15.045983886279847
Climate zone (Köppen–Geiger classification)	Csa: Warm temperate climate with dry and hot summer
BUILDING INFORMATION	
Building Type	Residential - Detached house
Project Type	New building
Completion Date	2012
Number of buildings	1
Number of storeys	1
Total Floor Area (m²)	180 m^2
Net Floor Area (m²)	150 m^2
Thermally conditioned space area (m²)	144 m^2
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	the ventilation of the entire building can be natural or mechanical
Total cost (€)	400 000 [1]
Cost /m² (€/m²)	2 666.7 [1]
Performance Standards or Certification	Passivhaus e CasaClima Gold [2]
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	Eng. Carmelo Sapienza
Architect / Designer	Eng. Carmelo Sapienza of Sapienza & Partners technical firm
Construction manager	Eng. Carmelo Sapienza
Environmental consultancy	Politecnico di Milano gruppo eERG
Structural Engineer, Civil Engineer	Eng Fabio Mondelli
Product Manufacturer	Rockwool Italia – Siemens building technologies
Certification company	Passivhaus standard [2]

ABC21 is funded by the EU's H2020 programme

PROJECT DESCRIPTION

Figure 1: Botticelli project external view [3]

Botticelli project is a single-story home, composed by a living room (including the kitchen), three bedrooms, a study room and two bathrooms (Figure 3). The layout has a U shape, with an internal patio communicating with the garden and allowing for crossflow ventilation and night-time ventilation strategies. The patio contributes also to daylighting. Botticelli project is among the first examples of Net Zero Energy Buildings located in the Mediterranean climate. The building, certified according to Passivhaus standard, is a single-family house monitored for research purposes and operated by a BACS, which is controlling the external solar blinds, the mixed-mode ventilation system, the PV, the thermal solar panels and the Earth-to-Air Heat Exchanger (EAHE).

Figure 2: Botticelli project aerial view [3]

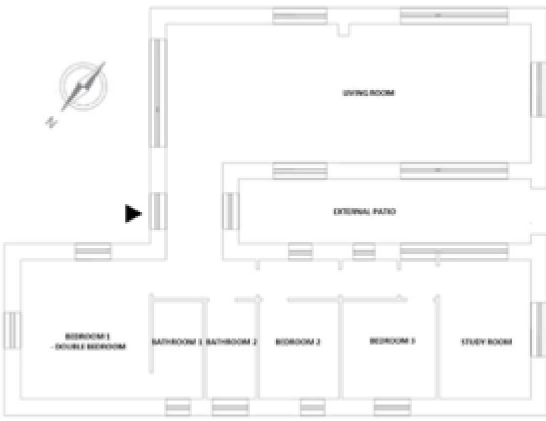
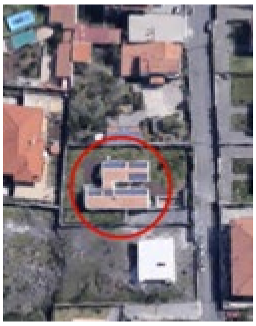


Figure 3: Botticelli project plan view [4]

SITE INTEGRATION



Botticelli project is an all-electric single-family detached house, located in the municipality of Mascalucia in Sicily, Italy. The U-shaped building is located in a residential urban context where surrounding constructions have a maximum height of two floors [5–7].

CLIMATE ANALYSIS

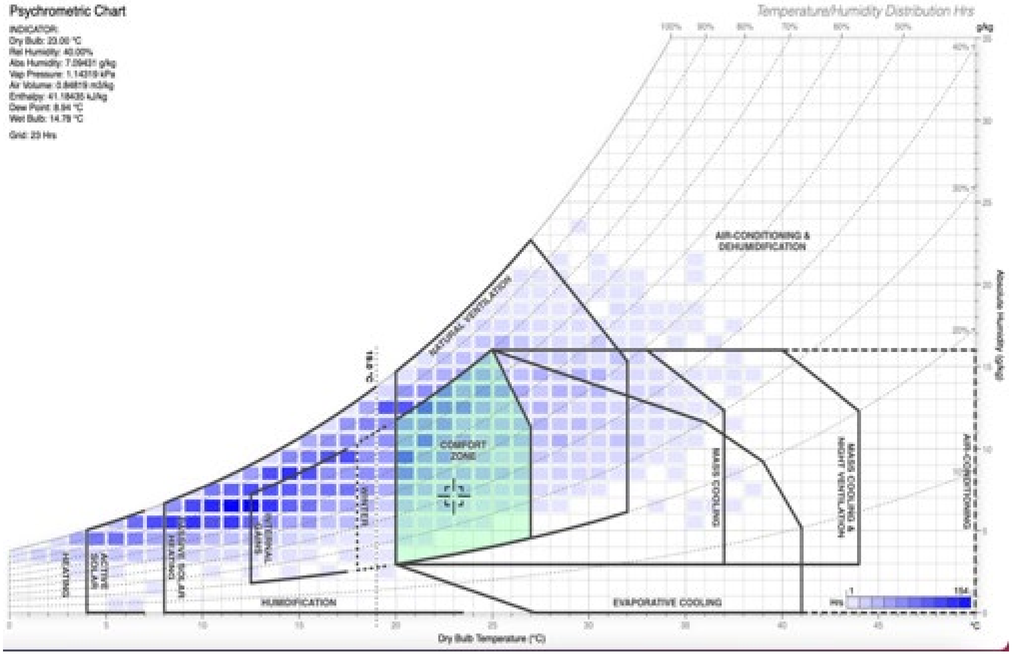


Figure 4: Givoni Bioclimatic chart for the climate of Mascalucia using Andrew Marsh online tool. Climate data are extracted from http://climate.onebuilding.org/WMO_Region_6_Europe/ITA_Italy/SC_Sicily/ITA_SC_Catania.Fontanarossa.AP.164600_TMYx.2004-2018.zip [8]

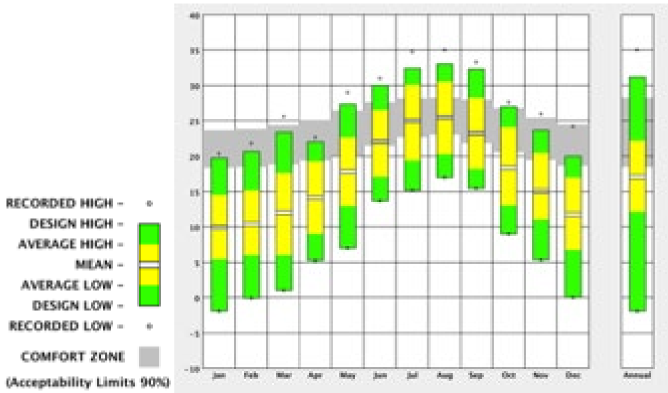


Figure 5: Temperature range by month for Mascalucia- Source: Climate consultant – Adaptative Comfort model [9]

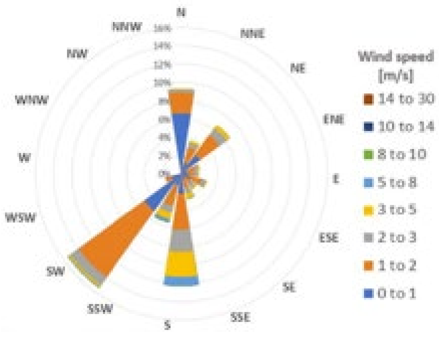


Figure 6: Annual wind rose for Mascalucia [4]

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **2 248** Wh/m² (Dec) Max: **7 599** Wh/m² (Jul) Mean: **4 906,5** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **1 129** CDD 10°C: **2 984**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD (Lower limit 80%):**566** CDD (Upper limit 80%): **554** The Degree Days have been calculated considering the heating season from 15/11 to 31/03 and the cooling season from 01/04 to 14/11.

Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **1 000** CDD 26º: **169** The Degree Days have been calculated considering the heating season from 15/11 to 31/03 and the cooling season from 01/04 to 14/11.

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	**Comfort ventilation:** Natural ventilation strategy is activated through the manual opening of windows and is detected and registered by the KNX bus by means of an electrical sensor installed on each window. **Nocturnal convective ventilation** The natural ventilation (cross ventilation) is exploited during the night-time. **The Source as cooling source:** The Earth-to-Air Heat Exchangers (EAHE) serves the cooling/heating coil in order to pre-heat/cool the inlet air.
Passive heating strategy	The building exploits the thermal mass and its activation via ventilation. Technological application consists of a multilayer wall including a continuous mineral wool layer facing the outdoor environment and a core layer of massive elements such as masonry (for walls) and concrete (for slabs).
Solar protection	Shading systems is a motorized solar system which can be controlled manually or through an automatic system (lowering or raising the shadings and by setting the orientation of the louvres).
Building orientation	The structure of the detached-dwelling is defined approximately by a U-shape and is characterized by a slope roof equipped with photovoltaic system mainly on the south side. The entrance to the building is located on the east-south facade.
Insulation	Exterior insulation finishing system. The structure in reinforced concrete framed is designed without thermal bridges. Insulation mineral wool rock with all doors and windows characterized by mono-block with mosquito nets and shading system.
Vegetation	The permeable surfaces (vegetation and external pavement area) are more than the 40% of the land plot area. Soil permeability is maintained at 95% by infiltration with permeable floor and garden and rainwater collection. During the summer months, the irrigation of vegetation takes place by the re-use of grey water (recycled back into the water cycle) through a small phyto-treatment plant.

ABC21 is funded by the EU's H2020 programme

Natural daylighting	The lighting project is designed to optimize the interaction between natural light and artificial light, also in terms of energy efficiency.
Use of local and embedded materials	N/A
Water saving and heat recovery on hot water drain	The project Botticelli is equipped with a system of rainwater collection and water reuse. The rainwater collected and filtered is used to power the wastewater of the WC's toilet and the washing machine. The constructed Wetlands in the summer complements the reserve for the irrigation of the garden. The entire system is supported by the home automation system, which regulates its efficiency. The water system provides for the separation and collection of waste water of the building.
Waste management	N/A
Others features	The asset is equipped with bicycle racks to improve the use of alternative transport and a line drying spaces.

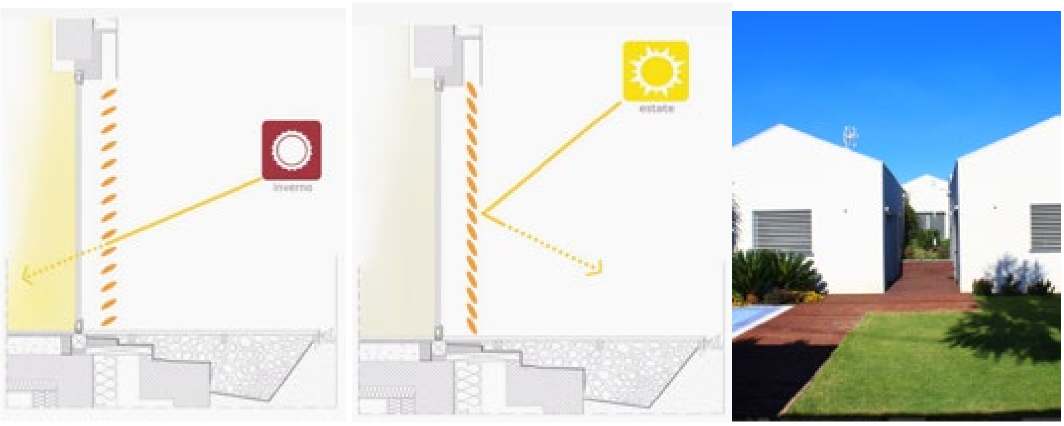


Figure 7: Project Botticelli shading systems [3]

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 *Ratio with number of users:* 2/4 showers/people
Ceiling fans	*In every room, even those conditioned:* No
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	*In every room, even those conditioned:* n/a
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	*In every room, even those conditioned*: Yes

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.:* It is not necessary since the building is a detached residential house and the users are aware how to use the building correctly.

BUILDING FABRIC AND MATERIALS	
Roof	The roof is structured as Figure 8: 1. Impermeable breathable membrane (0.5 cm) 2. Rockwool insulation (28 cm) 3. Vapour barrier (-) 4. Reinforced concrete slab (20 cm) 5. Internal plaster (3 cm)
	U-value: 0.130 [W/m^{2}K] Overall R-value: 7.69 [m^{2}K/W]
Basement floor	The basement floor is structured as Figure 8: 1. Parquet (2 cm) 2. Acoustic insulation (0.5 cm) 3. Expanded clay (20 cm) 4. Rockwool insulation (1 cm)
	U-value: 0.231 [W/m^{2}K] Overall R-value: 4.33 [m^{2}K/W]
Windows	Type: Triple + double glazing 3G-Internorm IBE-LIGHT ESG4b/18g/ESG4/18b/b4ESG + 2G-Internorm IBE-LIGHT 6ESG/12g/b6ESG Kr (U g-value = 0.7 W/m^{2}K, g-value = 54 %)
	Window-to-wall ratio (WWR): n/a
	Windows thermal transmittance: 0.90 – 1.10 [W/m2K]
	Visual transmittance: n/a
Walls	The wall is structured as Figure 8: 1. Hollow brick (30 cm) 2. Internal plaster (3 cm) 3. Rockwool insulation (20 cm) 4. External plaster (1 cm)
	U-value: 0.127 [W/m^{2}K] Overall R-value: 7.87 [m^{2}K/W]

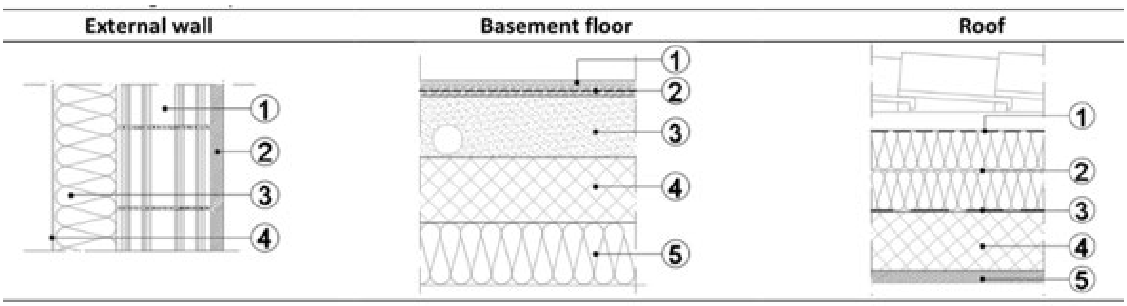


Figure 8: Main building envelope solutions [4]

ENERGY EFFICIENT BUILDING SYSTEMS [3,4,7]	
Low-energy cooling systems	The building is served by a reversible heat pump (air-water 6 kW) and an EAHE (Earth-to-Air Heat Exchangers) which provides the possibility for pre-heating or pre-cooling the handled air. This latter may then pass through a heat recovery unit before being processed by the heating/cooling coils and distributed to the bedrooms and the living room.
Low-energy heating systems	An electrical air to water reversible heat pump (6 kW) serves the heating/cooling coil in the main inlet ventilation duct. The climatization is realized by an all-air system in which the main air-inlet is connected to the heat exchanger EAHE (Earth-to-Air Heat Exchangers) and a heat recovery unit (air-air, cross-flow). The purpose of the EAHE is to pre-heat the handled air.
Ceiling fans	N/a
Mechanical ventilation / air renewal	The air renewal strategies are: ▪ Natural ventilation ▪ Nocturnal ventilation ▪ Mechanical ventilation with the exploitation of cross-flow heat recovery unit. The windows are equipped of sensors able to send signals to the BMS (bus Konnex). The mechanical ventilation is automatically unactive when the windows are open and vice versa.
Domestic Hot Water	The building is served by: ▪ Electrical air to water heat pump (the one over-mentioned for heating system) ▪ Solar thermal The thermal energy provided for domestic hot water system is generated by an integrated system: a water storage of 500 litres connected to the solar thermal system (7 m^2 of flat collectors) and the electrical heat pump (air-water).
Artificial lighting	The whole building is equipped with high-efficiency LED lighting.
Control and energy management	The connection of BMS with the room's sensors and the systems allows to exploit and monitoring in real time the comfort and the energy performance. The management is based on Konnex standard on the first part and secondly on BACnet communication protocol (*BACS class A realized with home automation KNX / connection for control, supervision and monitoring*).

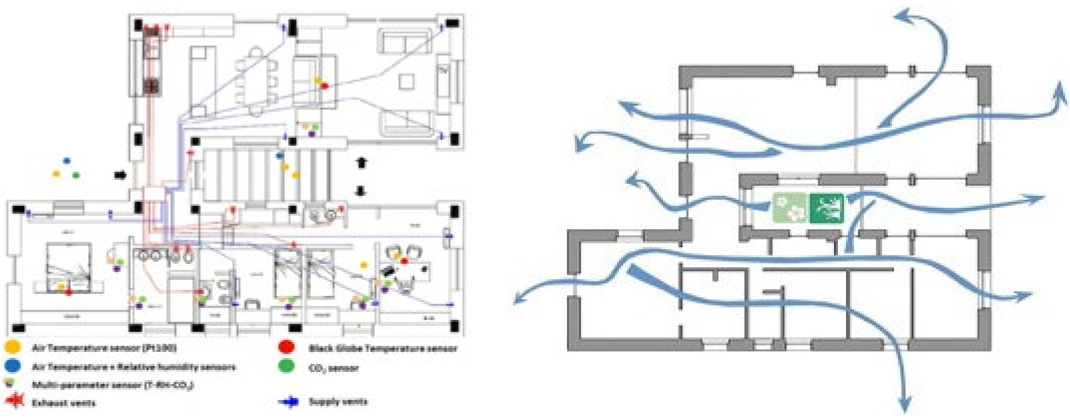


Figure 9: Botticelli Project view plan (on the left: sensors location, on the right: natural ventilation)[3]


Figure 10: Pictures of installed systems (on the left: thermal solar collectors, on the right Earth to Air Heat Exchanger) [3]

RENEWABLE ENERGY [3,4,7]	
PV	PV system (8.14 kW peak electric power) is installed alongside the building and on the sloped roof (both are mainly south-orientated). The electricity production by the PV panels is continuously monitored and compared with the instantaneous energy use of the building and the delivered energy (from the grid).
Solar thermal	Thermal solar panels are installed on roof and are part of an integrated system. (7 m^2 of flat collectors).
Wind	N/A
Geothermal	The EAHE (Earth-to-Air Heat Exchangers) provides the possibility for pre-heating or pre-cooling the ventilation air. The EAHE has been designed considering the geometric limits of the lot and the soil type and it can be excluded from the ventilation system by means of a by-pass duct, when required, according to the chosen control strategy.
Biomass	N/A

ABC21 is funded by the
EU's H2020 programme

Figure 11: Pictures of photovoltaic System and solar thermal collectors [3]

Figure 12: Pictures and schema of Earth to Air Heat Exchanger [3]

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

1. Percentage of time outside an operative temperature range (Adaptive, II category EN16798-1, cooling season): **3.9%**
2. Percentage of time outside an operative temperature range (Fanger, II category EN16798-1, heating season): **23.3%**
3. Degree-hours (Adaptive, II category EN16798-1, cooling season): **108**
4. Degree-hours (Fanger, II category EN16798-1, heating season): **303**
4. Percentage of time inside the Givoni comfort zone of 1m/s:
   Whole year: **88%** (Figure 15)
   Cooling season: **96%**
5. Percentage of time inside the Givoni comfort zone of 0 m/s:
   Whole year: **44%** (Figure 15)
   Cooling season: **41%**
6. Number of hours within a certain temperature range (Figure 13):

Heating season (15th-11 to 31th-03)		
Range	N° of Hours	frequency
T≤19	26	0.8%
19≤T<24	3201	98%
T≥24	38	1.2%

Cooling season (1st-04 to 14th-11)		
Range	N° of Hours	Frequency
T≤20	0	0%
20≤T<26	3526	64%
T≥26	1969	36%

Energy performance indicators

1. Energy needs for heating: **7.21** [kWh/m²/year] [4]
2. Energy needs for cooling: **10.25** [kWh/m²/year] [4]
3. Energy use for lighting: **27.72** [kWh/m²/year] [4]
4. Energy needs for Sanitary Hot water: **2.38** [kWh/m²/year] [4]

	5. Total Primary energy use: **144.5** [kWh/m^2_{net}/year] (total Primary Energy Factor (PEF) equal to 2.42 for electrical energy from the grid)
	6. Renewable Primary energy generated on-site: **76** [kWh/m^2/year] [4] (Figure 16)
	7. Renewable Primary energy generated on-site and self-consumed: **17.09** [kWh/m^2/year] [7]
	8. Renewable Primary energy exported to the grid: **56.02** [kWh/m^2/year] [7]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): **11.82%** [7]
	10. Delivered energy: **43.04** [kWh/m^2/year] [7]
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): *YES*
	2. Useful Daylight Illuminance (UDI): N/A
	3. Glare control: N/A
	4. Quality view: YES
	5. Zoning control: YES
Indoor Air Quality indicators	1. Organic compound: N/A
	2. VOCs: N/A
	3. Inorganic gases: *YES* *(CO_2)*
	4. Particulates (filtration): N/A
	5. Minimum outdoor air provision: N/A
	6. Moisture (humidity, leaks): N/A
	7. Hazard material: N/A
Users' feedback	n/a

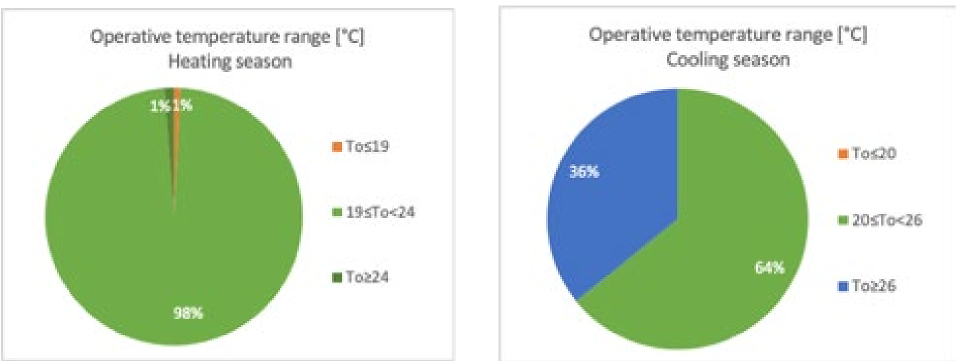


Figure 13: Percentage of hours within comfort range of operative temperature

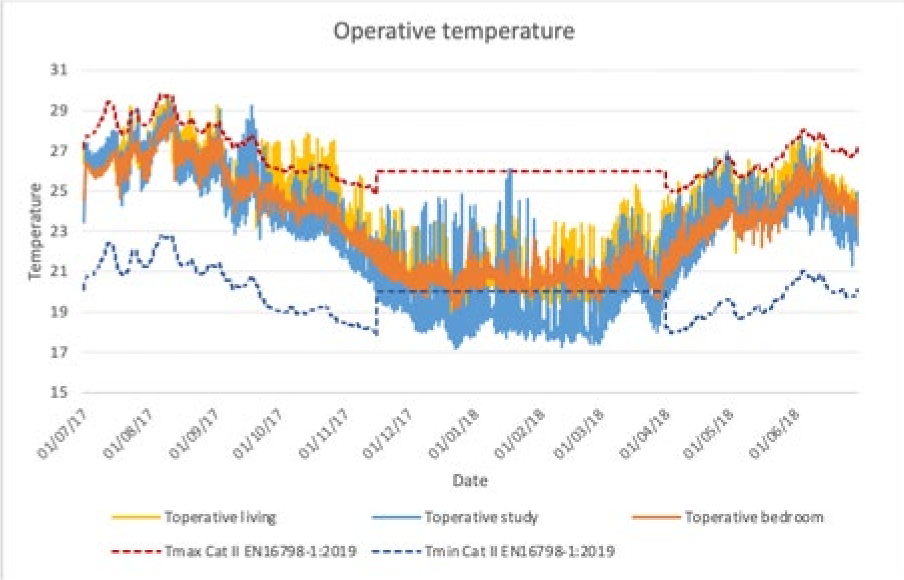


Figure 14: Operative temperature and comfort boundaries (EN16798-1:2019) (Fanger comfort model for heating season from 15/11 to 31/03 and adaptive comfort model the cooling season from 01/04 to 14/11, II comfort category)

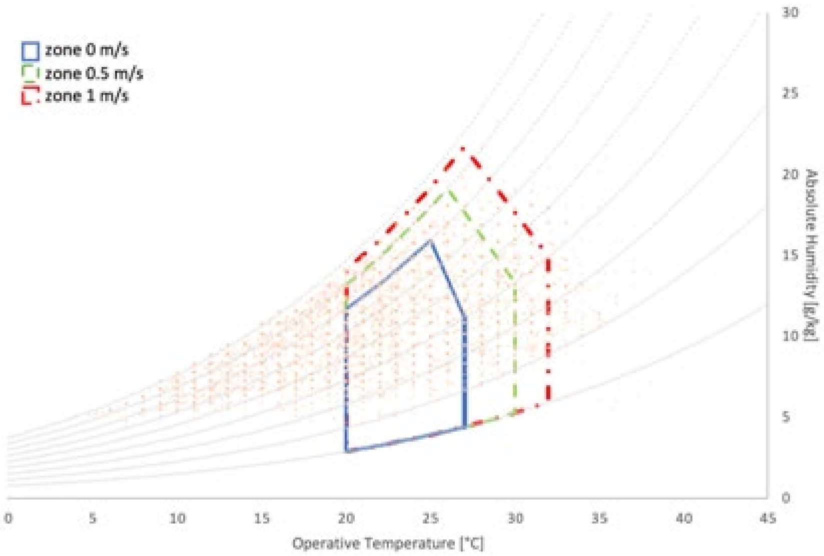


Figure 15: Givoni bioclimatic chart – distribution of hourly operative temperature of the monitored year (2017/2018)

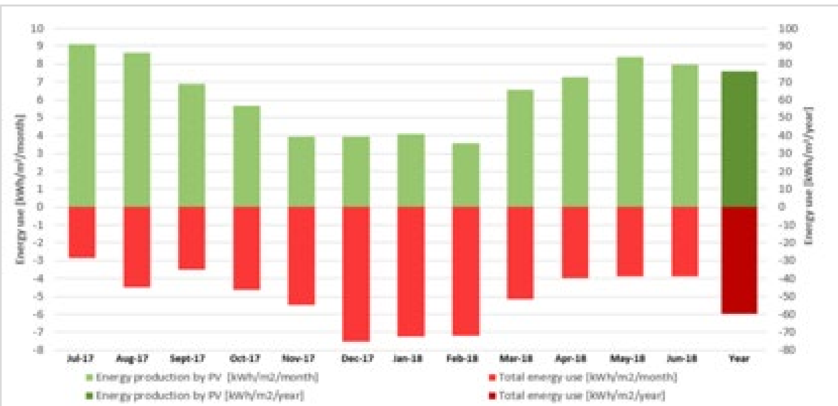


Figure 16: Monthly and yearly energy production by PV (green) and total energy use (red) during the investigated year (2017/2018)

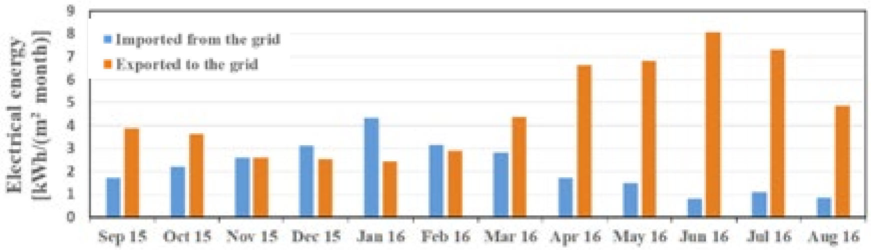
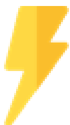
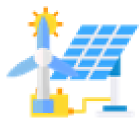


Figure 17: Comparison between the monthly electrical energy imported/exported (monitored year: 2015/2016)[7]

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	The analyses highlight that even under challenging outdoor temperatures without an active conditioning thanks to the building geometry, highly insulated envelope and external movable solar protections automatically controlled, the building remains in comfort zone. The presented comfort indexes allow verifying both how many degrees and how long the building is outside the comfort zone. During the cooling season, even though the percentage of hours in which the operative temperature higher than 26°C is 36%, the calculated operative temperature is just slightly higher than the comfort threshold.
Recommendations	The analysis of the building energy performance is important in terms of load-management strategies to optimize the use of renewable energy and to improve the balancing between production and use. Figure 17 shows that on a monthly basis the renewable energy generated on site is lower than the energy use for some months, therefore should be explored all the possibilities for shifting (on a daily basis) part of use of energy to hours where PV generation takes place, in order to reduce the daily mismatch, even without installation of electrical storage. Long term, inter-seasonal storage (e.g. storing for using in winter the energy generated by renewables in summer) remains a challenge both in terms of available spaces and cost, possibly to be addressed at district scale.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

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

Weaknesses

As reported in the previous analysis the building shows generally high energy and comfort performance throughout the year. However, the north-facing rooms may exceed the comfort thresholds (as shown in the Figure 14) because of their unfavourable position.

There is a small garden surrounding the building with only one tree, which is not sufficient to have a favourable impact from the point of view of the climatic comfort inside the building.

Artificial materials such as insulation mineral wool rock is used. There is no information about materials with low embedded energy and/or locally produced; this should be improved in future design.

This is single family house so posing challenges about replicability and affordability. Anyway, it shows that very high levels of external insulation (to the highest standard of PassivHaus), coupled with appropriate

ABC21 is funded by the EU's H2020 programme

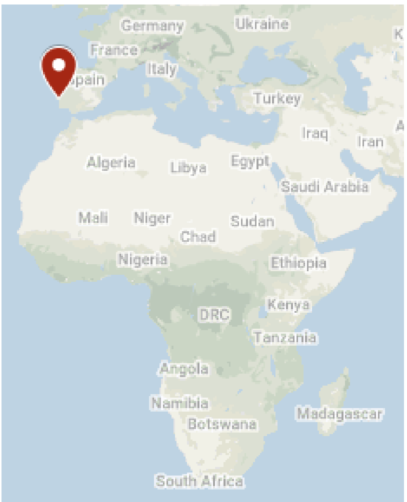
solar shading, and ventilation to flush away heat in summer, can achieve very low *energy needs for heating and cooling*. The relatively advanced measurement and control settings might be realised with recent, relatively inexpensive electronics, or by manual operation of the main elements (shading, natural ventilation). A more effective use of land, via multifamily buildings, should be considered.

REFERENCES

[1] Progetto Botticelli. construction21.org n.d. https://www.construction21.org/italia/case-studies/h/progetto-botticelli.html(accessed June 16, 2021).
[2] Botticelli project - Passive House Buildings n.d. https://passivehouse-database.org/index.php?lang=en#d_2123(accessed June 16, 2021).
[3] Sapienza & Partners. Progettiamo Nuovi Edifici & Ristrutturazioni | NZEB | Case Passive | Casaclima | Passivhaus n.d. https://www.sapienzaepartners.it/it/botticelli-home(accessed June 16, 2021).
[4] Causone F, Tatti A, Pietrobon M, Zanghirella F, Pagliano L. Yearly operational performance of a nZEB in the Mediterranean climate. Energy and Buildings 2019;198:243–60. https://doi.org/10.1016/j.enbuild.2019.05.062.
[5] Causone F, Pietrobon M, Pagliano L, Erba S. A high performance home in the Mediterranean climate: from the design principle to actual measurements. Energy Procedia 2017;140:67–79. https://doi.org/10.1016/j.egypro.2017.11.124.
[6] Carlucci S, Cattarin G, Causone F, Pagliano L. Multi-objective optimization of a nearly zero-energy building based on thermal and visual discomfort minimization using a non-dominated sorting genetic algorithm (NSGA-II). Energy and Buildings 2015;104:378–94. https://doi.org/10.1016/j.enbuild.2015.06.064.
[7] Erba S, Pagliano L, Shandiz SC, Pietrobon M. Energy consumption, thermal comfort and load match: study of a monitored nearly Zero Energy Building in Mediterranean climate. IOP Conf Ser: Mater Sci Eng 2019;609:062026. https://doi.org/10.1088/1757-899X/609/6/062026.
[8] PD: Psychrometric Chart n.d. https://drajmarsh.bitbucket.io/psychro-chart2d.html(accessed May 7, 2021).
[9] Milne (UCLA) M. Climate Consultant 6.0. n.d. http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php.
[10] Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. World map of the Köppen-Geiger climate classification updated 2006.
[11] Peel MC, Finlayson BL, McMahon TA. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences 2007;11:1633–44.
[12] Givoni B. Performance and applicability of passive and low-energy cooling systems. Energy and Buildings 1991;17:177–99. https://doi.org/10.1016/0378-7788(91)90106-D.

ABC21 is funded by the EU's H2020 programme

CASE STUDY 1-02: CML KINDERGARTEN | PORTUGAL



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Rua Margarida de Abreu 4, 1900-314, Lisbon, Portugal
Latitude; Longitude	38.74359816203614, -9.131250349942396
Climate zone (Köppen–Geiger classification)	Csa: Warm temperate climate with dry and hot summer
BUILDING INFORMATION	
Building Type	Educational (Kindergarten)
Project Type	New construction
Completion Date	2013
Number of buildings	1
Number of storeys	2
Total Floor Area (m²)	680
Net Floor Area (m²)	582.3
Thermally conditioned space area (m²)	0
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	The entire building is naturally ventilated
Total cost (€)	-
Cost /m² (€/m²)	-
Performance Standards or Certification	Portuguese National Code (RECS, 2013)
Awards	-
STAKEHOLDERS	
Building Owner/ Representative	Municipality of Lisbon (CML)
Architect / Designer	Appleton & Domingos, Arquitetos
Construction manager	Municipality of Lisbon (CML)
Environmental consultancy	NaturalWorks
Structural Engineer, Civil Engineer	A2P
Product Manufacturer	-

Certification company	NaturalWorks

PROJECT DESCRIPTION

Figure 18 : Elements of the natural ventilation system

The CML kindergarten, constructed in 2013, is a small two-story building with a total area of 680 m2 distributed in two floors with 3 m floor to ceiling height.

This school is naturally ventilated and does not have a mechanical cooling or ventilation. A natural displacement ventilation system was developed to provide fresh air with adequate acoustic insulation.

The CML Kindergarten uses solar thermal energy to heat water that feeds the hydraulic radiators installed in each classroom.

The design also includes high exposed thermal mass, daylighting, and solar shading.

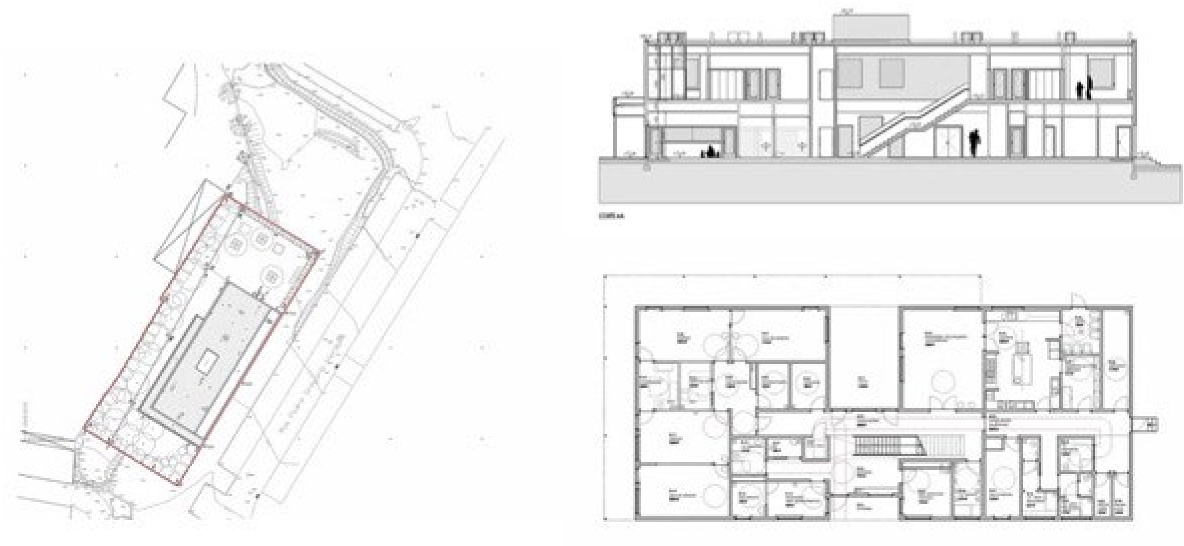


Figure 19: CML kindergarten building schematics.

SITE INTEGRATION

Figure 20: Aerial view of the building.

The building is located in the outskirts of an urban dense neighbourhood in Lisbon, and it is a grid connected building. The CML Kindergarten is immediately surrounded by a garden (Southwest and Northwest, as shown in the figure), a playground area (Northeast) and a parking lot (Southeast). Regarding other buildings, the CML Kindergarten is surrounded by low to mid-rise buildings from the South, West, and North directions and from East by a small cliff (equivalent to a low-rise building).

ABC21 is funded by the EU's H2020 programme

CLIMATE ANALYSIS

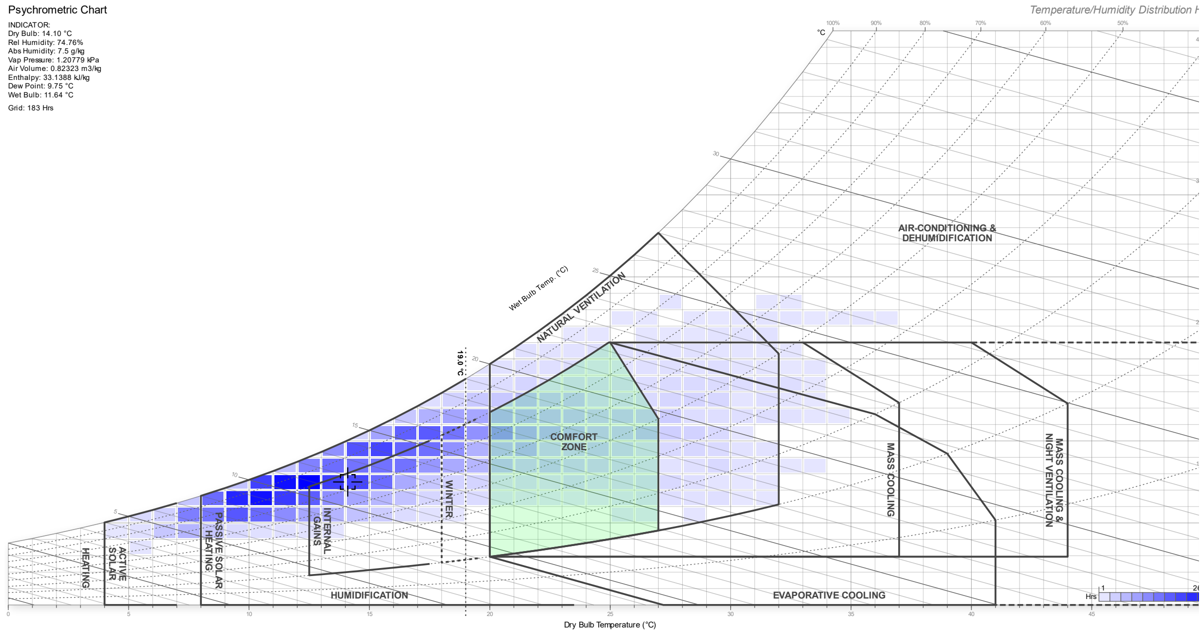


Figure 21 – Givoni Bioclimatic chart for the climate of Lisbon (Source: Andrew Marsh online tool).

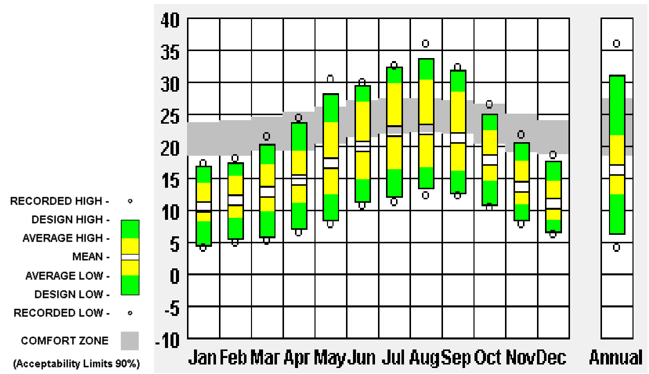


Figure 22 – Typical monthly air temperature range in Lisbon (Source: Climate consultant – Adaptative Comfort model).

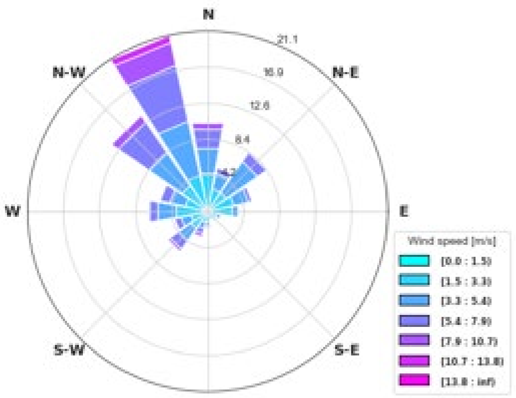


Figure 23 : Annual wind rose for Lisbon (Beaufort wind scale).

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **1 946** Wh/m² (December) Max: **7 548** Wh/m² (July)
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **978** CDD 10°C: **2 549**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD (Lower limit 80%): **1 295** CDD (Upper limit 80%): **18.5**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **1 063** CDD 26º: **17**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	The natural ventilation strategy consists of air being introduced into the space through low level grilles (or openable windows) on the façade and being exhausted in the centre or back of the room, through one or two chimneys depending on the size of the room. With this strategy, both comfort ventilation and nocturnal convective ventilation are used in summertime (see figure below in summer operation mode).
Passive heating strategy	The winter operation mode allows for a semi-passive heating strategy with the heating being provided by passive convectors, fed by a heat pump.
Solar protection	Passive solar protection for the ground floor with horizontal overhangs, and active solar protection for the first floor with horizontal fins (see figure below).
Building orientation	The building has a rectangular shape with its main façades facing Northwest and Southeast.
Insulation	Insulation applied in the outer layers of the façades and roof.
Vegetation	-
Natural daylighting	The lighting project included natural and artificial lighting. There are several skylights throughout the building. Due to limited financial resources for initial and running costs, the systems are manually operated.
Use of local and embedded materials	-
Water saving and heat recovery on hot water drain	-
Waste management	-
Others features	-

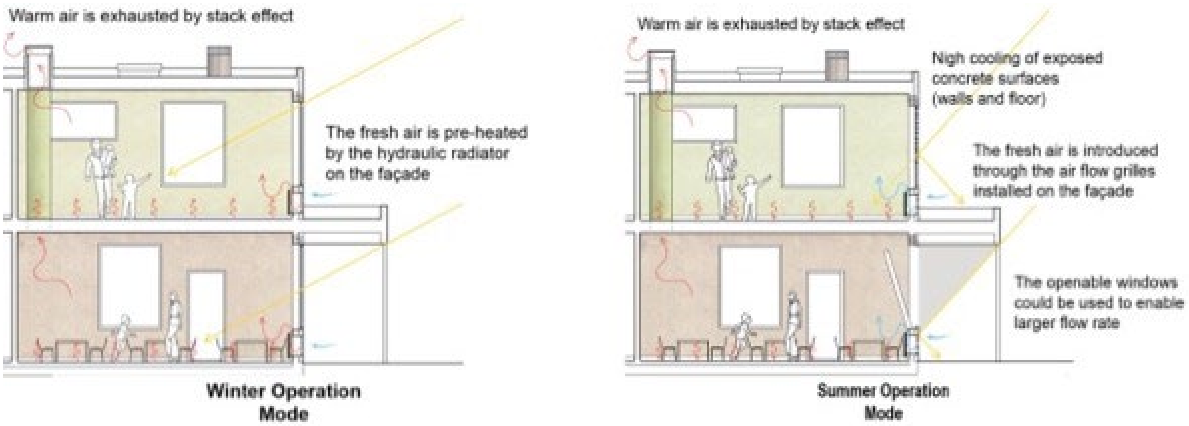


Figure 24: Winter and Summer operation modes.

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): No
Protected bike parking and showers	No Ratio with number of users:
Ceiling fans	In every room, even those conditioned: No

Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: No
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
BUILDING FABRIC AND MATERIALS	
Roof	The roof is structured as (from outside to inside): 1. Aluminium (thickness 0.01 m, thermal conductivity 15.1 W/m·ºC, thermal resistance 0 m^2·ºC/W and density 8055 kg/m^3) 2. Rockwool (thickness 0.10 m, thermal conductivity 0.04 W/m·ºC, thermal resistance 2.5 m^2·ºC/W and density 150 kg/m^3) 3. Air space (thickness 0.05 m, thermal conductivity 0.03 W/m·ºC, thermal resistance 1.67 m^2·ºC/W and density 1.16 kg/m^3) 4. Rockwool-gypsum board (thickness 0.065 m, thermal conductivity 0.04 W/m·ºC, thermal resistance 1.63 m^2·ºC/W and density 40 kg/m^3)
	Overall R-value: 6.01 [m^2·K/W] **U-value:** 0.38 [W/m^2·K]
Ceiling	The ceiling is structured as: 1. Rockwool- gypsum board (thickness 0.065 m, thermal conductivity 0.04 W/m·ºC, thermal resistance 1.63 m^2·ºC/W and density 40 kg/m^3) 2. Air space (thickness 0.05 m, thermal conductivity 0.03 W/m·ºC, thermal resistance 1.67 m^2·ºC/W and density 1.16 kg/m^3) 3. Heavyweight concrete (thickness 0.2 m, thermal conductivity 2.3 W/m·ºC, thermal resistance 0.09 m^2·ºC/W and density 1375 kg/m^3)
	Overall R-value: 3.59 [m^2·K/W] **U-value:** 0.28 [W/m^2·K]
Exterior Wall	The exterior wall is structured as (from outside to inside): 1. Plaster (thickness 0.01 m, thermal conductivity 1.3 W/m·ºC, thermal resistance 0.01 m^2·ºC/W and density 2000 kg/m^3) 2. Polyethylene (thickness 0.08 m, thermal conductivity 0.04 W/m·ºC, thermal resistance 2 m^2·ºC/W and density 40 kg/m^3) 3. Heavyweight Concrete (thickness 0.13 m, thermal conductivity 2.3 W/m·ºC, thermal resistance 0.27 m^2·ºC/W and density 2300 kg/m^3)
	Overall R-value: 2.45 [m^2·K/W] **U-value:** 0.41 [W/m^2·K]

ABC21 is funded by the EU's H2020 programme

Interior Wall	The interior wall is structured as: 1. Gypsum board (thickness 0.025 m, thermal conductivity 0.25 W/m·ºC, thermal resistance 0.56 m²·ºC/W and density 500 kg/m³) 2. Air space (thickness 0.05 m, thermal conductivity 0.03 W/m·ºC, thermal resistance 1.67 m²·ºC/W and density 750 kg/m³) 3. Rockwool (thickness 0.07 m, thermal conductivity W/m·ºC, thermal resistance 0.18 m²·ºC/W and density kg/m³) 4. Gypsum board (thickness 0.025 m, thermal conductivity 0.04 W/m·ºC, thermal resistance 0.63 m²·ºC/W and density 35 kg/m³)
	Overall R-value: 3.3 [m²·K/W] **U-value:** 0.30 [W/m²·K]
Floor	The floor is structured as (from outside to inside): 1. Soil (thickness 1.7 m, thermal conductivity 1.14 W/m·ºC, thermal resistance 1.49 m²·ºC/W and density 1000 kg/m³) 2. Riprap (thickness 0.25 m, thermal conductivity 1.2 W/m·ºC, thermal resistance 0.21 m²·ºC/W and density 1000 kg/m³) 3. Heavyweight concrete (thickness 0.2 m, thermal conductivity 2.3 W/m·ºC, thermal resistance 0.18 m²·ºC/W and density 2240 kg/m³)
	Overall R-value: 1.88 [m²·K/W] **U-value:** 0.41 [W/m²·K]
Windows	Low-emissivity double glazed windows (λ=0.9 W/m·K; τ=0.75)
	Window-to-wall ratio (WWR) 18%
	U-value: 3.5 [W/m²·K] Visual transmittance 0.75

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	None
Low-energy heating systems	The winter operation mode allows for a low-energy heating strategy with the fresh outdoor air being pre-heated by passive convectors fed by a heat pump which has a maximum heating power output of 38.6 kW and a COP of 3.5 (see Figure 24 above, in winter operation mode).
Ceiling fans	None
Mechanical ventilation / air renewal	The air renewal strategies are: • Natural ventilation: 1. Displacement ventilation; 2. Single sided ventilation. The ventilation solution consists in a high-level openable window plus low-level grilles installed on the façade of each classroom that control the inflow air. The air will be exhausted in the back of the room, through one or two thermal chimneys. Due to limited financial resources for initial and running costs, the implemented natural ventilation strategies are manually operated, and their usage relies on the occupant perception of the internal environment
Domestic Hot Water	Solar thermal system The building is served by:

	• The heat pump over-mentioned for heating system; • Solar thermal system. The solar thermal system is composed by 6 solar panels and a 500 litres water deposit. The heat pump is used as an auxiliary system whenever the solar thermal panels cannot supply the necessary amount of energy.
Artificial lighting	The whole building is equipped with high-efficiency LED lighting.
Control and energy management	None
RENEWABLE ENERGY	
PV	None
Solar thermal	The solar thermal system consists of seven flat collectors installed on the roof with a total area of 10m².
Wind	None
Geothermal	None
Biomass	None

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

1. Percentage of time outside an operative temperature range (Adaptive, II category EN16798-1, cooling season): **39.7%**
2. Percentage of time outside an operative temperature range (Fanger, II category EN16798-1, heating season): **1.07%**
3. Degree-hours (Adaptive, II category EN16798-1, cooling season): **505**
4. Degree-hours (Fanger, II category EN16798-1, heating season): **93**
5. Percentage of time inside the Givoni comfort zone of 1 m/s:
   Whole year: **80% /** Cooling season: **83%** (see Figure 25)
6. Percentage of time inside the Givoni comfort zone of 0 m/s:
   Whole year: **69% /** Cooling season: **63%** (see Figure 25)
7. Number of hours within a certain temperature range

Heating Season (1st-10 to 31th-03)		
Range	Nº of Hours	Frequency
T≤20	**253**	17.1%
19≤T≤24	**1223**	82.9%
T≥24	**0**	0.0%

Cooling Season (1st-04 to 30th-09)		
Range	Nº of Hours	Frequency
T≤23	**0**	0.00%
23≤T≤26	**1050**	90.21%
T≥26	**114**	9.79%

Energy performance indicators

1. Energy needs for heating: **0.7** [kWh/m²/year]
2. Energy needs for cooling: **13.0** [kWh/m²/year]
3. Energy use for lighting: **22.7** [kWh/m²/year]
4. Energy needs for Sanitary Hot water: **9.5** [kWh/m²/year]
5. Total Primary energy use: **193.4** [kWh/m²/year]
6. Renewable Primary energy generated on-site: **8.1** [kWh/m²/year]
7. Renewable Primary energy generated on-site and self-consumed: **7.6** [kWh/m²/year]
8. Renewable Primary energy exported to the grid: **0.5** [kWh/m²/year]

ABC21 is funded by the EU's H2020 programme

	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): **4.2** (%)
	10. Delivered energy: **34.5** [kWh/m²/year] (from electricity bills)
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance): **500** [lux]
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	-

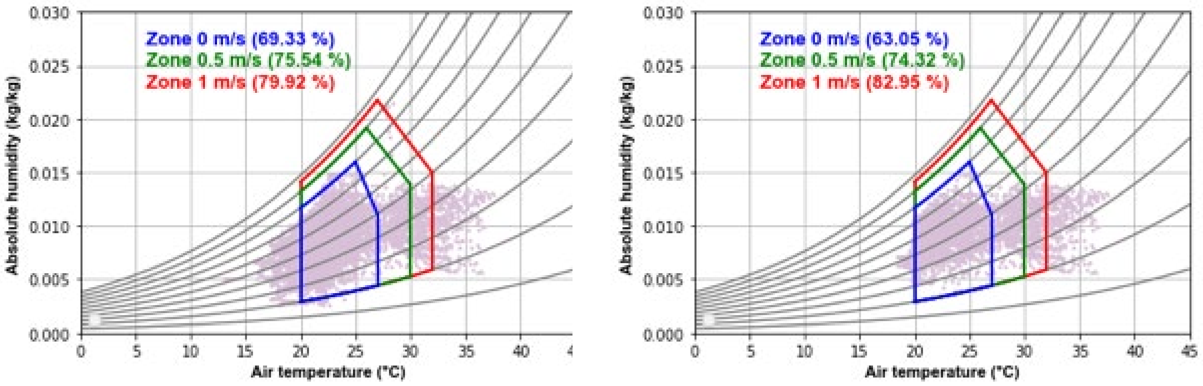


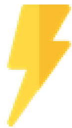
Figure 25 : Givoni bioclimatic chart – distribution of hourly mean air temperature: (a) for the whole year and (b) for the summer period.

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	The stack driven natural ventilation (NV) system is very effective and self-regulating. This system can meet the airflow rate goals during the spring and winter periods. If possible, this sort of NV system should have easily accessible manual control.
Recommendations	User training is essential and may need to be periodic (every 3 to 4 years). In this school, the current users were convinced that the chimneys were poorly designed skylights.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

Passive Design



Energy Efficiency

Weaknesses

The main problem of this NV system occurs during the hottest days of summer, when it is necessary to promote the interior air renewal (to maintain acceptable CO2 concentration, below the limit of 1625 ppm for hybrid/passive buildings) but the outdoor air is much warmer than indoor air, which makes the use of natural ventilation prohibitive. In these cases, the users will determine what comfort parameter is more relevant to his comfort and to define if the openings should be maintained closed or be opened.

REFERENCES

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

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

Persily, Evaluating building IAQ and ventilation with indoor carbon dioxide, ASHRAE Transactions 103 (1997) 1–12.

EnergyPlus (2013). Energy Plus Documentation: Getting Started with EnergyPlus, EnergyPlus Engineering Reference, Input and Output Reference.

R. Wallider, D. Norback, G. Wieslander, G. Smedje, C. Erwall, Nasal mucosal swelling in relation to low air exchange rate in schools, Indoor Air 7 (1997) 198–205.

RECS, Regulamento de Desempenho Energético dos Edificios de Comércio e Serviços, Decreto-Lei nº 118/2013 de 20 de Agosto. Diário da República nº159 - Ministério da Economia e do Emprego, Lisboa, 2013.

Nuno M. Mateus, Guilherme Carrilho da Graça, A validated three-node model for displacement ventilation, Building and Environment, Volume 84, January 2015, Pages 50-59, ISSN 0360-1323, http://dx.doi.org/10.1016/j.buildenv.2014.10.029.

Nuno M. Mateus, Gonçalo Nunes Simões, Cristiano Lúcio, Guilherme Carrilho da Graça, Comparison of measured and simulated performance of natural displacement ventilation systems for classrooms, Energy and Buildings, Volume 133, 1 December 2016, Pages 185-196, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2016.09.057.

Nuno M. Mateus, Armando Pinto, Guilherme Carrilho da Graça, Validation of EnergyPlus thermal simulation of a double skin naturally and mechanically ventilated test cell, Energy and Buildings, Volume 75, June 2014, Pages 511-522, ISSN 0378-7788, http://dx.doi.org/10.1016/j.enbuild.2014.02.043.

CASE STUDY 1-03: IZUBA ENERGIES BUILDING | FRANCE

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	34690 Fabrègues, France
Latitude; Longitude	43.56050216309316, 3.7915132981980086
Climate zone (Köppen–Geiger classification)	Csa: Warm temperate climate with dry and hot summer
BUILDING INFORMATION	
Building Type	Offices
Project Type	New construction
Completion Date	2015
Number of buildings	1
Number of storeys	2
Total Floor Area (m²)	-
Net Floor Area (m²)	424
Thermally conditioned space area (m²)	424
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	0
Total cost (€)	934 000
Cost /m² (€/m²)	2 061,8
Performance Standards or Certification	None
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	Izuba Energies / Eduardo Serodio - eduardo.serodio@izuba.fr - 0467186221
Architect	RIGASSI et Associés Architectes / Vincent RIGASSI vincent.rigassi@ra2.fr - 0476471172 -
Construction manager	RIGASSI et Associés Architectes
Environmental consultancy	Izuba Energies

Structural Engineer, Civil Engineer	Gaujard Technologie Scop (Wood structures) Soraetec (Concrete)
Energy Engineer	IZUBA énergies
Fluid Systems Engineer	Agence Des Fluides Cognin
Product Manufacturer	Jolie Terre entreprise (Earth plasters) Sud Est Charpente (Timber frame insulation straw)
Certification company	-

PROJECT DESCRIPTION [1] [2]

Figure 26 : Exterior view of the Izuba building

Izuba Energies Building is an office building located in France, more precisely near Montpellier, in the Fabrègues Ecoparc. The building follows the approach of bioclimatic architecture and passive systems, and uses local bio-based materials to reduce environmental impacts. The building was built to adapt to the local Mediterranean climate, ensuring a comfortable working environment in summer and in winter, in terms of thermal and visual comfort. This building reflects what IZUBA Energies has supported since its creation in 2001, i.e a "negawatt" energy approach with its 3 components (sufficiency, efficiency, and renewable energies). This includes: hygrothermal comfort, low impact components, user behaviour, waste management, indoor air quality, etc.

Figure 27: Floor plan of the first floor

Figure 28: Floor plan of the second floor

SITE INTEGRATION

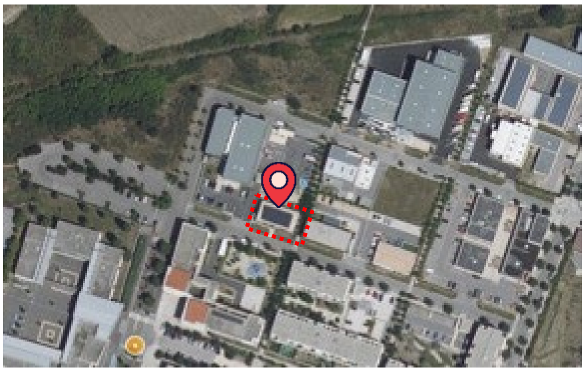


Figure 29 : Aerial view of the building in its surrounding environment

The building is located in the Eco-Parc Fabrègues, between a residential area and a rural area. A direct connection of the area from the centre of Montpellier will be possible through a future extension of the tramway line.

CLIMATE ANALYSIS

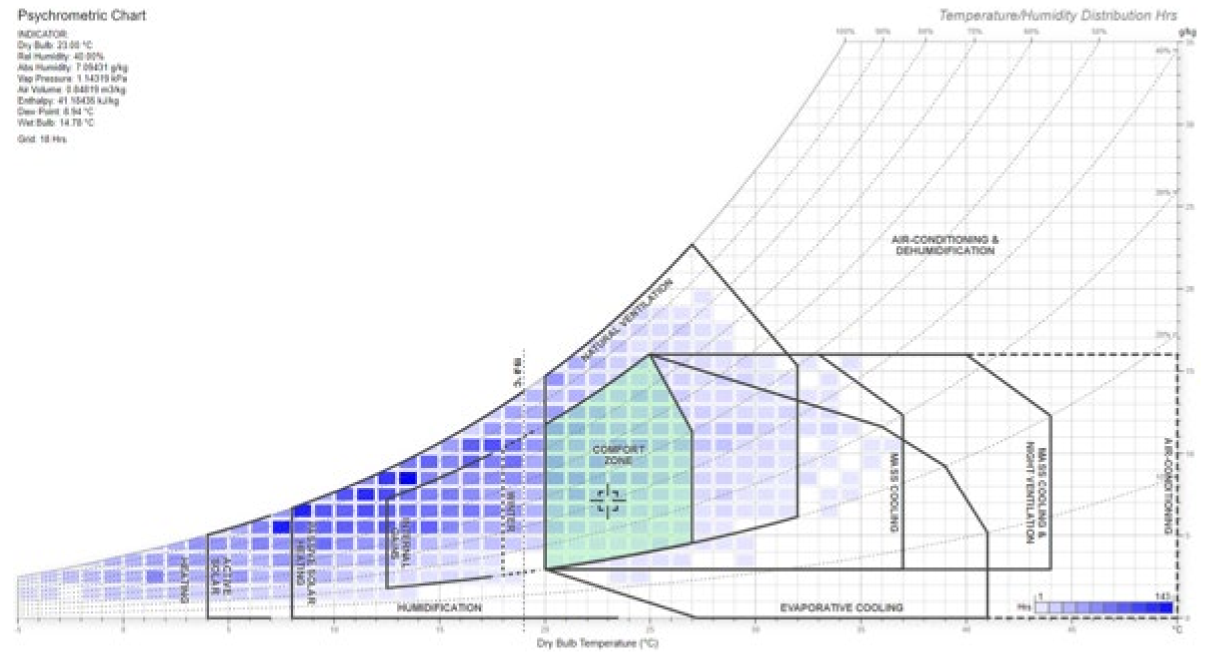


Figure 30: Givoni Bioclimatic chart for the climate of Montpellier using Andrew Marsh online tool. Climate data are extracted from https://energyplus.net/weather-region/europe_wmo_region_6/FRA%20%20 [3].

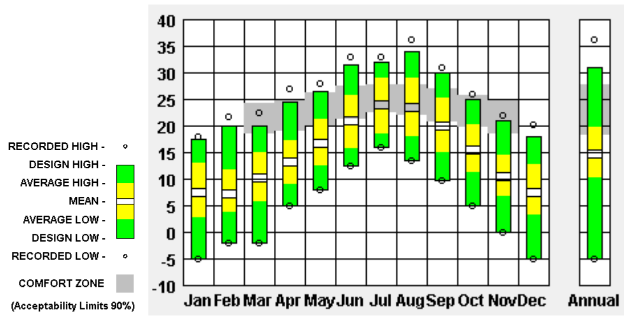


Figure 31: Temperature range by month for Montpellier - Adaptative Comfort model [4]

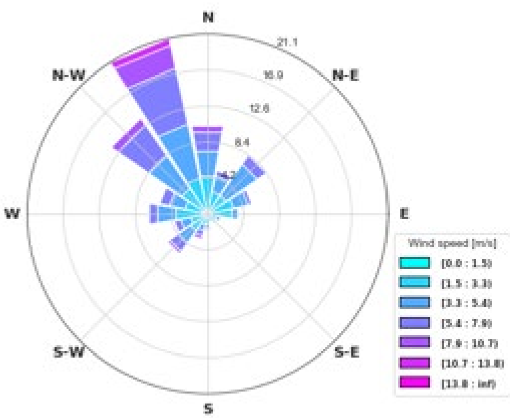


Figure 32: Annual wind rose for Montpellier ((Beaufort wind scale). [4]

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **1 413** Wh/m² (Dec) Max: **6 746** Wh/m² (Jul) Mean: **4 004,17** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **1 769** CDD 10°C: **2 181**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **1 884** CDD: **20**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **1 918** CDD 26º: **65**

KEY BIOCLIMATIC DESIGN PRINCIPLES [1] [2]	
Passive cooling strategy	**Natural ventilation** (see *Figure 33*) **Thermal inertia** (wood frame+ interior partitions of earth-straw and mud brick)
Passive heating strategy	High level of insulation of the walls and the roof Simple shape and good compactness of the building, limiting heat losses on surfaces. The main façade is south oriented to optimize solar gain in offices in the winter period.
Solar protection	Built-in fixed protection: - The building is completely surrounded by open-cut wood siding. - Motor drive external venetian blinds (see Figure 35). The building is equipped with fixed and mobile solar protection blocking direct sunlight while allowing solar gain in winter.
Building orientation	Main orientation south to take advantage of solar gain.
Insulation	The exterior walls and the roof are composed of timber frame insulated with straw bales which provides a very high level of insulation. Interior walls also provide high level of thermal and acoustic insulation with different strategies such as wood wool, mud bricks or cob. The high insulation levels, combined with perfect air tightness and strong solar inputs, reduce heating requirements.
Vegetation	Mediterranean plants, adapted to conserve water and survive summer drought, have been planted around the building. The different species have been chosen according to the solar exposition, i.e., linden trees for the shading of the parking areas, jasmine for the North and South façades. Also, a small common herb garden is provided.
Natural daylighting	The large openings on the main façades, as well as the fixed and mobile solar protection have been designed to allow natural daylighting in the building (see Figure 36).
Use of local and embedded materials	The earth used in the construction was extracted from a quarry near Uzes, composed of sand, clay and plant fibres (mostly straw).
Water saving and heat recovery on hot water drain	Flow controller fitted onto water tap in the bathroom to reduce water consumption.

ABC21 is funded by the EU's H2020 programme

	Hand wash basin **with knee operation** and with automatic shut-off.
Waste management	Sorting of recyclable waste and compost bin for kitchen waste.
Others features	**Eco-design material:** To limit the environmental impact of the manufacture of building materials and processing at end of life, the design has largely favoured bio-sourced materials, minimally processed and recyclable: - Wooden frame insulated with straw bales - earth plasters, clay walls and straw wall in mud brick - wood for exterior and interior joinery and furniture - anhydrite screed sanded and oiled finished floor The building includes a 19-seat parking lot, with shading structures designed to limit the use of air conditioning. There are also electric vehicle charging stations and local bicycle coverage.

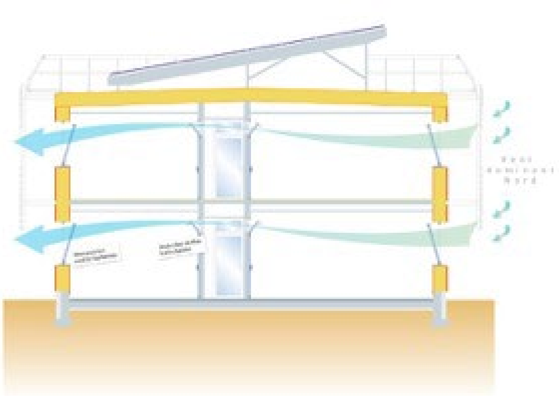


Figure 33: Natural ventilation principle

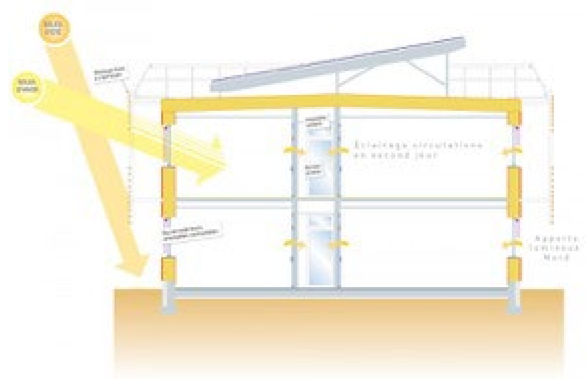


Figure 34 : Shading and natural daylighting principle

Figure 35: Motor drive external venetian blind. Type: Grinotex from Griesser.

Figure 36: Tilt and turn windows

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. **3 bike racks** and **2 showers** for 16 employees Ratio with number of users: **0.125**
Ceiling fans	In every room, even those conditioned: **Yes**

	Celing fans are installed in the offices, the kitchen and the meeting room. No ceiling fans in the large training room.
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.: **No** The users work in the energy efficiency area and are aware of how to correctly use the building, but this point could be improved.

BUILDING FABRIC AND MATERIALS [1] [2]	
Roof	The roof is structured as illustrated in Figure 41 (from outside to inside): ▪ thermoplastic polyolefin membrane ▪ OSB wood panel (1.8 cm) ▪ Straw bale (34cm) ▪ Vapour barrier ▪ Wooden batten (3 cm) ▪ Acoustical false ceiling in wood fiber
	U-value= 0.15 [W / m²K] Overall R-value: 6.67 [m²K/W]
Windows	Type of materials: Wooden-framed double-glazed windows 4/16/4 with argon, low-E
	Window-to-wall ratio (WWR): -
	U-value: 1.5 [W / m²K]
	Visual transmittance: -
Walls	The **Exterior Walls** are structured as illustrated in Figure 40 (from outside to inside): ▪ Raw earth outside coating ▪ Wooden box with thick straw bales (0.37 m) ▪ OSB panel (0.018 m) ▪ Raw earth coating
	U-value= 0.17 [W / m²K] Overall R-value: 5.88 [m²K/W]
	The different types of **Interior Walls** are structured as illustrated in Figure 42 (from outside to inside): **Type 1 (thickness= 0.198m):** ▪ Gypsum board (0.013 m) ▪ Timber frame 45/120mm with 0.12m of wood wool ▪ OSB panel (0.012 m) ▪ Gypsum board (0.013 m) **Type 2 (thickness= 0.172m):** ▪ Raw earth coating

- Mud bricks
- Timber frame 45/120mm and OSB panel (0.012 m)
- Raw earth coating

Type 3 (thickness= 0.100m):

These interior walls are designed using the old-fashioned cob method: a self-supporting lath made of pine from “Cévennes” supports the earth-straw mixture. The total thickness of the wall is 10 cm. To ensure acoustic insulation, it is composed of two 3 cm layers of cob separated by 2 cm of wood wool insulation and 2cm of raw earth coating.

Figure 37: Wood timber structure

Figure 38: Bunches of straw and wood fiber insulation in exterior walls

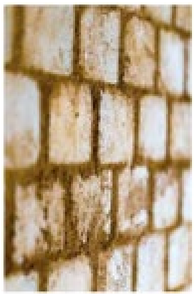


Figure 39: Mudbric wall

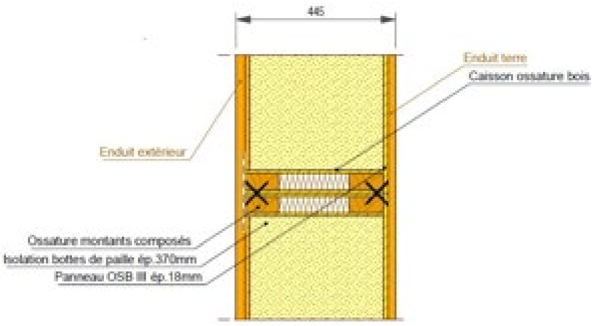


Figure 40: Exterior wall section

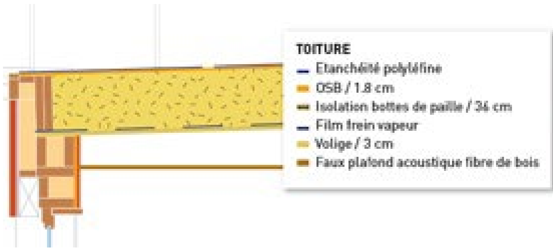
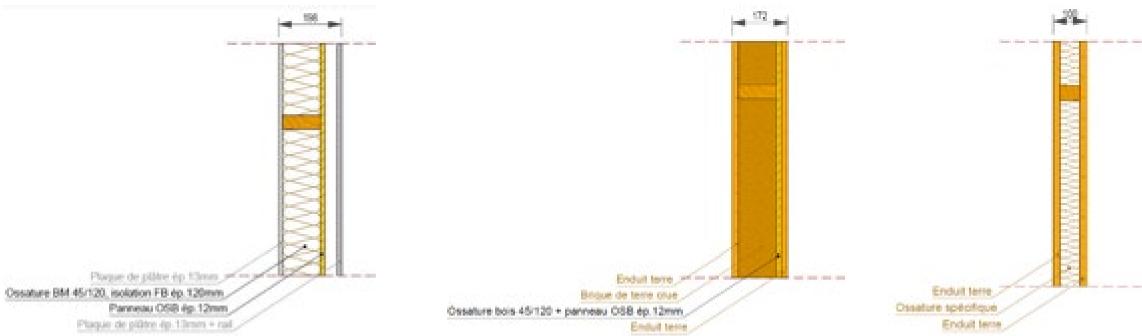


Figure 41 : Roof section details



Type 1 Type 2 Type 3

Figure 42: Details of the different types of interior walls that compose the building.

ENERGY EFFICIENT BUILDING SYSTEMS [1] [2]	
Low-energy cooling systems	Comfort ventilation & Nocturnal ventilative cooling Geothermal heat pump Floor cooling Fan coil

Low-energy heating systems	Geothermal heat pump; Low temperature floor heating Fan coil
Ceiling fans	1 in each office and 1 in the meeting room. Ceiling fans with 3 blades and with integrated LED lighting and remote control from Shakespear brand.
Mechanical ventilation / air renewal	Dual flow ventilation system: Swegon Gold RX TOP Maximum flow = 1200 m^3/h Efficiency of heat recovery of the wheel exchanger = 81% Air tightness of the duct system = Class C
Domestic Hot Water	Solar Thermal ECS electro-solar water heater of 200 litres 1 solar thermal collector of 2 m²
Artificial lighting	**Offices, training rooms and meeting rooms:** T5 light bulbs - 6 to 14 W / m² - equipped with ***presence sensors and daylight linked dimming systems.*** **Circulation areas and sanitary facility:** LED – 3 to 8 W/m² - equipped with presence sensors. **Storage, server room:** compact fluorescent lamps - 13 W/m²
Control and energy management	Building Management System: Trend 963 Supervisor Measurement of the energy consumption and the energy production with a 10 minutes timestep. Visualization and control of the heating, cooling and ventilation systems. Different energy savings features have been implemented such as presence sensors and daylight linked dimming systems, as well as multi-socket adaptors with a power switch.

Figure 43: The building is equipped with an under-floor heating/cooling system powered by a ground source heat pump

Figure 44 : Double flow mechanical ventilation system

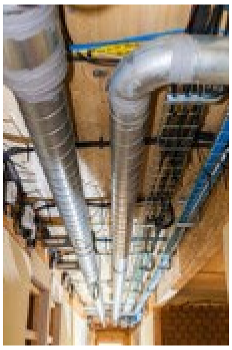


Figure 45 : Air distribution system of the building

Figure 46 : Lighting of the training room with presence sensors and daylight linked dimming systems

Figure 47 : Multi-socket adaptors with a power switch

RENEWABLE ENERGY [1] [2]	
PV	88 PV modules from the Sunpower brand - E20-327-COM **Total Power=** 28.8 kWp Solar Cell Efficiency= 20.4%
Solar thermal	ECS electro-solar water heater of 200 litres 1 solar thermal collector of 2 m²
Wind	None
Geothermal	Heat Pump on geothermal probes Heat pump Weishaupt WWP S 10 IBER - Heat: 9.5 kW, COP 4.2 - Cold: 14.6 kW, EER 9.1
Biomass	None

Figure 48: View of the PV panels installed on the rooftop of the building

Figure 49: Solar inverter and sensors of the PV system

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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: **100%**
	6. Percentage of time inside the Givoni comfort zone of 0m/s: **96%**

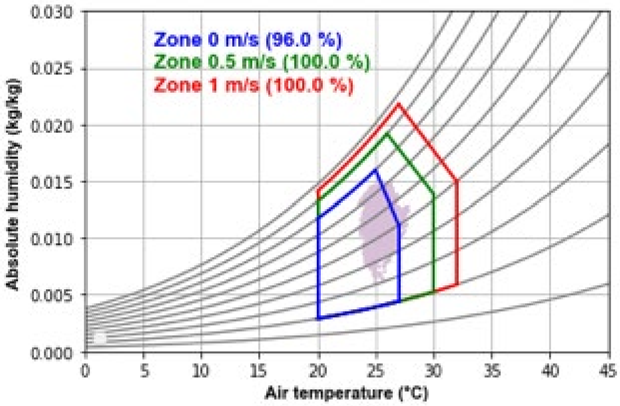


Figure 50 : Givoni comfort zones on the psychometric chart obtained for the 5 monitored rooms of the IZUBA building during occupied hours for the hot period (June 23th to September 6th, 2022). The heat pump was switched on.

7. Number of hours within a certain temperature range:

Summer period (Jun. 23th to Sept. 6th, 2022) Occupation time: 9:00am to 6:00pm		
Range	Nb of Hours	Frequency
Ta≤24	21	1%
24<Ta≤26	2061	76%
26<Ta≤28	618	23%
Ta>28	0	0%

Energy performance indicators	1. Energy needs for heating= **4.1** [kWh/m²/year]
	2. Energy needs for cooling= **2.1** [kWh/m²/year] The part for ventilation is equal to **11.8** [kWh/m²/year]
	3. Energy use for lighting= **7.1** [kWh/m²/year]
	4. Energy needs for Sanitary Hot water= **1.3** [kWh/m²/year]
	5. Total primary energy use = **73,5** [kWh/m²/year] (total Primary Energy Factor (PEF) equal to **2.58** for electrical energy from the grid)
	6. Renewable primary energy generated on-site = **117.1** [kWh/m²/year] in 2017 PV: 82.9% / Geothermal: 16.9% / Solar thermal: 0.2%
	7. Renewable primary energy generated on-site and self-consumed= **20** [kWh/m²/year] in 2017 (Geothermal & Solar thermal)
	8. Renewable primary energy exported to the grid= **97.1** [kWh/m²/year] in 2017 (PV)
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation) = **27% (generated on-site and self-consumed)** **132% (exported to the grid)**
	10. Delivered energy (measured in 2017) = **28,5** [kWh/m²/year]
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material

ABC21 is funded by the EU's H2020 programme

Users' feedback	The occupant satisfaction is generally very positive. 80% of the respondents consider that their environment is thermally comfortable, both in summer and winter. The users also find that the building is comfortable in terms of acoustic and natural lighting. They also appreciate the smell of wood. The post occupancy evaluation highlighted that thermal comfort is sometimes difficult to adjust due to the individual sensitivity of the occupants.

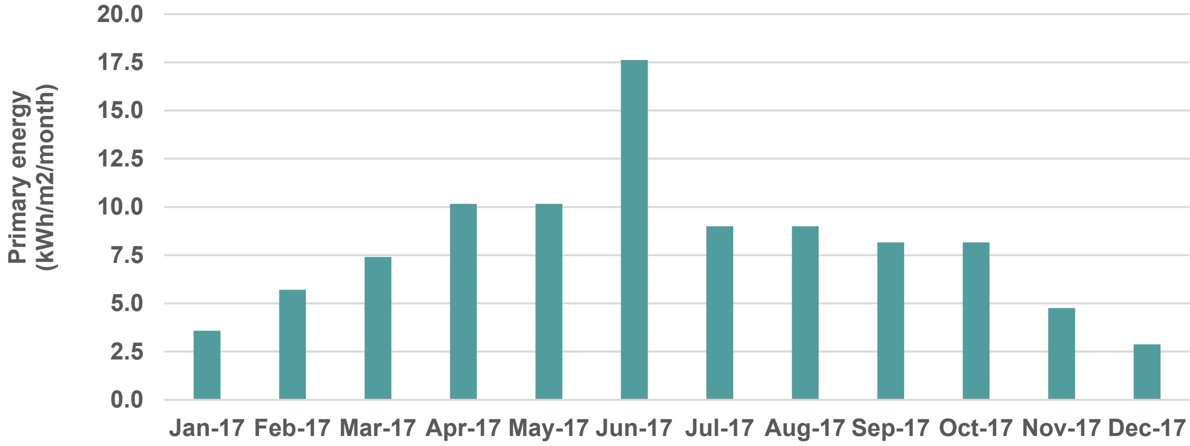


Figure 51: Monthly primary energy generated on-site from PV for the year 2017.

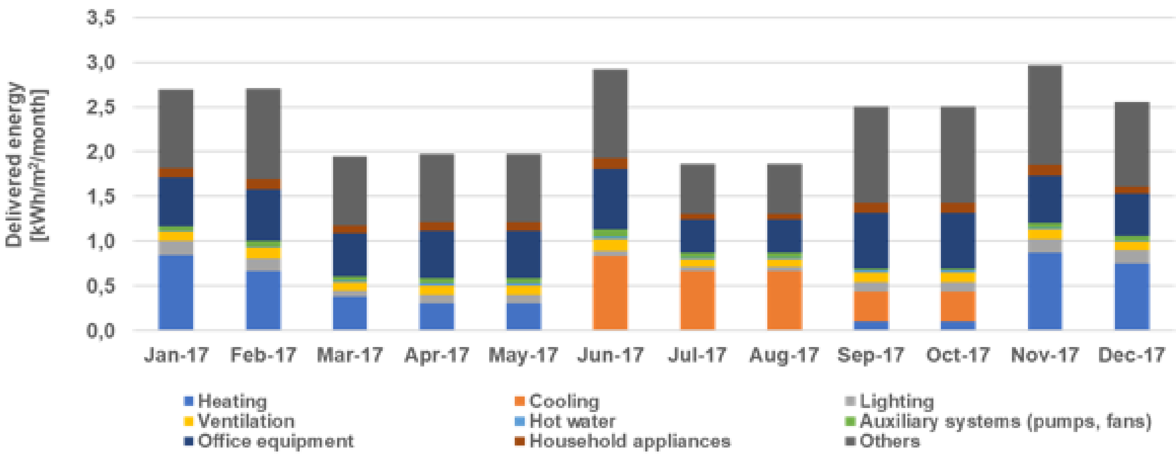


Figure 52: Monthly delivered energy by end-uses for the year 2017.

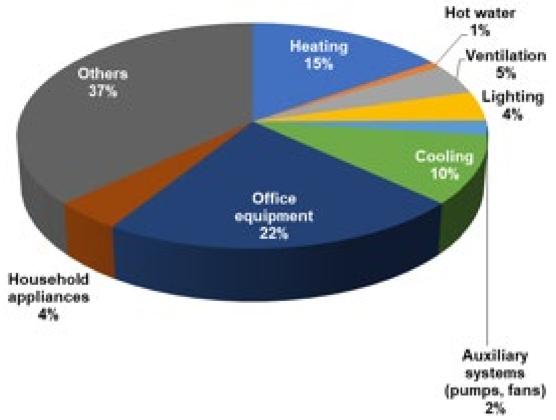


Figure 53: Distribution of all end-uses of the building over the year 2017.

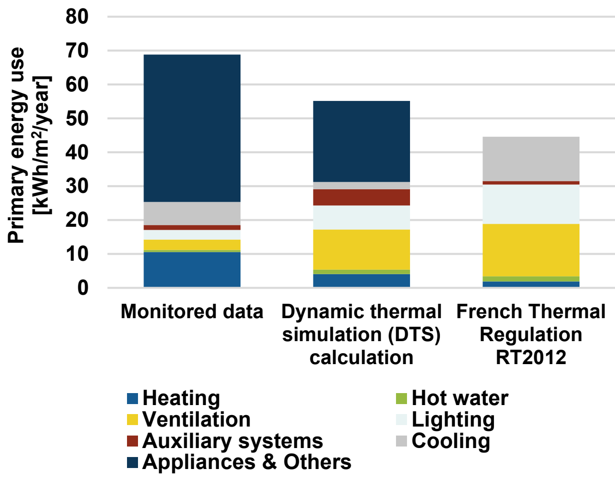


Figure 54: Primary energy use of the building by end-uses for the year 2017. Measured data are different from the simulated and calculated ones. The energy use for non-regulatory uses (Appliances & Others) is almost twice as high as the estimated one. The primary energy use of the building for all regulatory uses (All uses except appliances & others) is lower than the results predicted by the simulation or the French Regulation RT2012 calculations.

LESSONS LEARNED AND RECOMMENDATIONS

Lessons learned

An analysis of the monitored data obtained for energy and thermal comfort was done after the first year of operation. The first finding is that the measured delivered energy part for heating is higher than the calculated one. This difference can be explained by a higher setpoint temperature (21°C) than the one considered in the calculation (19°C) as well as by a non-optimal operation of the installation during this first year.

The measured ventilation and lighting delivered energy are lower than those calculated. These results show that the ventilation system is very efficient and that the air handling system has been correctly sized. The good natural lighting of the building combined with efficient and well-regulated equipment explains the good result on lighting. The delivered energy for non-regulatory uses such as appliances or office's equipment (and others than heating, cooling, ventilation, lighting, hot water) is almost twice as high as the estimated one obtained from simulation. The lack of additional sub-meters makes it difficult to carry out a detailed analysis that would provide a better understanding of the distribution of this energy consumption and the precise origin of this underestimation. Overall, the delivered energy of the building for all regulatory uses is lower than the results predicted by the simulation or the French Regulation RT2012 calculations.

With a higher photovoltaic production than the one predicted by the calculation as well as a consumption balance that is globally lower, the positive energy balance is confirmed by the measurements.

After an initial period of adjustments for the first winter, the set point for optimal comfort for all was found: 21°C. This temperature, higher than the 19°C proposed by the heating engineers, proved to be more suitable for work in a sitting position.

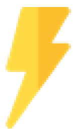
For summer comfort, practice has contradicted some of the initial assumptions. Indeed, (7. In summer, the office departure times in the afternoon/evening are incompatible with the opening of the windows. The outside temperature is still 5 to 10°C higher than the inside temperature. Unfortunately, the occupants have left by the time it gets cool at night. In addition, the geocooling mode of the heat pump is not used since the return temperature of the probes is just at the limit of the maximum temperature required by the heat pump to allow this operating mode (17°C). The

	possibilities of setting the parameters of the heat pump are limited. A test borehole would have made it possible to anticipate this behaviour of the ground, but it was not economically feasible on such a small project. Initially designed to ventilate without heat loss in winter, the double flow ventilation was also a very good ally in the fight against overheating. The excellent exchange efficiency allowed the outside air to be cooled from 35°C to 28°C before insufflation and after exchange with the extract air at 26-27°C.
Recommendations	The introduction of a rainwater collection system would lead to an efficient and sustainable use of water for domestic purpose. The measurement of the delivered energy of a building is recommended. The measured consumptions can be compared to the simulation and regulatory calculations, which allows to appreciate the relevance of the retained calculation hypotheses, as well as the strengths and weaknesses of the real building. Besides, it allows to identify and correct, if necessary, any drift or anomalies in the delivered energy consumption. Monitored data also improve knowledge of the behaviour of the building, its equipment and its occupants. Feedback on high performance buildings is essential to encourage the replication of this type of design.

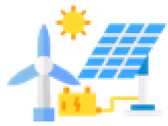
BUILDING STRENGTHS AND WEAKNESSES

Strengths

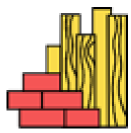
Passive Design



Energy Efficiency



Renewable Energy



Local Materials

Weaknesses

The site where the building is located is bare of vegetation and shaded areas which increases the heat caused by radiation especially in the summer season.

REFERENCES

[1] https://batiment.izuba.fr/

[2] https://www.construction21.org/case-studies/fr/izuba-energies-building.html

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

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

ABC21 is funded by the EU's H2020 programme

CASE STUDY 1-04: NIAMA | LA REUNION

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Ravine Blanche, Saint-Pierre, La Réunion, France
Latitude; Longitude	-21.337417747378176, 55.46382756587495
Climate zone (Köppen–Geiger classification)	Aw: Tropical savannah with dry winter
BUILDING INFORMATION	
Building Type	RESIDENTIAL - Collective Social Housing
Project Type	New construction
Completion Date	End of year 2014
Number of buildings	1
Number of storeys	4
Total Floor Area (m²)	-
Net Floor Area (m²)	1695
Thermally conditioned space area (m²)	0
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	1363 (all apartments are naturally ventilated)
Total cost (€)	3 219 000 (all taxes included)
Cost /m² (€/m²)	1 899
Performance Standards or Certification	RTAADOM (Thermal, Acoustic and Ventilation Regulation in the overseas department)
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	SIDR (Social landlord)
Architect / Designer	Co-Architectes - peyrebonne@co-architectes.com
Construction manager	BTB
Environmental consultancy	-
Structural Engineer, Civil Engineer	Integrale Ingénierie
Product Manufacturer	-
Certification company	-

PROJECT DESCRIPTION [1] [2] [3]

Figure 55: Northern Facade of the 'Niama' social housing building. Photo credits: N. Peyrebonne.

Located in the eco-neighbourhood of 'Ravine Blanche', in Saint-Pierre, La Réunion, '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). The RTAADOM is applied to the design of new residential buildings only and requires mandatory rules concerning thermal, acoustic and ventilation performances. The four-storey building includes a total of 19 units. The building includes passive features such as cross natural ventilation and solar shading devices so as to enhance thermal comfort while reducing energy consumption.

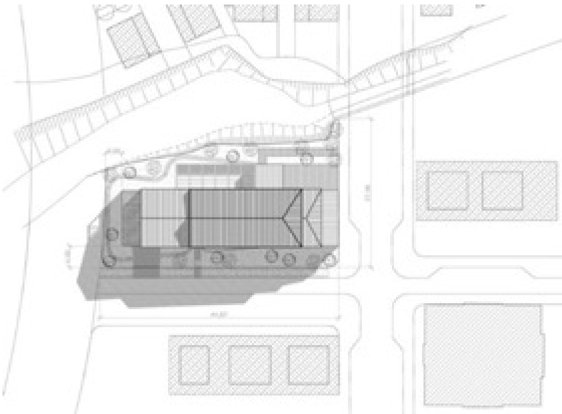
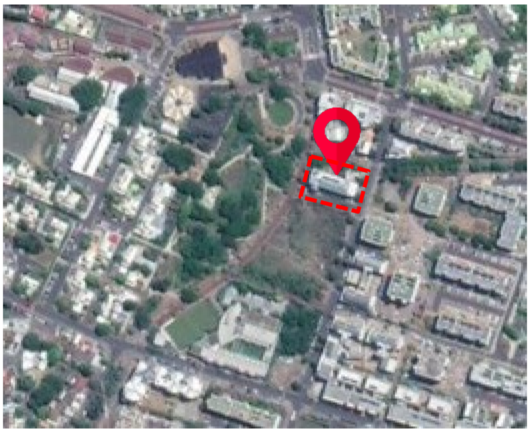


Figure 56: Master plan of 'Niama'. Design: Co-architectes.

Figure 57: Floor plan of the first floor of the Niama building [1]. Design: Co-architectes.

SITE INTEGRATION



Niama is closed to a new urban park, both part of an urban renewal program that aims at restructuring the neighbourhood and connecting it to the city center. The new park, which was part of the process of urban tissue restructuring of the neighborhood, is a green lung for the city of Saint-Pierre. Niama has been harmoniously integrated between the vegetalised area of the new park and the mineral area of the existing buildings. The building is surrounded by native plants and trees. The East facade of the building is more mineral with light-coloured painted walls and metal cladding whereas on the urban park side, it is the wood materials that prevail.

CLIMATE ANALYSIS

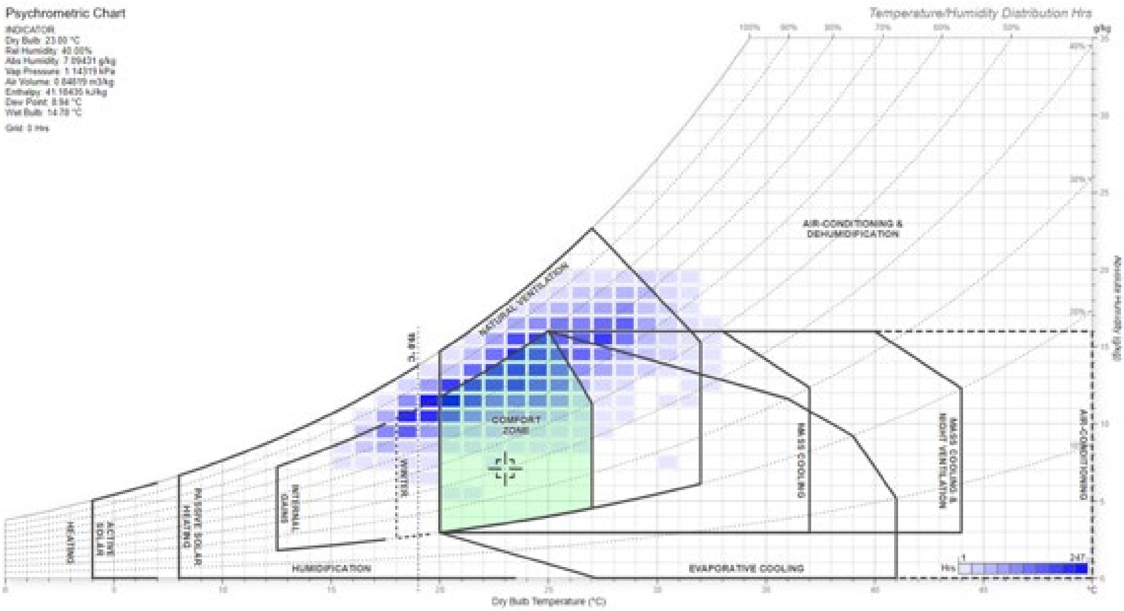


Figure 58: Givoni Bioclimatic chart for the climate of Saint-Pierre using Andrew Marsh tool. [4]

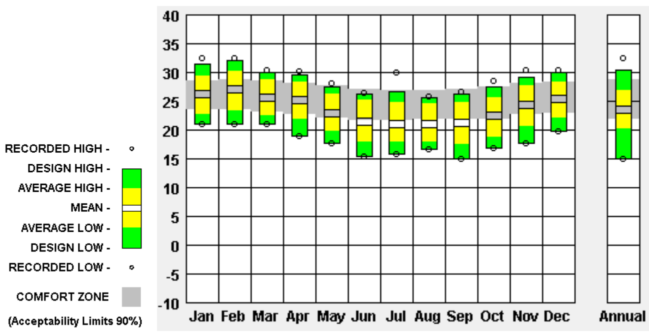


Figure 59: Temperature range by month for Saint-Pierre. Source: Climate consultant - Adaptative Comfort model [5]

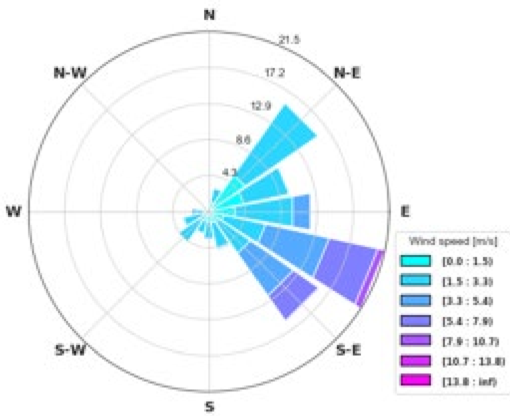


Figure 60:Annual wind rose for Saint-Pierre (Beaufort wind scale). [5]

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **3 933** Wh/m² (Jun) Max: **7 580** Wh/m² (Dec) Mean: **5 750,25** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **9** CDD 10°C: **4977**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **158** CDD: **8**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **20** CDD 26º: **171**

KEY BIOCLIMATIC DESIGN PRINCIPLES [1] [2] [3]	
Passive cooling strategy	Comfort ventilation The building is naturally cross ventilated thanks to its optimal orientation and the use of glass louvers located on opposite facades, with a high porosity.
Passive heating strategy	None
Solar protection	Main facades and windows are solar protected thanks to fixed vertical or horizontal solar protection depending on the orientation. The exterior facades of the lowest storey are made in light painted concrete. The two last storeys of the building, which are more solar exposed, are covered in wood or clear sheet metal siding facade. Solar absorptivity is low and prevents overheating of exposed parts. Exterior verandas also aim at preventing the sun from entering the building.
Building orientation	The North/South orientation of the apartments allows to optimize sun protection and to maximize the effect of thermal breezes.
Insulation	The roof is composed of an insulated sheet metal complex "Mauka Brizz" (from ArcelorMittal) and 13 mm of plasterboard. Concerning the exterior walls, each floor is composed of different materials according to the facade orientation and the sun exposure. The walls on the first floor are isolated with 2 cm of expanded polystyrene and an air gap of 0,5 cm. On the last floor, the walls are insulated thanks to 2 cm of wood, 3 cm of expanded polystyrene and an air gap of 10 cm.
Vegetation	The building is surrounded by native plants and benefits from its proximity to the urban park.
Natural daylighting	Large windows allow to benefit from natural lighting.
Use of local and embedded materials	NA
Water saving and heat recovery on hot water drain	NA
Waste management	The building is equipped with a sorting for recyclable waste
Others features	The building is surrounded by native plants and benefits from its proximity to the new urban park, to public transport network and bicycle paths. The building includes an underground car park so as to maximise the vegetation and common areas around the building while reducing the heat island effect due to asphalt pavement.

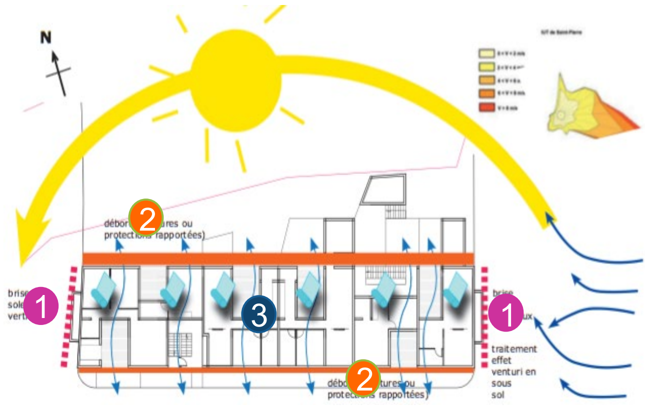


Figure 61: Bioclimatic strategies set up [1].
Design :Co-architectes

The passive solutions are described below:

1: Fixed vertical solar shading, louvered shutter on the East side so as to protect from the morning sunlight and the trade winds; Pergola on the West side.

2: Solar protection measures on the main facades include simple roof overhang, fixed horizontal solar shading and sun and rain protected exterior veranda.

3: Inside porosity is maximized by the use of louvers on opposite facades, allowing cross natural ventilation.

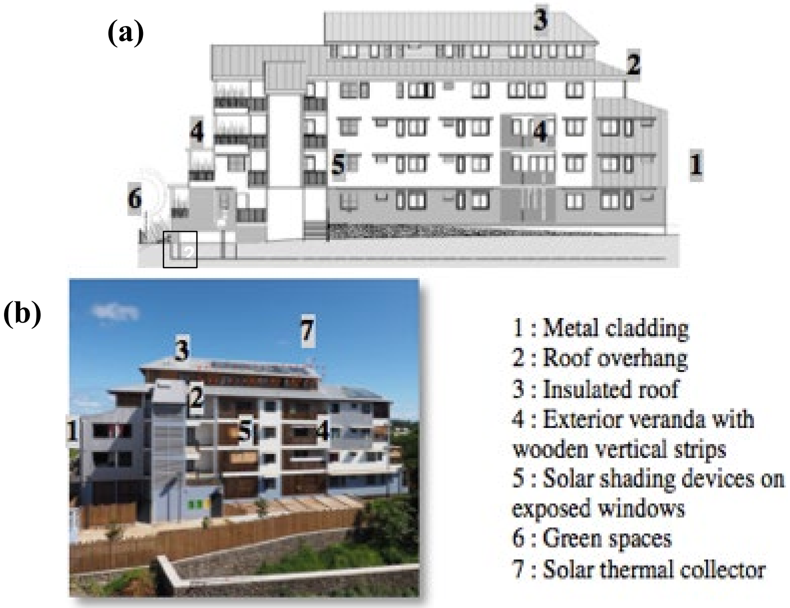


Figure 62: (a) South Façade and (b) North Façade of 'Niama', Saint-Pierre, Reunion Island [1]. Design: Co-architectes. Photo credits: N. Peyrebonne.

Figure 63: Solar protection strategies [3]. Photo credits: N. Peyrebonne.

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 The building includes a bike parking of 17,30 m^2 on the first underground level Ratio with number of users: -
Ceiling fans	In every room, even those conditioned: No Ceiling fans have been installed in the bedrooms but not in the living rooms.
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: No The building is equipped with timer switch for the lighting control in the common areas (corridor, car park, exterior)
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	In every room, even those conditioned: Yes The exterior verandas with the vertical wood strips provide an optimal space for drying clothes.
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: Unknow

BUILDING FABRIC AND MATERIALS	
Roof	Type: Gable roof Materials: Insulated sheet metal complex Mauka Brizz (ArcelorMittal) + 13mm of plasterboard
	Overall R-value: 1,8 m²K/W
Windows	Different types of windows: Aluminium French style opening windows, aluminium jalousie window and aluminium sliding door
	Window-to-wall ratio (WWR) : Superior to 20% on the main facades
	U-value: -
	Visual transmittance: -
Walls	**Exterior Walls** are composed from the outside to the inside: **First floor (NSE orientation):** 0,18 m of concrete + 0,02 m of expanded polystyrene + air gap of 0,005 m + 0,013 m of plasterboard **Overall R-value:** 0,73 m².K/W
	Last floor (NSEO orientation): 2 cm of wood + 3 cm of expanded polystyrene + air gap of 10 cm + 1,3 cm of plasterboard **Overall R-value:** 1,06 m².K/W
	Other floors: Insulated sheet metal complex Mauka Brizz (from ArcelorMittal) + 0,025m air gap + 18cm of concrete **Overall R-value:** 0,46 m².K/W

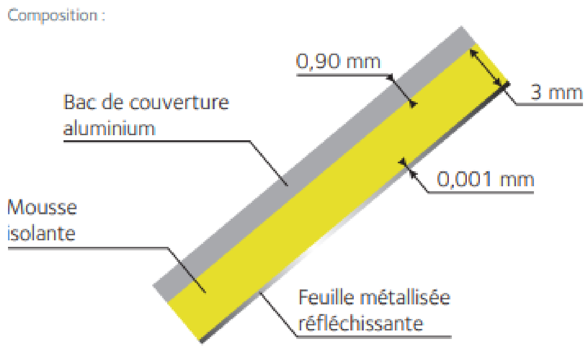


Figure 64: Mauka Brizz composition for hot climates (aluminium cover, insulating foam and metallised reflecting sheet). Design: @Arcelor Mittal

Figure 65: Exterior wall made with the Mauka Brizz system. Photo credits: N. Peyrebonne.

ENERGY EFFICIENT BUILDING SYSTEMS [3]	
Low-energy cooling systems	None The installation of ceiling fans and the design of the building so as to enhance cross natural ventilation and reduce direct solar heat gain allow to avoid the use of mechanical cooling systems.
Low-energy heating systems	None
Ceiling fans	All apartments are equipped with highly efficient ceiling fans, installed in the bedrooms: Type: Hunter Industry 2 BN - 1Ceiling Fan/10 m^2. Size diameter (cm): 132 Power: 16 to 70 W 3 speeds with wall control
Mechanical ventilation / air renewal	None
Domestic Hot Water	Domestic hot water for all the units of the building is produced thanks to 40 m² of solar thermal collectors. Individual water tanks are installed in each apartment.
Artificial lighting	**Exterior and car park:** PALERMO T5 - 2*49W **Hallway and stairway:** Downlight Jumbo Tridonic 2*42W Controls: timer switch
Control and energy management	The common areas are equipped with timer switch for the lighting control.

Figure 66: Energy efficient systems installed in the building

RENEWABLE ENERGY [3]	
PV	None
Solar thermal	Yes EZINC - Model E23HP-V Total area= 40m^2
Wind	None
Geothermal	None
Biomass	None

Figure 67 Solar thermal solar panels are installed on the rooftop of the building for the production of hot water

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	1. Percentage of time outside an operative temperature range (Adaptive model): -
	2. Percentage of time outside an operative temperature range (Fanger model): -
	3. Degree-hours (Adaptive comfort model): -
	4. Degree-hours (Fanger comfort model): -
	5. Percentage of time inside the Givoni comfort zone of 1 m/s: **cooling season: >80%** (see Figure 68 and Figure 69)
	6. Percentage of time inside the Givoni comfort zone of 0 m/s: **cooling season: < 3%** (see Figure 68 and Figure 69)
	7. Number of hours within a certain temperature range: Hottest months of the cooling season (31th January to 8th April 2018)

Bedroom-First floor			Bedroom – Third floor		
Range	Nb of Hours	Frequency	Range	Nb of Hours	Frequency
Ta<26	**55**	4%	Ta<26	**0**	0%
26≤Ta<28	**660**	47%	26≤Ta<28	**620**	44,3%
28≤Ta<30	**605**	43%	28≤Ta<30	**760**	54,3%
30≤Ta<32	**80**	6%	30≤Ta<32	**20**	1,4%
Ta≥32	**0**	0%	Ta≥32	**0**	0%

ABC21 is funded by the EU's H2020 programme

Energy performance indicators	1. Energy needs for heating: - [kWh/m²/year]
	2. Energy needs for cooling: - [kWh/m²/year]
	3. Energy use for lighting: - [kWh/m²/year]
	4. Energy needs for Sanitary Hot water: - [kWh/m²/year]
	5. Total Primary energy use: **100.7** [kWh/m²/year] (total Primary Energy Factor (PEF) equal to **3.3** for electrical energy from the grid)
	6. Renewable Primary energy generated on-site: - [kWh/m²/year]
	7. Renewable Primary energy generated on-site and self-consumed: - [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): - **%**
	10. Delivered energy (from electricity bills) = **30,5** [kWh/m²/year]
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	A global satisfaction survey was carried out with the occupants in 2018. Thermal perception was evaluated according to a symmetrical 7-degree two-pole scale (from cold to hot). All the respondents felt neutral during the cold period while they globally felt hot during the summer, especially during the afternoon and the evening. The perception of air movement was also evaluated and perceived as neutral (neither still nor draughty). They found that natural ventilation is quite effective during the hot period and cited the lack of ceiling fans in the living room (only bedrooms are equipped with ceiling fans). Water infiltration issues and poor maintenance (ceiling fans, blinds) were also identified. Overall, the tenants are globally satisfied of their apartment with a score a 6.3 over 7 point with good natural daylight and air quality.

ABC21 is funded by the EU's H2020 programme

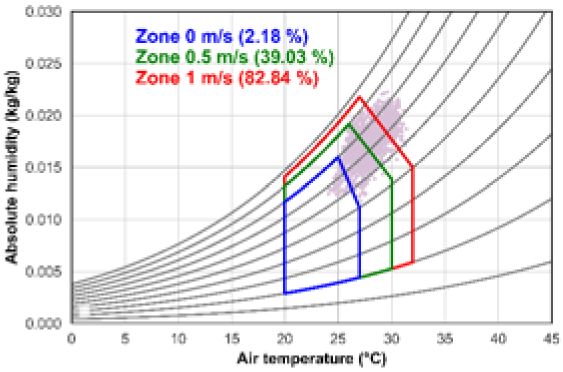


*Figure 68 : Givoni bioclimatic chart obtained for a **bedroom at the first floor**, showing that only 2% of the points are in the 0m/s comfort zone while more than 82% are in the 1m/s comfort zone during the cooling season (31 January to 8th April 2018).*

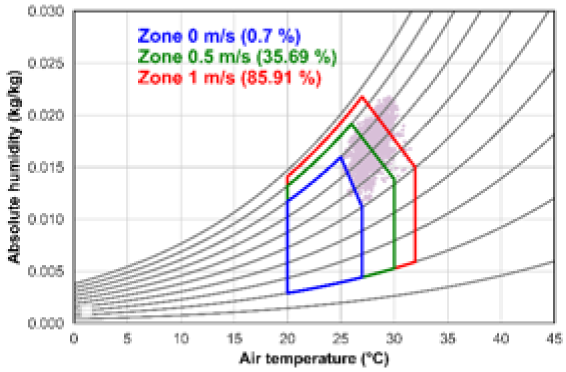


*Figure 69 : Givoni bioclimatic chart obtained for a **bedroom of the third floor**, showing that less than 1% of the points are in the 0m/s zone while more than 85% are in the 1m/s comfort zone during the cooling season (31 January to 8th April 2018).*

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	1. Use of local materials with low embodied energy and sustainable production (natural, reused or recycled) The choice of good quality material is of particular importance in achieving the goals of sustainable development in construction projects. 2. Building maintenance Proper and consistent building maintenance is essential for bioclimatic building in order to ensure comfortable conditions and makes it more durable over the time of the building. 3. Affordability and replicability of the buildings Only some passive bioclimatic systems or energy efficient systems could be replicable because of the use of a very elementary cooling system with natural ventilation.
Recommendations	1. Passive cooling and/or passive ventilation Buildings should be designed considering and solving potential privacy issues so as to be sure that the occupants can open the windows and that natural ventilation can correctly operate 2. Energy efficient systems All living rooms should be equipped with ceiling fans. The timer switch for the lighting control could be extended also to the private flats. 3. Use of local materials with low embodied energy and sustainable production (natural, reused or recycled) The use of local and natural materials in the project would have been recommended. It would be better to use natural materials for insulation instead of polystyrene.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

Passive Design	**Energy Efficiency**

Weaknesses

1. The lack of ceiling fans in the living room (only bedrooms are equipped with ceiling fans);
2. Water infiltration issues and poor maintenance (ceiling fans, blinds);
3. Rapidly degrading construction materials;
4. Privacy issues due to the windows of the bedrooms overlooking the common corridors of the building.

REFERENCES

[1] Grosdemouge Virginie, et François Garde. 2016. « Passive design in tropical climates: Key strategies implemented in a French certified sustainable neighbourhood ». In PLEA 2016 Cities, Buildings, People: Towards Regenerative Environments.

[2] https://www.envirobat-reunion.com/fr/portail/357/observatoire/46884/fiche-envirobat-reunion-niama-saint-pierre-co-architectes.html

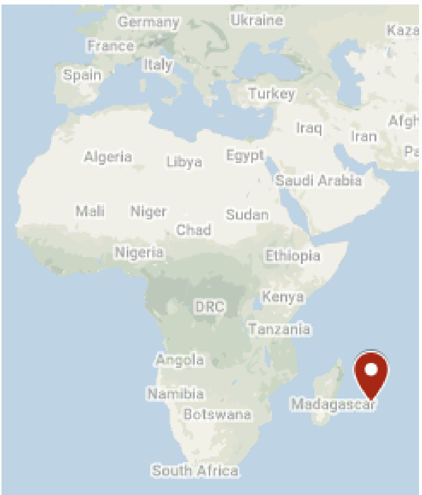
[3] https://www.construction21.org/france/case-studies/h/niama.html

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

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

ABC21 is funded by the EU's H2020 programme

CASE STUDY 1-05: ENERPOS | LA REUNION



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	40 avenue de Soweto, Saint-Pierre, La Réunion, France
Latitude; Longitude	-21.34080841368781, 55.491067294562335
Climate zone (Köppen–Geiger classification)	Aw: Tropical savannah with dry winter

BUILDING INFORMATION [1]	
Building Type	Educational - University
Project Type	New building
Completion Date	2008
Number of buildings	2
Number of storeys	2
Total Floor Area (m²)	739
Net Floor Area (m²)	681
Thermally conditioned space area (m² area type)	286
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	435
Total cost (€)	2 372 000
Cost /m² (€/m²)	3 209.74
Performance Standards or Certification	PERENE 2004 (Local standard for efficient buildings in La Reunion)
Awards	Winner of the PREBAT ADEME award (local award)

STAKEHOLDERS [1]	
Building Owner / Representative	University of La Reunion
Architect / Designer	Thierry Faessel-Bohe

Construction manager	Leon Grosse
Environmental consultancy	TRIBU Paris and IMAGEEN
Structural Engineer, Civil Engineer	RTI
Mechanical, Electrical Engineer	INSET

PROJECT DESCRIPTION [2]

Figure 70 : Southern façade with solar shadings (overhang and wooden strips) [2]

ENERPOS is a classroom and office building on the French island of La Reunion near Madagascar, which demonstrates that sustainable design saves significant energy while providing a comfortable environment. ENERPOS (French acronym for POSitive ENERgy) is the first net zero energy building (Net ZEB) on La Reunion. The two-story building splits into two parallel blocks separated by a green patio. The blocks are composed of an administration zone on the ground floor (seven offices and a meeting room), two computer rooms and five classrooms for a total net floor area of 681 m², as well as a car park under the building. The building has been designed with priority given to the passive design such as cross natural ventilation and solar shading [2].

Figure 71 : Eastern façade [2]

Figure 72 : Outdoor corridor and overhangs

SITE INTEGRATION

Figure 73 : Site integration of the building in the campus

The building is surrounded by native plants to prevent the air from heating up before entering the building. The car park is located under the building to avoid the excess heat that occurs from having pavement around the building, and to increase the soil permeability to prevent flooding after heavy tropical storms.

CLIMATE ANALYSIS

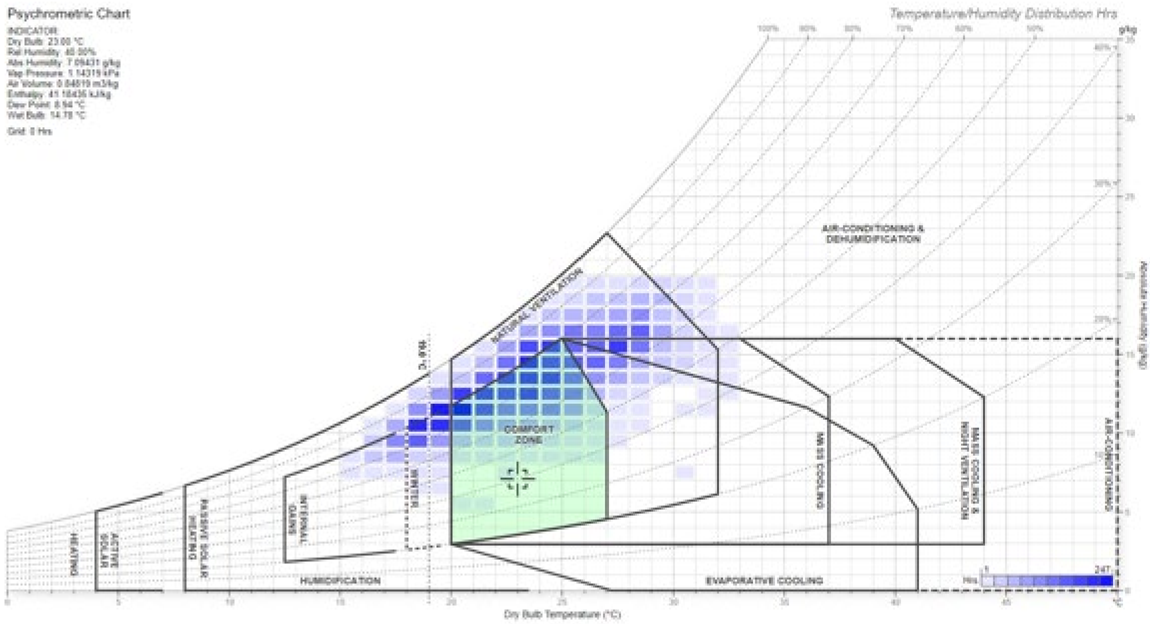


Figure 74: Givoni Bioclimatic chart for the climate of Saint-Pierre. [3]

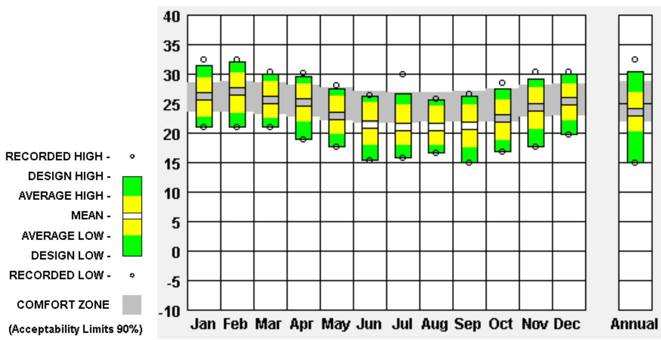


Figure 75: Temperature range by month for Saint-Pierre. Source: Climate consultant – Adaptative Comfort model [4]

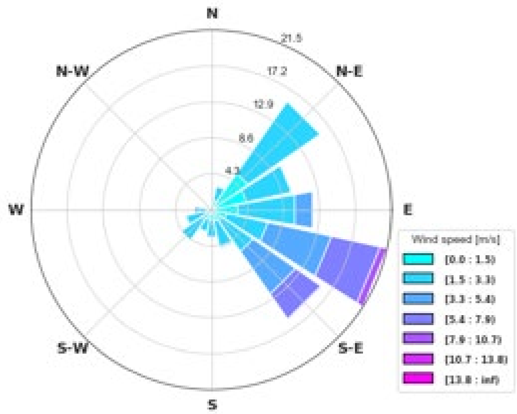


Figure 76 : Annual wind rose for Saint-Pierre (Beaufort wind scale) [4]

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **3 933** Wh/m² (Jun) Max: **7 580** Wh/m² (Dec) Mean: **5 750,25** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **9** CDD 10°C: **4 977**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **158** CDD: **8**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **20** CDD 26º: **171**

KEY BIOCLIMATIC DESIGN PRINCIPLES [5] [6] [7] [8]	
Passive cooling strategy	**Comfort ventilation / cross natural ventilation** The building is naturally cross ventilated by using glass louvers, which have the advantage of allowing regulation of the airflow while also providing protection against cyclones and break-ins. In the administration zone, the central corridor around which the offices are located was cutting off the ventilation. The installation of indoor louvers enhances interior airflow. providing a porosity of 30%.
Solar protection	North and South Façades are solar protected with horizontal wooden strips, that have been simulated and optimized with Sketchup. Besides electricity production, the PV panels provide a ventilated double roof, which creates solar shading of the terrace roof of the building.
Building orientation	The main façades are facing **north and south** respectively, to use the thermal breezes during summer and to reduce the solar energy gained by the building on the western and eastern façades, which are of smaller size.
Insulation	The walls of the East and West facades are insulated thanks to 2 cm of polystyrene and wooden cladding. The roof is insulated with 8 cm polystyrene + solar protected by a BIPV roof. North and South facades are not insulated but solar protected.
Vegetation	The building is surrounded by a 3 m band of native plants to prevent the air from heating up before entering the building. Native plants have low water needs and are adapted to cyclones. The planted patio in ENERPOS creates a microclimate around the building by decreasing the air temperature. It also brings conviviality in a crossing point of the building.
Natural daylighting	The solar protections of the facades have been optimized for daylighting. Useful Daylight Index of 90% in most spaces. **No artificial lighting in two classrooms on the first level facing the sea.**
Use of local and low embedded energy materials	No local materials have been used but chairs were made from recycled plastic. The paint used for the coatings is completely organic.
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** (only 6). No showers.
Ceiling fans	In every room, even those conditioned: **Yes**
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	**Signs in classrooms explain how to properly use the building** by opening the louvers or turning on ceiling fans, switching off unnecessary lights, and using the stairs, rather than the elevator. Signs also provide suggestions for reducing waste by printing on both sides of paper, **using reusable cups and glasses,** sorting the garbage for recycling, etc.

ABC21 is funded by the EU's H2020 programme

(lighting…) in order to promote sufficiency and efficiency actions	
Water saving	Low-flow toilets
Waste management	Not taken into consideration. Initial efforts focused on energy efficiency.

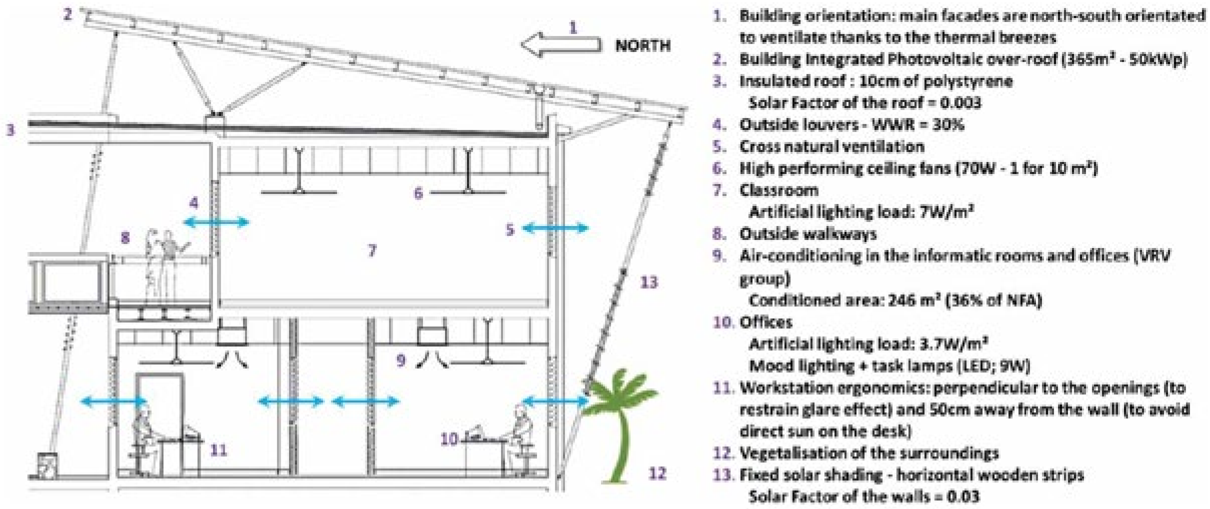


Figure 77 : cross section of the passive solutions [5]

BUILDING FABRIC AND MATERIALS [2]	
Roof	**Type:** BIPV over-roof + 10 cm (3.9 in.) of polystyrene + 20 cm (7.9 in.) concrete
	Overall R-value: 3.4
Windows	**Type: Glass** louvers
	Window-to-wall ratio: 30%
	U-value: 1.4
	Visual transmittance: 0.4
Walls	**Type:** East and West: 18 cm (7.1 in.) concrete + 8 cm (3.1 in.) mineral wool or 18 cm (7.1 in.) concrete + ventilated air gap + wooden siding North and South: 18 cm (7.1 in.) concrete + solar shading
	Overall R-value: East and West: 1.8 North and South: 0.1

ENERGY EFFICIENT BUILDING SYSTEMS [5] [6] [7] [8]	
Low-energy cooling systems	A variable refrigerant flow (VRF) air conditioning system is installed to cool the offices and the computer rooms. Its cooling capacity is 25.3 kW (89 tons) and the energy efficiency ratio is 4.8 (provided by the manufacturer).
Ceiling fans	Large ceiling fans ceiling fan is 70 W (239 Btu/h), which represents 7 W/m² (255 Btu/ft²), with a ratio of one ceiling fan per 10 m² [108 ft²]). Ceiling fans are controlled individually (offices) or in groups of two or four (classrooms) from wall-mounted switches and have three speed levels.
Artificial lighting	Low energy T-5 tubular fluorescent luminaires provide indirect ambient lighting, while 9W LED **desk lamps** in the offices provide additional local lighting as needed. The installed electric density for artificial lighting is lower than in a standard building (7 W/m² [255 Btu/ft²] in the classrooms and 3.7 W/m² [134 Btu/ft²] in the offices). **Timers** in the classrooms turn the lights off automatically after two hours.

Control and energy management	Energy management strategies are used to decrease the total consumption of the active systems. A building management system controls the air-conditioning system (operating period, setpoint temperature); the schedules of exterior lighting; and energy consumption by type of end uses (lighting, ventilation, plug loads, air conditioning, elevator). The Building Management System includes **15 energy and power meters**; 15 temperature and humidity sensors and presence detectors (in all classrooms and offices).

Figure 78 : a typical classroom with large louvers on both sides and efficient ceiling fans [2]

Figure 79 : Indoor louvers to facilitate indoor natural cross ventilation

Figure 80 :Efficient ceiling fans have been installed in the classrooms.

RENEWABLE ENERGY [5] [6] [7] [8]

PV	**Type:** Building Integrated PV over-roof **Technology:** Polycrystalline cells (efficiency or kWp /m^2 . n.a.) **Surface:** 365 m^2 **Nominal power:** 50 kWp The slope of the PV cells is 9° for both roofs which is not the best choice in terms of photovoltaic efficiency as the optimum position for PV panels on La Reunion is a north orientation with a slope of 21°. The architect who designed the building wanted architectural homogeneity, with half the over-roof facing north and the other half facing south.

Figure 81 : The 50 kWp BIPV roofs [2]

Figure 82 : PV production on the panel [2]

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS [2] [5] [6] [7] [8]

Thermal comfort indicators	1. Percentage of time outside an operative temperature range [Adaptive comfort method, Category II, EN16798-1, cooling season (1st-11 to 31th-03)]: **2.2%**
	2. Percentage of time outside an operative temperature range (Fanger): -

3. Degree-hours [Adaptive comfort method, Category II, EN16798-1, cooling season (1st-11 to 31th-03)]: **13**
4. Degree-hours (Fanger): -
5. Percentage of time inside the Givoni comfort zone of 1m/s:
   Summer period (1st-11 to 31th-03**): 90 %**
   Whole year: 95%
6. Percentage of time inside the Givoni comfort zone of 0m/s:
   Summer period (1st-11 to 31th-03**): 6.5 %**
   Whole year: 36%
7. Number of hours within a certain temperature range: Monitored data of the year 2015 – Occupation time: 8:00am to 6:00pm

All year		
Range	Nb of Hours	Frequency
Ta≤26	1302	**39%**
26<Ta≤28	1093	**32%**
28<Ta≤30	931	**28%**
Ta>30	46	**1%**

Hot period (1st-11 to 31th-03)		
Range	Nb of Hours	Frequency
Ta≤26	98	**7%**
26<Ta≤28	504	**37%**
28<Ta≤30	732	**53%**
Ta>30	41	**3%**

Energy performance indicators

1. Energy needs for heating: **0** [kWh/m^2/year]
2. Energy needs for cooling: **4** [kWh/m^2/year]
3. Energy use for lighting: **3** [kWh/m^2/year] **(indoor and outdoor)**
4. Energy needs for Sanitary Hot water: **0** [kWh/m^2/year]
5. Total Primary energy use: **66** [kWh/m^2/year] (total Primary Energy Factor (PEF) equal to 3.3 for electrical energy from the grid)
6. Renewable Primary energy generated on-site: **105** [kWh/m^2/year]
7. Renewable Primary energy generated on-site and self-consumed: **0** [kWh/m^2/year]
8. Renewable Primary energy exported to the grid: **105** [kWh/m^2/year]
9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): **0%** *(energy generated on site and self-consumed)*
   159% *(considering the energy from PV exported to the grid)*
10. Delivered energy (from electricity bills): **20** [kWh/m^2/year]

Acoustic comfort indicators

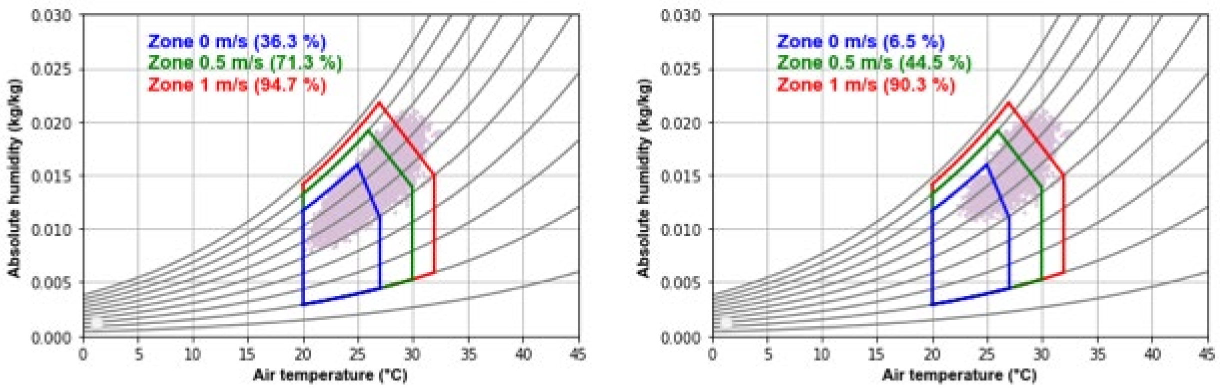
1. Airborne sound insulation
2. Equivalent continuous sound Level
3. HVAC noise level
4. Reverberation time
5. Masking/barriers

Visual comfort indicators

1. Light level (illuminance)
2. Useful Daylight Illuminance (UDI)
3. Glare control
4. Quality view
5. Zoning control

ABC21 is funded by the EU's H2020 programme

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: N/A
Users' feedback	To assess the comfort level of ENERPOS, a post occupancy evaluation was conducted during three hot seasons (October to April). It involved surveying students and lecturers during the hours of occupancy. Students were asked to complete a questionnaire at the same time that the environment parameters were being recorded (air temperature, wet-bulb temperature, globe temperature, relative humidity and air velocity). More than 2 000 questionnaires were filled in by 600 students and their teachers. The main results are that the occupants usually don't complain about the heat and generally feel comfortable, even during the hottest period of the year [2].



(a) *(b)*

Figure 83: Givoni comfort zones on the psychometric chart obtained for all monitored rooms of the ENERPOS building during occupied hours: (a) for the whole year 2015 and (b) for the hot period (November 1st to March 31th). In summer, 90% of the points are located in the zone of 1m/s, which is very close to the one that was predicted during the design phase (86%).

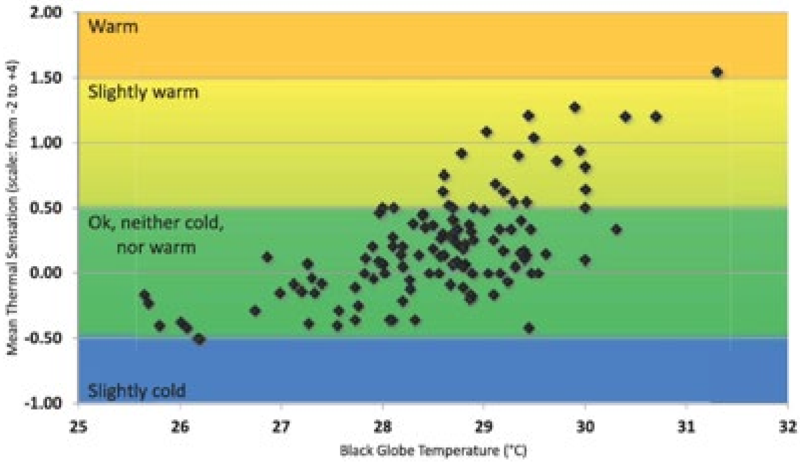


Figure 84 : Mean Thermal Sensation of the students inside the Enerpos building during 125 lectures over three summer seasons. Students were asked about their thermal sensation on a 7-point scale ranging from 'cold' (−2) to 'extremely warm' (+4). We can see that only 16% of the values are above 0.5 and that temperatures around 30◦C can be felt as "neutral" [5].

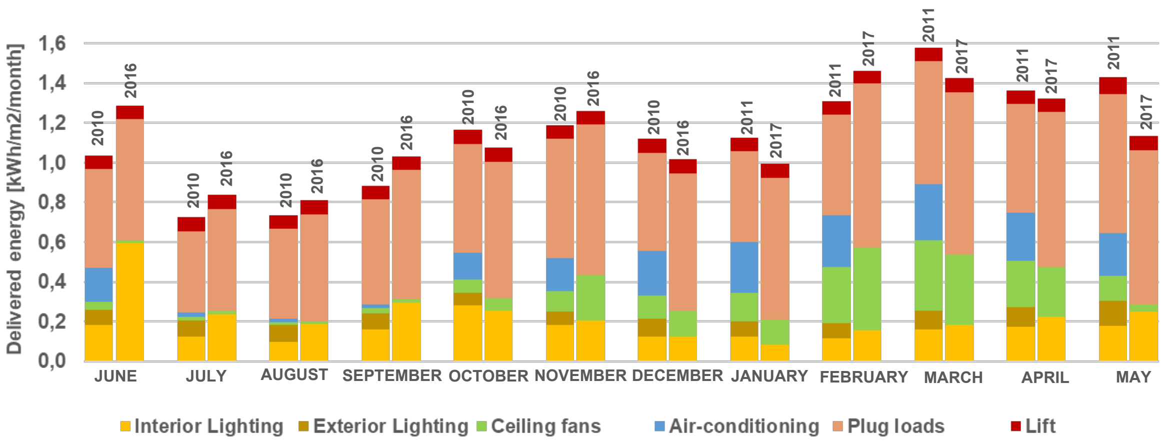


*Figure 85: Monthly delivered energy for the years 2010-2011 and 2016-2017. In 2010-2011, the main source of consumption corresponds to **the plug loads** (46% of consumption over a year), followed by the air conditioning and ventilation (15%), interior lighting (14%), the ceiling fans (11%), the exterior lighting (7%) and the lift (7%). During the period 2016-2017, the delivered energy for the plug loads is higher (61% over a year), as well as for the interior lighting (20%) whereas the delivered energy for the ceiling fans and the lift are almost the same (respectively 12% and 6%). The air-conditioning and the exterior lighting were not used during this year.*

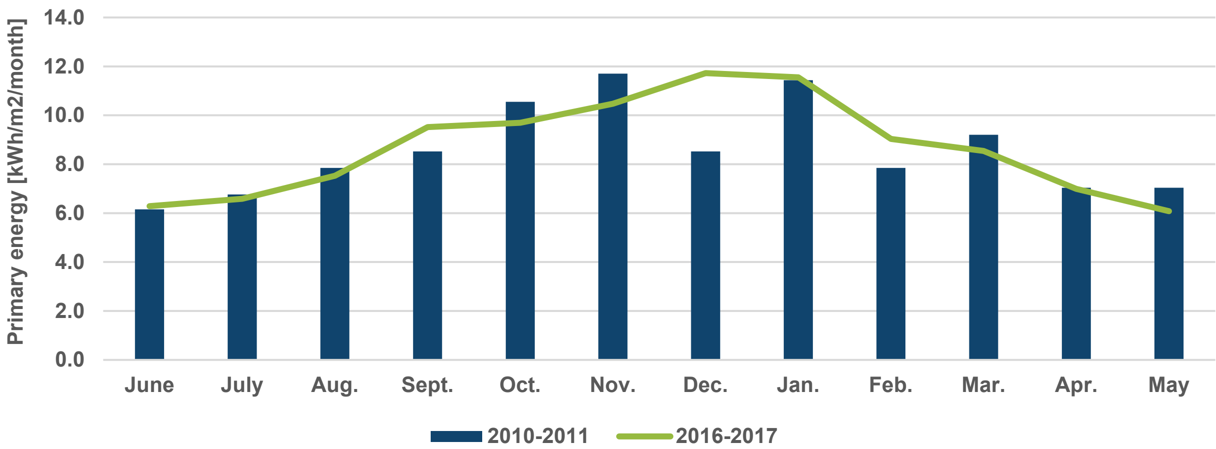


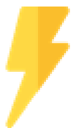
Figure 86: Monthly primary energy generated on-site from PV for the years 2010-2011 and 2016-2017.

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	Designers reduced the predicted cooling period for the computing rooms to six weeks by using natural ventilation and ceiling fans. However, monitoring found that air conditioning has only been used about one week per year. ENERPOS shows that with current technologies and only **9% additional cost**, it is possible to build a building that consumes 10 times less energy than a standard building and produces seven times more energy than it consumes at the daily scale. It also demonstrates that an academic building can significantly reduce its energy consumption by avoiding air conditioning while maintaining a good level of thermal comfort for its occupants by enabling them to use passive methods.
Recommendations	It is really important to get active people in a passive building, instead of passive people in an active building. To achieve this result, people need to be correctly informed on how to use the passive features of their building and to be conscious about their green behaviour impact. Communication and awareness-raising are essential.

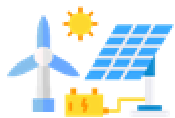
BUILDING STRENGTHS AND WEAKNESSES

Strengths

Passive Design



Energy Efficiency



Renewable Energy

Weaknesses

-

REFERENCES

[1] Enerpos. construction21.org, https://www.construction21.org/france/case-studies/h/enerpos.html (accessed 12 May 2021).

[2] University of La Reunion's ENERPOS: Saint-Pierre, La Reunion, France. HPB Magazine, Summer 2012, https://www.hpbmagazine.org/university-of-la-reunions-enerpos-saint-pierre-la-reunion-france/ (2012, accessed 12 May 2021).

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

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

[5] Aurélie Lenoir, George Baird & François Garde (2012): Post-occupancy evaluation and experimental feedback of a net zero-energy building in a tropical climate, Architectural Science Review, DOI:10.1080/00038628.2012.702449

[6] IEA. 2008 "International Energy Agency SHC Task 40 / ECBCS Annex 52 – Towards Net Zero Energy Solar Buildings." www.iea-shc.org/task40/.

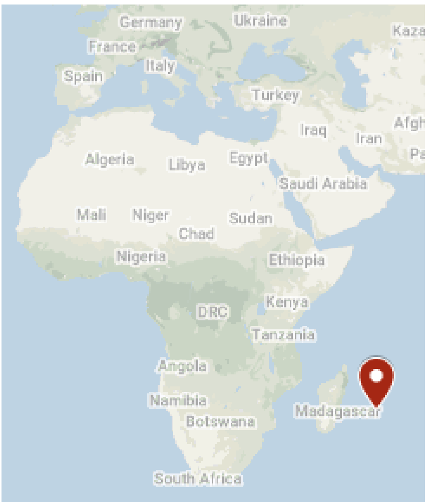
[7] Garde, F., A. Lenoir, and F. Thellier. 2011. "Towards net zero energy buildings in hot climates. Part I: new tools and methods." *ASHRAE Transactions* 117(1):458-65.

[8] Lenoir, A., F. Garde, and M. David. 2011. "Towards net zero energy buildings in hot climates. Part II: experimental feedback." *ASHRAE Transactions* 117(1):450-7

[9] Aurélie Lenoir. On Comfort in Tropical Climates. The Design and Operation of Net Zero Energy Buildings.. Physics. Université de La Réunion, 2013. English. <tel-01100526>.

ABC21 is funded by the EU's H2020 programme

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 m^2
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

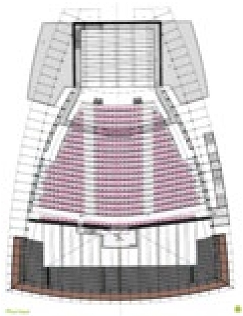


Figure 90 : Plan view of the lecture theatre

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.

CLIMATE ANALYSIS

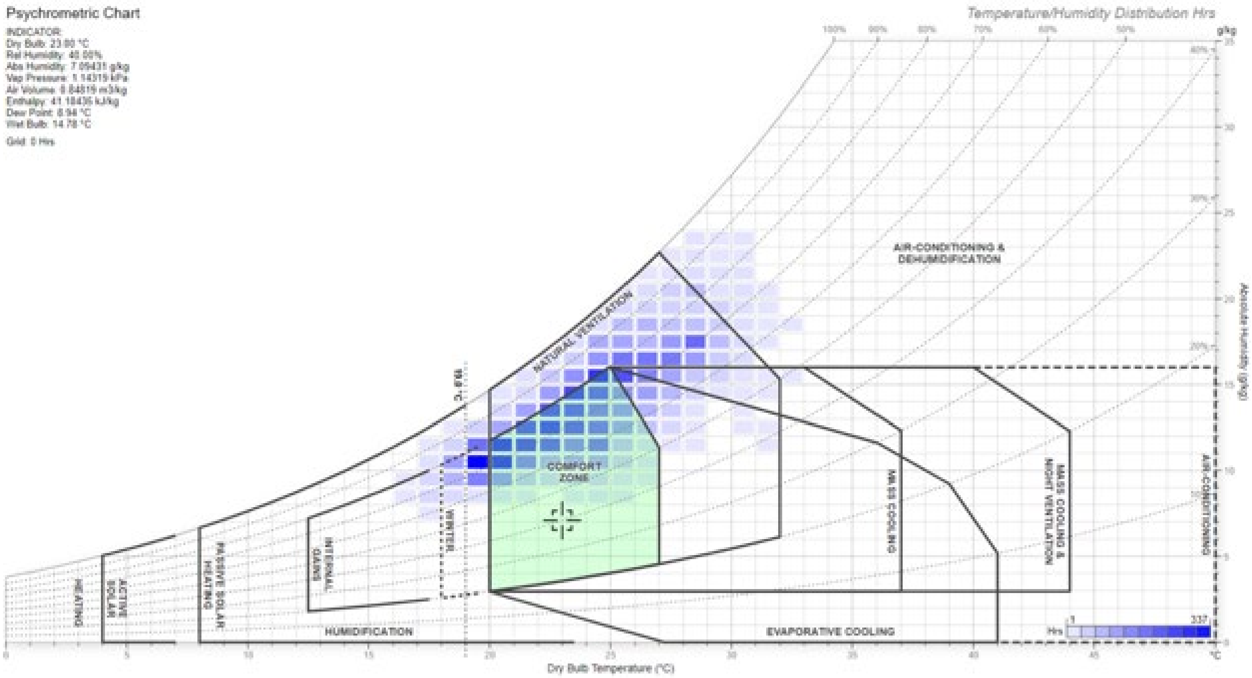


Figure 92 : Givoni Bioclimatic chart for the climate of Saint-Denis [5].

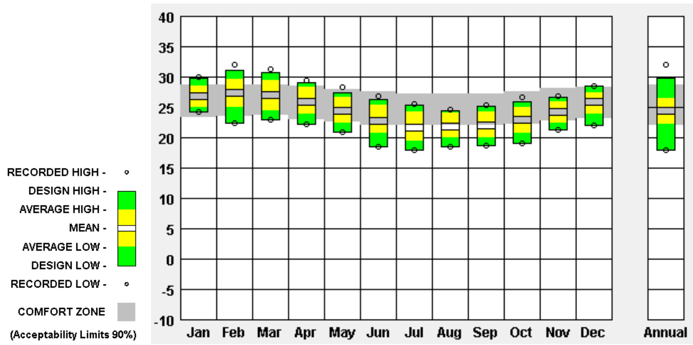


Figure 93 : Monthly temperature range for Saint-Denis. Source: Climate consultant - Adaptative Comfort model [6]

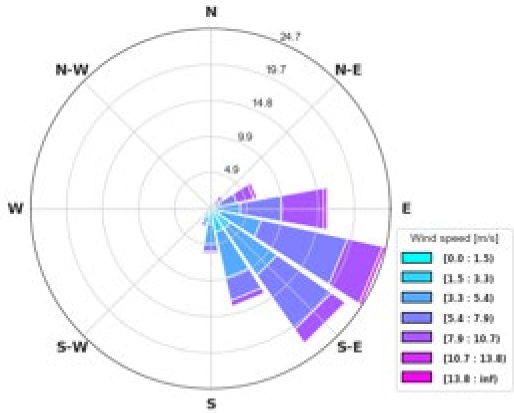


Figure 94 : Annual wind rose for Saint-Denis (Beaufort wind scale). [6]

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**

ABC21 is funded by the EU's H2020 programme

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 creates a natural low pressure thanks to the venturi effect. Glass louvers are installed on opposite facades. 4 differentiated air inlets (see *Figure 95*)
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

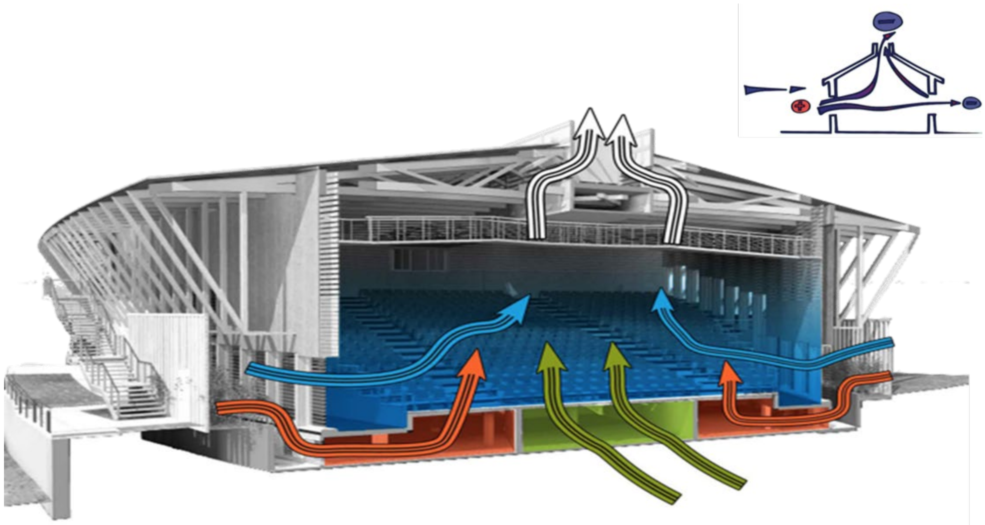


Figure 95 : Visualization of the air flow with the low-pressure shaft on top of the roof and the 4 air inlets located underneath the seats and at the side louvers.

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

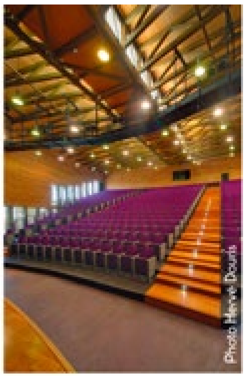


Figure 100 : Low pressure shaft (top of the roof)

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

ABC21 is funded by the EU's H2020 programme

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: 8 am to 6 pm]: **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%

ABC21 is funded by the EU's H2020 programme

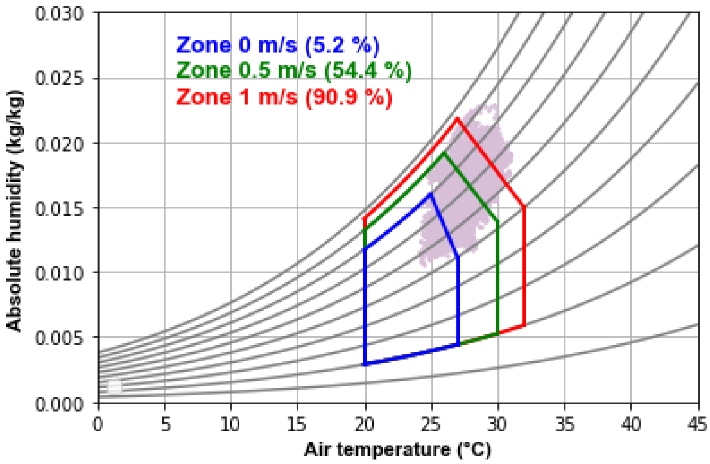


Figure 108 : Givoni bioclimatic chart – distribution of air temperature for the summer period (8th February to 30th April 2016) in the bioclimatic Amphitheatre during occupation time (8:00 – 18:00). Only 5% of the points are in the 0m/s comfort zone while approximately 91% are in the 1m/s comfort zone.

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]

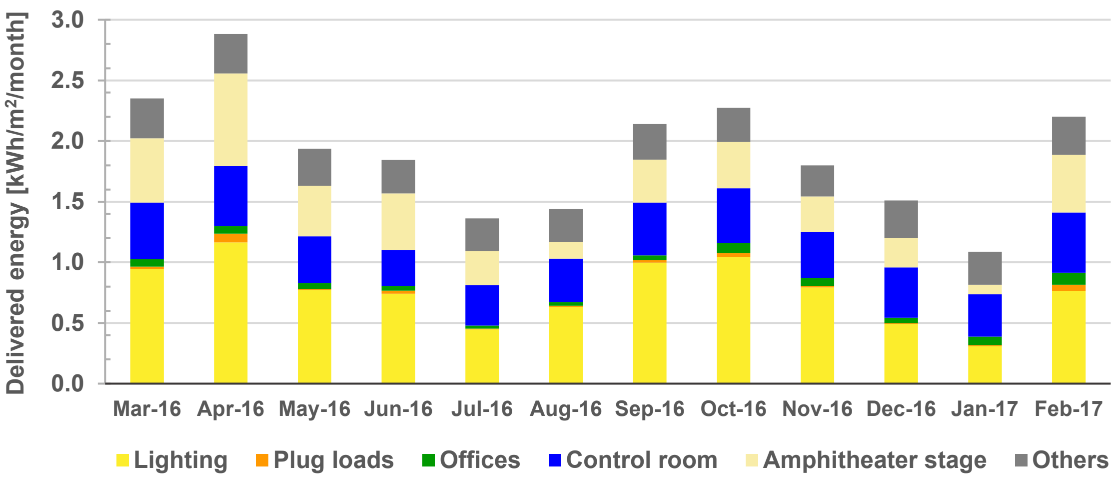


Figure 109 : Monthly delivered energy by end-uses for one year of occupancy (2016-2017).

ABC21 is funded by the
EU's H2020 programme

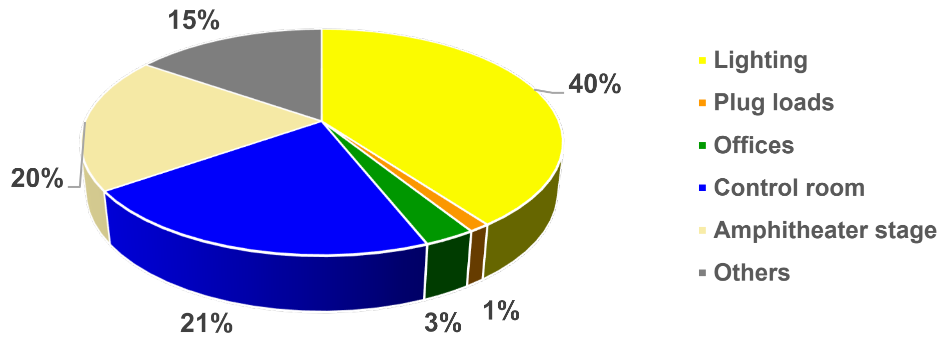


Figure 110 : Distribution of all end-uses of the building over one year (2016-2017). Lighting has the highest share in the building delivered energy.

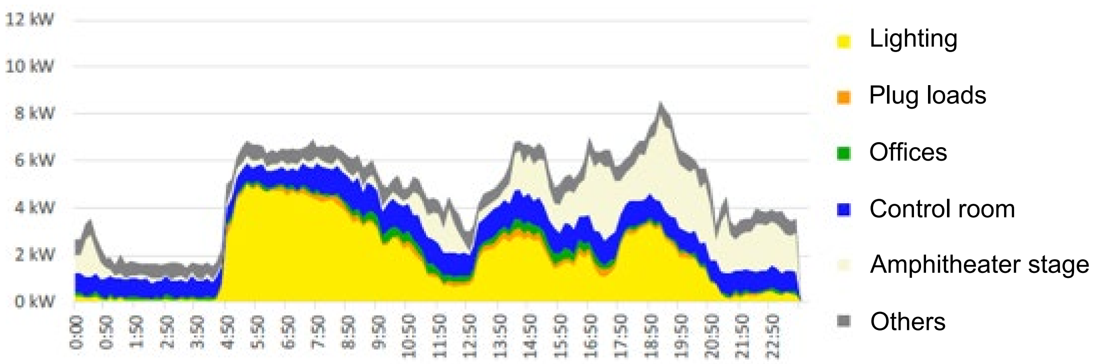


Figure 111: Load curves by end-use category for a typical working day in Feb. 2017

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

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.

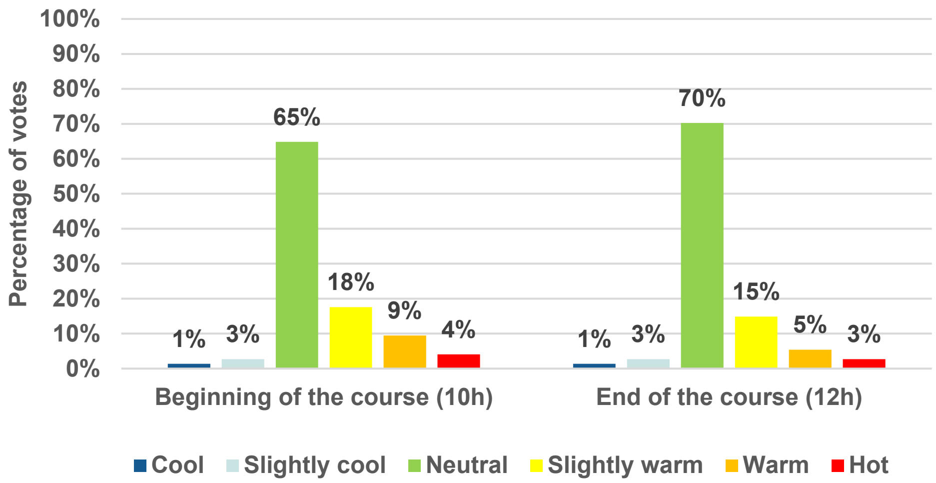


Figure 112: Frequency distribution of thermal sensation votes obtained on a summer day (3rd February 2016). The total number of votes was 74.

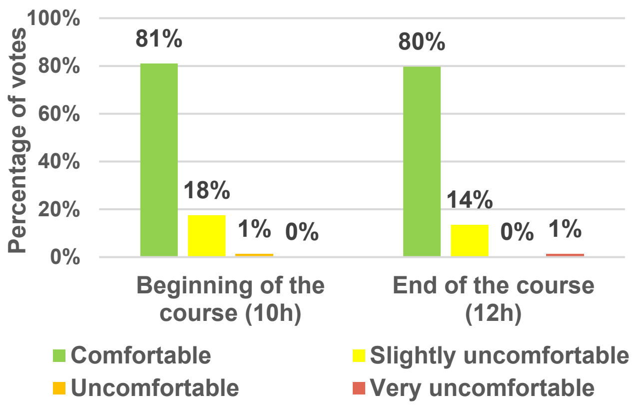


Figure 113: Frequency distribution of thermal comfort votes on the3rd February 2016.

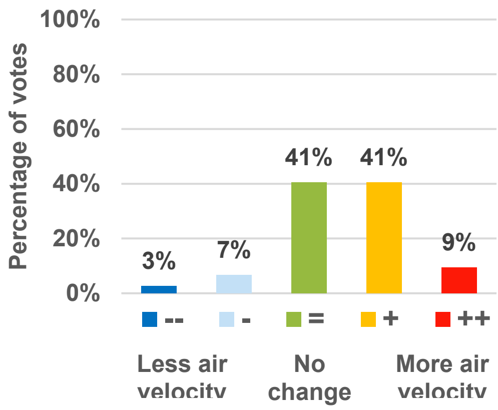


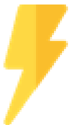
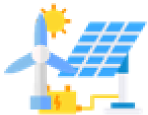
Figure 114 : Frequency distribution of questionnaire responses on air movement preference on the3rd February 2016.

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

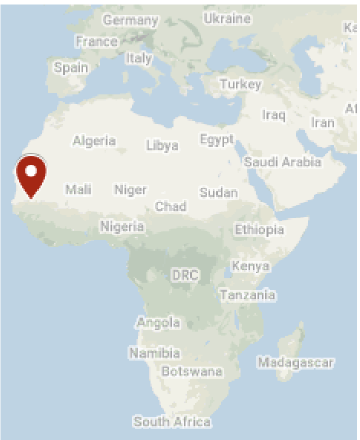
[3] http://www.cpu.fr/actualite/developpement-durable-luniversite-de-la-reunion-invente-le-premier-amphitheatre-bioclimatique/

[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.

CASE STUDY 1-07 : MAISON DES ENERGIES | SENEGAL



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Sinthiou Bamambe, District Ngapougou, Matam SENEGAL
Latitude; Longitude	15.3726727929116, -13.12709036192232
Climate zone (Köppen–Geiger classification)	BWh: Hot desert
BUILDING INFORMATION	
Building Type	Offices & Housing
Project Type	New construction
Completion Date	2009
Number of buildings	2
Number of storeys	2
Total Floor Area (m²)	2 200
Net Floor Area (m²)	600
Thermally conditioned space area (m²)	Room: 11,08 m² Questionnaire office: 16,8 m²
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	-
Total cost (€)	~91 544,18 (60.000.000 FCFA) excluding PV system
Cost /m² (€/m²)	~152,55 (100.000 FCFA) excluding PV system
Performance Standards or Certification	None
Awards	None
STAKEHOLDERS	
Building Owner	Country council of Kanel
Project Manager	Community of municipalities of the “Val de Drôme”, in collaboration with the municipality of Sinthiou Banadji and the rural community of Ndendory
Architect / Designer	Mathieu Hardy
Construction manager	SASERCO, Association la Voûte Nubienne, VN burkinabès

ABC21 is funded by the EU's H2020 programme

Environmental consultancy	-
Structural Engineer, Civil Engineer	-
Product Manufacturer	Association la Voûte Nubienne, VN burkinabès
Certification company	-
Others	-

PROJECT DESCRIPTION

Figure 115: Exterior view of the building « Maison des Energies ». It is a traditional structure in adobe banco.

The house of alternative energies, located in Matam, Senegal, is a house with a useful surface of 2 700 m² which includes offices and housing on two levels. The building is made of traditional structure in adobe banco. This house was designed in such a way as to be able to respect key principles of bioclimatic comfort such as the use of natural ventilation.
In addition, its Nubian-vaulted technical concept offers numerous solutions to Africa's economic and environmental problems while offering comfort to its users.

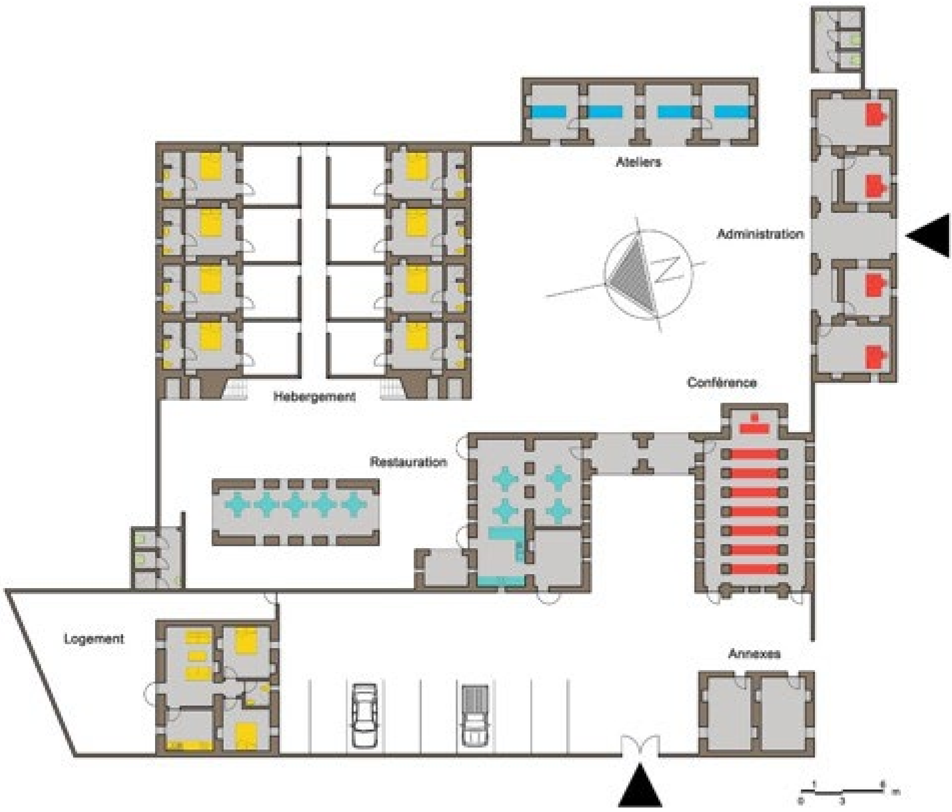


Figure 116 : Floor plan of the building [1]

SITE INTEGRATION

Figure 117: Aerial view of the building.

The house of alternative energies is located in the middle of a rural area. It is a desert area where the vegetation is very little present, hence the importance of adding small gardens within the building. This allows to decrease the air temperature, clearly felt especially in the summer period, but also to have a beautiful atmosphere for the users.

CLIMATE ANALYSIS

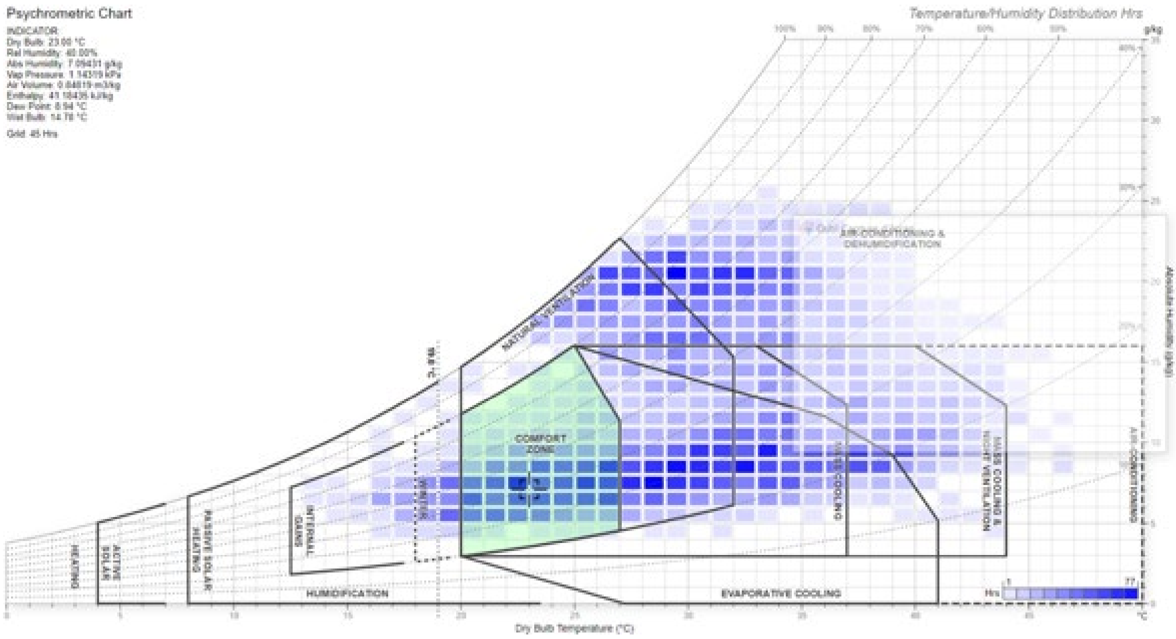


Figure 118: Givoni Bioclimatic chart for the climate of Matam using Andrew Marsh online tool [2]. Climate data are extracted from http://climate.onebuilding.org/WMO_Region_1_Africa/SEN_Senegal/SEN_MT_Matam.616300_TMYx.2004-2018.zip

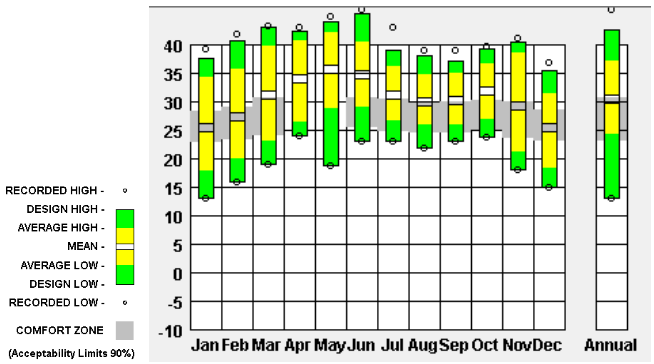


Figure 119: Temperature range by month for Matam. Source: Climate consultant – Adaptative Comfort model [3].

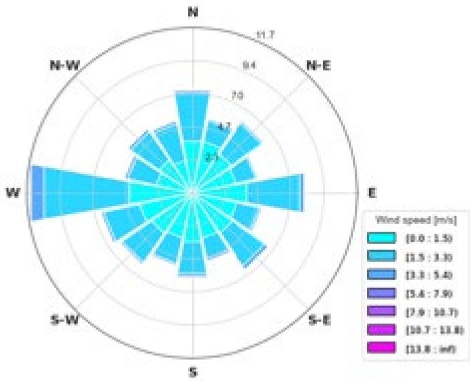


Figure 120: Annual wind rose for Matam (Beaufort wind scale) [3].

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **5422** Wh/m² (Dec) Max: **7550** Wh/m² (Apr) Mean: **6421,25** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **6** CDD 10°C: **7500**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **92** CDD: **783**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **10** CDD 26º: **1940**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	**Comfort Ventilation:** The strategy mainly used is the natural ventilation due to the presence of a large outdoor courtyard, shutter doors and louvre shutter system with adjustable slats, which allow optimal air circulation. The presence of ceiling fans in each zone of the building, allows to ensure ventilation when it is slightly hot and natural ventilation is not favourable enough. In addition, they are used to avoid the use of air conditioning. In order to dehumidify the air, some air conditioners are also present.
Passive heating strategy	None
Solar protection	**Zone 1:** Three windows with movable blinds and a half-blind door with movable blinds **Zone 2:** Three half-blind doors with swivel blades and a fixed blind window with swivel blades But there is also the presence of sunshades on some windows. Indeed, the swivel blades will make it possible to stop the solar radiation in the room while keeping a certain luminosity inside it.
Building orientation	North-West
Insulation	**Mineral wool (rock, glass)**: cheap, strong insulating power, very good fire resistance (insulation of roofs, walls and floors) **Cork:** Good sound and thermal insulation, waterproof, flame retardant (insulate slabs, walls, ceilings and roofs) **Perlite:** Fire and heat resistant (for floors and hollow walls) **Polystyrene:** Better insulation, good moisture resistance **Coconut wool:** Thermal and acoustic insulation, high moisture resistance, very elastic (filling of cavities (between walls and frames for example)) **Hemp wool:** Good moisture regulator, no risk of irritation (roof insulation, walls and floors) **Linen wool:** Easy to handle, good sound insulation, insulates surfaces very well (insulation of exterior walls and hard-to-reach areas)
Vegetation	At the level of the exterior courtyard, we have the presence of small gardens, in order to be able to decrease the air temperature at the different zones but also to allow a beautiful atmosphere for the users.
Natural daylighting	The louvre shutter system with the adjustable slats installed in the building allow to optimise the use of the natural light.
Use of local and embedded materials	Locally used Mud Bricks

ABC21 is funded by the EU's H2020 programme

Water saving and heat recovery on hot water drain	None
Waste management	None
Others features	-

Figure 121: View of the exterior courtyard of the « Maison des Energies » and its garden [1].

Figure 122: Interior view of the building "Maison des Energies" with the ceiling fans [1].

Figure 123: Office's photos

Figure 124: Room's photos

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	No Ratio with number of users: -
Ceiling fans	In every room, even those conditioned: Yes
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: No
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	Available through leaflets and posters at relevant places, online, etc.: No

(windows, solar protections, water savings) and active (lighting…) in order to promote sufficiency and efficiency actions

BUILDING FABRIC AND MATERIALS	
Roof	Type of materials: Mud Bricks (banco)
	Overall R-value: 0.95 [W m^{-2} K^{-1}]
Windows	Type: Fixed structure in steel and louvre shutter system with adjustable slats
	Window-to-wall ratio (WWR): -
	U-value: -
	Visual transmittance: -
Walls	Type of materials: Mud walls
	Overall R-value: 0.95 [W m^{-2} K^{-1}]

Figure 125: The roof-terrace made of raw clay[1].

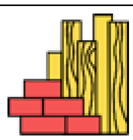
Figure 126: View of the banco walls

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	Natural ventilation Air conditioners: 4 of the brand Westpoint whose power per unit is 2 200 W and 2 of the brand Samsung whose power per unit is 2 100 W
Low-energy heating systems	No heating system
Ceiling fans	Yes – 1 ceiling fan in each room Power=75W
Mechanical ventilation / air renewal	No mechanical ventilation but possibility of air renewal by natural ventilation and air mixing by ceiling fans
Domestic Hot Water	None
Artificial lighting	Compact and fluorescent light bulbs Power: 18W (Zone 1) and 11W (Zone 2)
Control and energy management	None

Figure 127: View of the cooling equipment of the rooms

RENEWABLE ENERGY	
PV	Yes, but the technical data are not available
Solar thermal	Unknown
Wind	None
Geothermal	None
Biomass	None

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating: - [kWh/m^2/year]
	2. Energy needs for cooling: - [kWh/m^2/year]
	3. Energy use for lighting: - [kWh/m^2/year]
	4. Energy needs for sanitary hot water: - [kWh/m^2/year]
	5. Total Primary energy use: - [kWh/m^2/year]
	6. Renewable Primary energy generated on-site: - [kWh/m^2/year]
	7. Renewable Primary energy generated on-site and self-consumed: - [kWh/m^2/year]
	8. Renewable Primary energy exported to the grid: - [kWh/m^2/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): - %
	10. Delivered energy (from electricity bills) : - [kWh/m^2/year]
	1. Airborne sound insulation
	2. Equivalent continuous sound Level

Acoustic comfort indicators	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	N/A
LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	The Association "la Voûte Nubienne" (www.lavoutenubienne.org) was a strong partner in the project. The construction work on site was accompanied by this organisation, as well as technical training activities for a local workforce. A little more than 10 years later, awareness-raising activities to widen access to the Nubian Vault concept is continuing in the Senegalese Fouta, thanks to the joint efforts of the Association "la Voûte Nubienne" and its local partners, in particular the NGO "Le Partenariat" which is located in Saint Louis (www.lepartenariat.org).
Recommendations	▪ In a desert area like that, more plants and more green areas are suitable for a more comfortable built environment. ▪ Some air-conditioners are installed. In order to have a more sustainable design, it's better to use only natural ventilation.Given the large temperature difference between day and night, typical of dry climates/periods, night ventilative cooling should be included in the management routines, traying the occupants for this. ▪ Different artificial materials are used for insulation: mineral wool, perlite, polystyrene. In order to have a more sustainable design, it's better to use only natural and local materials.
BUILDING STRENGTHS AND WEAKNESSES	
Strengths	
 **Passive Design**	 **Local Materials**

Weaknesses
-

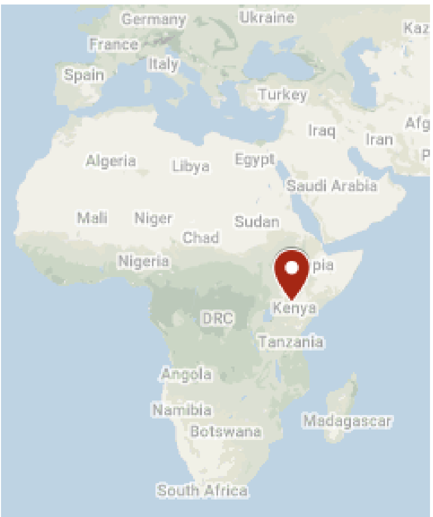
REFERENCES

[1] https://almizan-sahel.com/maison-des-energies

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

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

CASE STUDY 1-08: UNON OFFICE BUILDING | KENYA



GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Parklands/Highridge, United Nations Ave, Nairobi, Kenya
Latitude; Longitude	-1.2326008075647548, 36.81796828684429
Climate zone (Köppen–Geiger classification)	Cwb: subtropical highland climate. Temperate, dry winter, warm summer

BUILDING INFORMATION	
Building Type	Offices
Project Type	New construction
Completion Date	2011
Number of buildings	8
Number of storeys	3
Total Floor Area (m²)	20 000
Net Floor Area (m²)	-
Thermally conditioned space area (m²)	0
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	20 000
Total cost (€)	18 500 000
Cost /m² (€/m²)	925,0
Performance Standards or Certification	ISO 14001 (2004)
Awards	Top 6 stars by Australia's Green Star

STAKEHOLDERS	
Building Owner/ Representative	United Nations Office at Nairobi (UNON)
Architect / Designer	Beglin Woods Architects
Construction manager	Harold R. Fenwick & Associates, Chartered Quantity Surveyors
Environmental consultancy	UN-HABITAT / UNEP

ABC21 is funded by the EU's H2020 programme

Structural Engineer, Civil Engineer	EngPlan Consulting Engineers
Building Services Engineers	Geomax Consulting Engineers
Certification company	-

PROJECT DESCRIPTION [1] [2] [3]

Figure 128: Exterior view of the UNON Office building [1]

The UNON Office building is the first facility in sub-Saharan Africa, which hosts the headquarters of both the United Nations Environment Programme (UNEP) and the United Nations Human Settlements Programme (UN-HABITAT). The building is composed of four blocks linked by airy walkway, A central atrium runs the length of the building, allowing natural light to flood into offices, while encouraging airflow and comfortable internal temperatures by drawing warm air up and out of the building. In terms of renewable energy, this building has been designed to generate electricity for all its 1 200 occupants thanks to 6 000 square meters of solar panels with a total peak power of 550 kWp. [2].

(a)

(b)

Figure 129: (a) Fountains and ponds at the entrance of the building using collected rainwater and (b) vegetation in the atrium area of the building [1].

SITE INTEGRATION

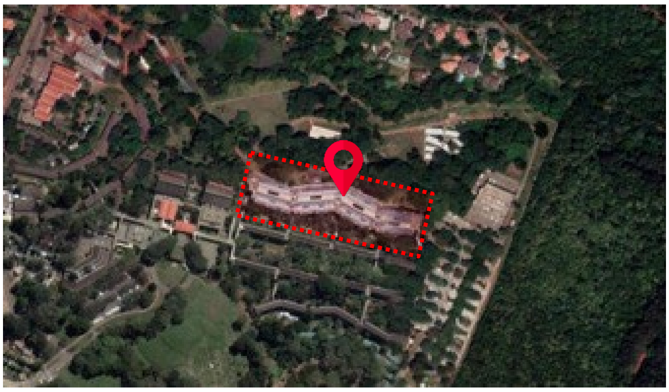


Figure 130: Aerial view of the UNON building (Source : google map)

For the landscaping of the new building the building was deliberately sited in such a way that the maximum number of existing trees could be preserved. Moreover, thanks to the preservation of indigenous plants more drought-resistant the building encourages birds and other smaller wildlife. Besides, the building follows traditional principles of Kenyan build like for the colour of the façades that refers to old traditional buildings.

CLIMATE ANALYSIS

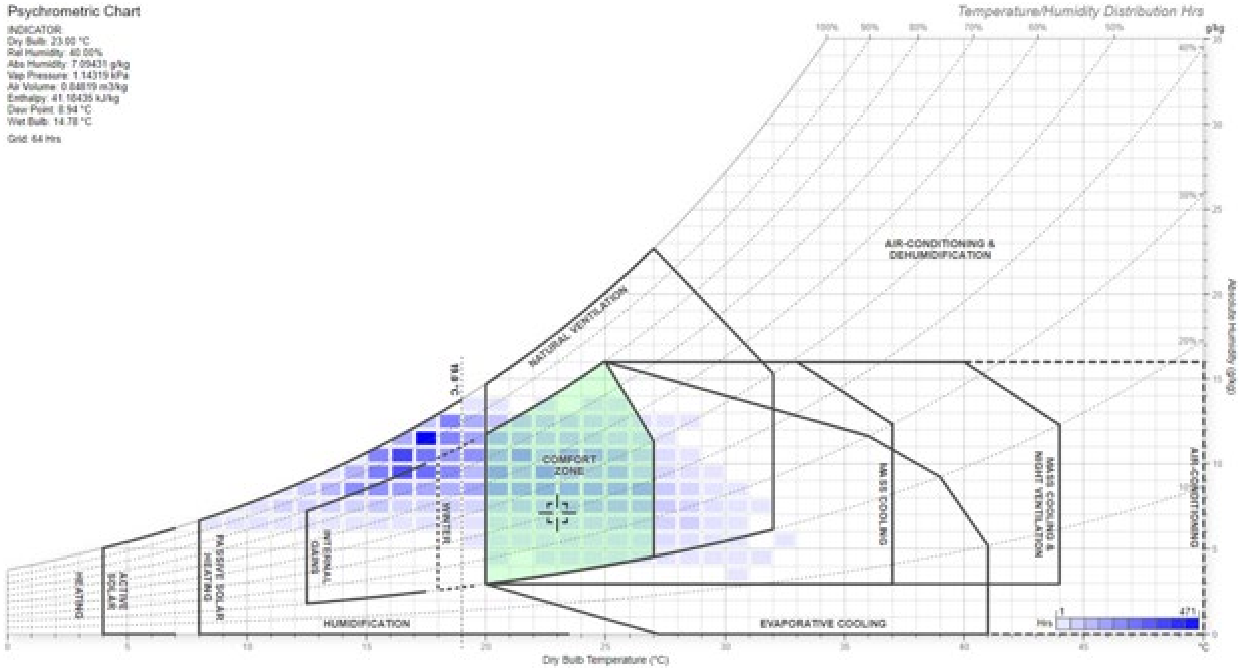


Figure 131: Givoni Bioclimatic chart for the climate of Nairobi using Andrew Marsh online tool [4]. Climate data are extracted from http://climate.onebuilding.org/WMO_Region_1_Africa/KEN_Kenya/NB_Nairobi/KEN_NB_Nairobi-Kenyatta.Intl.AP.637400_TMYx.2004-2018.zip

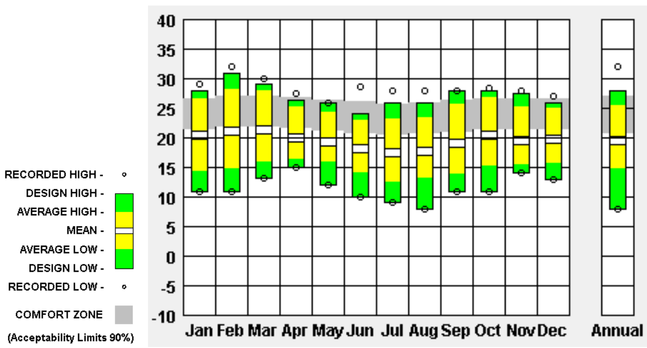


Figure 132: Temperature range by month for Nairobi. Source: Climate consultant – Adaptative Comfort model [5].

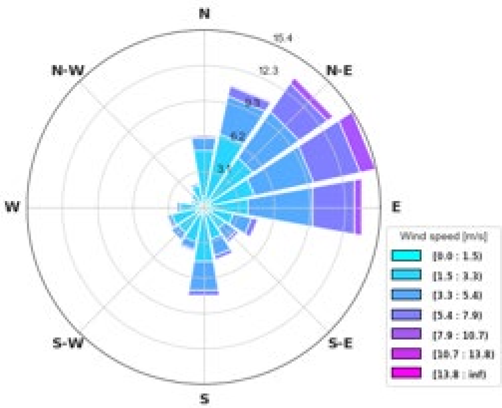


Figure 133: Annual wind rose for Nairobi (Beaufort wind scale) [5].

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **4025** Wh/m² (Jun) Max: **6243** Wh/m² (Feb) Mean: **5084** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **315** CDD 10°C: **3 480**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **765** CDD: **6**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **419** CDD 26º: **32**

KEY BIOCLIMATIC DESIGN PRINCIPLES [1] [2] [3]	
Passive cooling strategy	Natural ventilation via chimney effect of warm air moving through the atrium. Fixed louvres at the top of the building allow free air movement out of the atrium Open plan offices Windows can be opened and closed by occupants for temperature regulation
Passive heating strategy	E-W elongated orientation to minimize heat intake. Main facades are facing N and S High thermal capacity walls (stones)
Solar protection	Canopy produces shade which reduces solar gain in through windows.
Building orientation	N/S orientation for daylighting
Insulation	High quality solar glass insulates the building against heat and cold. The roof is protected by all solar panels
Vegetation	Rainwaters is collected to irrigate the landscape areas all around the building, indigenous tree has been planted. Atrium encourages landscape areas and so biodiversity with a minimal of irrigation water.
Natural daylighting	N/S orientation achieving maximum daytime lighting. Atrium and glass permit natural daylighting. Indeed, glazed roof lights are set into the building's flat roof, and toughened glass set at floor level beneath them on each floor, enabling natural light to penetrate right through to the ground floor.
Use of local and embedded materials	Locally produced cement and steel and blockwork form building superstructure Maximum use of stones
Water saving and heat recovery on hot water drain	Water saving taps and lavatories reduce water consumption. Installation of high-efficiency water systems, which include features such as dual flush toilets and push taps. Waste water is also treated. Rainwater is collected from the roofs to feed the fountains and ponds at the four entrances and sewage is treated in a state-of-the-art aeration system and recycled to irrigate the beautifully landscaped compound. All the water from the offices, kitchens, washrooms and recreation centre ends up at the local wastewater plant. There are three oxidation ponds that use natural UV rays and biological processes to treat the water, which is then reused for irrigation around the compound [6].
Waste management	All waste produced in the buildings are recycled to produce other materials. One of the UNON objectives is to reduce the amount of waste from the complex that goes directly to landfill. Since 2008, the Near Zero Station has been sorting waste produced on the compound and reducing the amount sent for disposal. In 2017, a new waste sorting station was built,

	and waste collected from the complex is now sorted and measured, and either recycled or disposed of appropriately. Waste sorting bins are located in each office building on the complex to enable sorting at source [6].
Others features	The 1200 employees of the building walk on a 100% recyclable carpet, and the paint used on the walls is environmentally friendly. The green spaces surrounding the building are made up of local plants and trees.

(a)

(b)

Figure 134 : sewage is treated in a state-of-the-art aeration system (a) and recycled to irrigate the beautifully landscaped compound (b) [1].

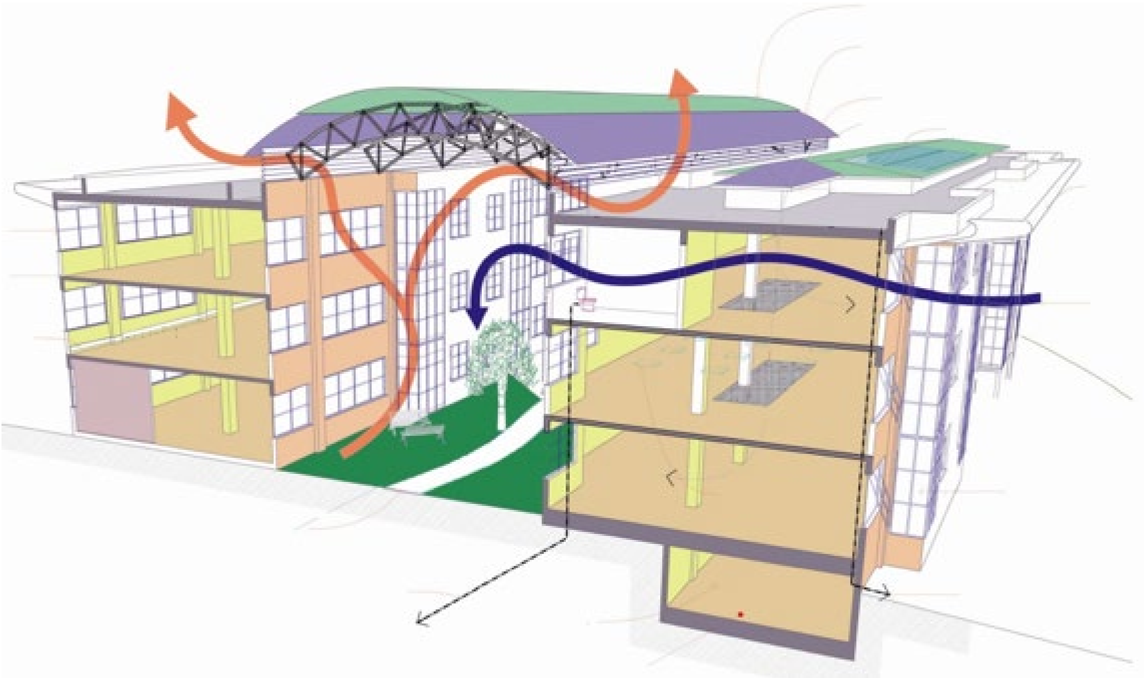


Figure 135: The UNON Office building's natural ventilation principle via chimney effect of warm air moving through the atrium. Fixed louvres at the top of the building allow free air movement out of the atrium [2].

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. There are several bike parkings within the complex to allow cycling from the entrance of the complex situated two km away to the building.
Ceiling fans	In every room, even those conditioned: No
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: Yes There are no switches. **Sensors of presence operate the lighting**.
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.: No

BUILDING FABRIC AND MATERIALS	
Roof	Bricks Thickness Unknown
	Overall R-value : Unknown
Windows	High performance glazing, double glazing aided by a system of light reflectors
	Window-to-wall ratio (WWR): Unknown
	U-value : Unknown
	Visual transmittance: Unknown
Walls	Stones, Thickness: 20 cm
	Overall R-value : Unknown

ABC21 is funded by the
EU's H2020 programme

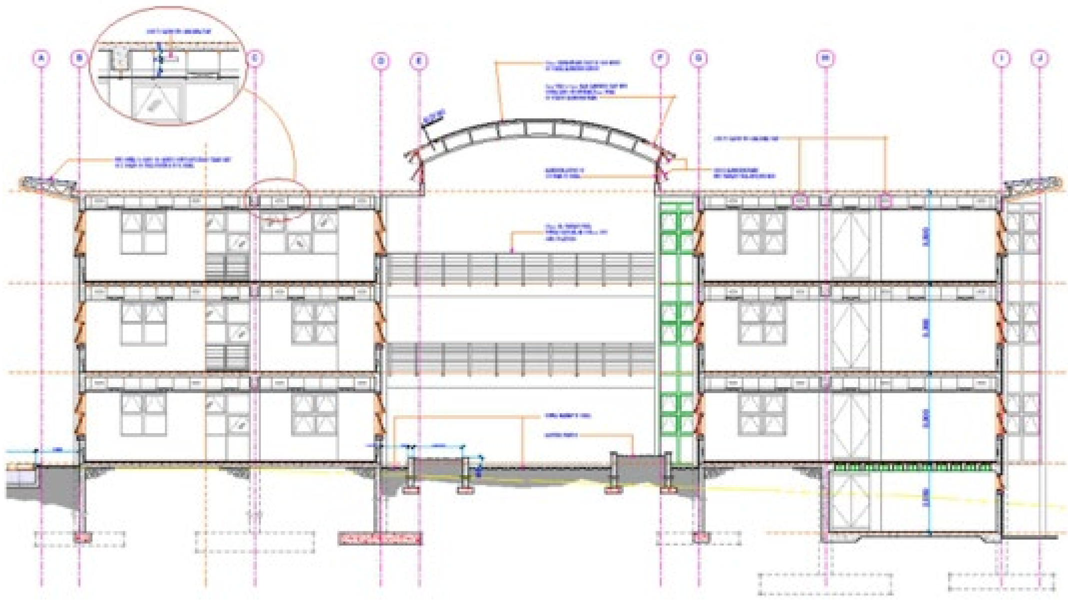


Figure 136: Atrium and light well section of the UNON building [1].

ENERGY EFFICIENT BUILDING SYSTEMS [1] [3]	
Low-energy cooling systems	Uses of passive cooling system, natural airflow, fans, vegetation. These systems work firstly thanks to natural airflow though the building that contributes to decrease the temperature felt. Also, the vegetation contributes to decrease the temperature during heating days. Fans are only used for the refreshment of IT systems against to the use of air conditioning.
Low-energy heating systems	Uses of natural heating. The double glazing contributes to retain the heat during fresh days, also the concrete contributes to capture the heat and redistribute the heat when temperature goes down.
Ceiling fans	Fans are used only in the computer rooms.
Mechanical ventilation / air renewal	Not applicable
Domestic Hot Water	Few solar water heaters provide water to the kitchens (bars)
Artificial lighting	Use of fluorescent luminaires - Low energy fluorescent lighting Density by spaces (W/m^2): Unknow
Control and energy management	Energy management strategies are used to decrease the total consumption of the active systems: - daylight sensing and presence detection system - Water saving taps Only laptop computers are allowed in the office

(a) (b)

Figure 137 : Interior views of the offices with natural daylighting wells and the energy efficient artificial lighting systems installed [1]

RENEWABLE ENERGY	
PV	**Type :** Solar **Technology :** Mixed polycrystalline and amorphous silicon solar modules. **Nominal power :** 550 kWp. The building was designed for maximum solar energy yield, with panels set on the flat, E/W elongated roof.
Solar thermal	Solar water heater
Wind	None
Geothermal	None
Biomass	None

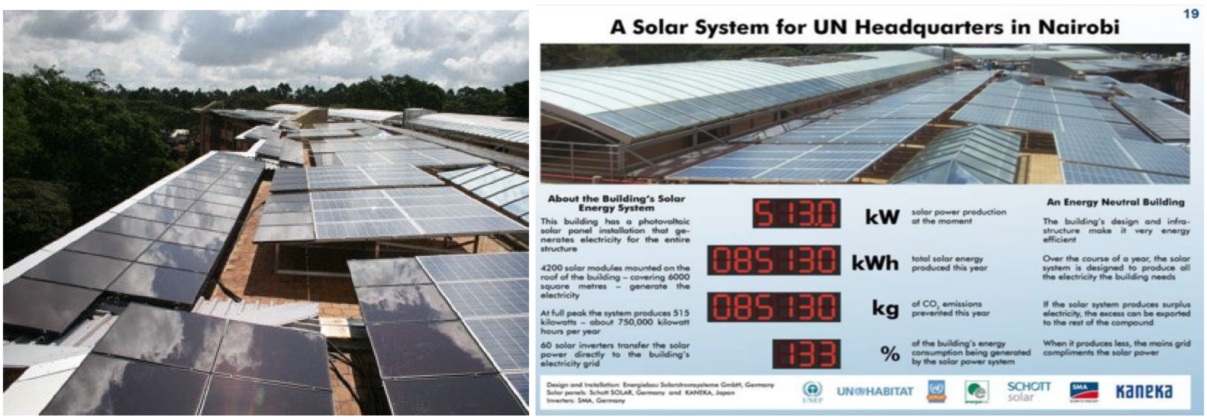


Figure 138: 6000 m2 of solar panels of 550 kWp are installed on the rooftop of the building [1].

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS

Thermal comfort indicators

1. Percentage of time outside an operative temperature range (Adaptive) : 0%
2. Percentage of time outside an operative temperature range (Fanger) : 0%
3. Degree-hours (Adaptive)
4. Degree-hours (Fanger)
5. Percentage of time inside the Givoni comfort zone of 1m/s: **≥ 96 % (from Nov-22 to May-23)**
6. Percentage of time inside the Givoni comfort zone of 0m/s: **≥ 96 % (from Nov-22 to May-23)**
7. Number of hours within a certain temperature range, tables available

	METER 10B roof		METER 19 Cecilia Office C		METER 31 Raf Window		METER 66 Vincent office C		OUTSIDE	
	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.
Ta<16°C	2	0,%	0	0%	0	0%	0	0%	7	1%
16°C≤Ta<18°C	42	3%	0	0%	0	0%	0	0%	90	7%
18°C≤Ta<20°C	122	9%	0	0%	0	0%	17	1%	206	15%
20°C≤Ta<22°C	120	9%	215	16%	91	7%	325	24%	182	13%
22°C≤Ta<24°C	130	10%	727	53%	737	54%	635	46%	234	17,%
24°C≤Ta<26°C	168	12%	376	27%	486	36%	298	22%	297	22%
26°C≤Ta<28°C	202	15%	50	4%	54	4%	89	7%	205	15%
28°C≤Ta<30°C	209	15%	0	0%	0	0%	4	0%	124	9%
30°C≤Ta<32°C	186	14%	0	0%	0	0%	0	0%	23	2%
32°C≤Ta<34°C	143	10%	0	0%	0	0%	0	0%	0	0%
Ta≥34°C	44	3%	0	0%	0	0%	0	0%	0	0%

Energy performance indicators

1. Energy needs for heating: - [kWh/m^2/year]
2. Energy needs for cooling: - [kWh/m^2/year]
3. Energy use for lighting: - [kWh/m^2/year]
4. Energy needs for sanitary hot water: - [kWh/m^2/year]
5. Total Primary energy use: - [kWh/m^2/year]
6. Renewable Primary energy generated on-site: - [kWh/m^2/year]
7. Renewable Primary energy generated on-site and self-consumed: - [kWh/m^2/year]
8. Renewable Primary energy exported to the grid: - [kWh/m^2/year]
9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): - %
10. Delivered energy (from electricity bills): - [kWh/m^2/year]

Acoustic comfort indicators

1. Airborne sound insulation
2. Equivalent continuous sound Level
3. HVAC noise level
4. Reverberation time
5. Masking/barriers

Visual comfort indicators

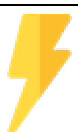
1. Light level (illuminance)
2. Useful Daylight Illuminance (UDI)

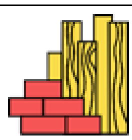
ABC21 is funded by the EU's H2020 programme

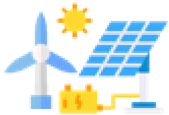
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	Users are overall very satisfied by their working environment. No complains have been listed.

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	This is the first energy plus building in Sub Saharan Africa. It has inspired the construction of more than 20 other buildings with solar rooftop in Nairobi. It also helped the adoption of a legislation on net metering. In fact, the building does not have batteries, excess energy is feed into the national grid during the day. At night, the energy is consumed from the grid. This was also the first bioclimatic architecture design of the architect who learned by doing. The main lesson learnt is that air conditioning is not necessary in Nairobi. It is possible to design a comfortable bioclimatic office building in Nairobi with no active air conditioning systems. Thermal comfort conditions can be easily reached with a well ventilated building, an appropriate orientation and insulation in walls and roofs in subsequent projects, using local materials, such as bio-sourced fibers. Ceiling fans are not necessary as well.
Recommendations	After the construction of the building, several recommendations were made to reproduce a bioclimatic building such as: - Set clear objectives for the building from the start - Work from general targets towards specific actions and not the other way around - Involve the future occupants from the start - Prepare background studies on all major issues - Set up green task force - Keep an eye on development technology

BUILDING STRENGTHS
Strengths





				
Passive Design	**Energy Efficiency**	**Renewable Energy**	**Water conservation**	**Local Materials**
Weaknesses				
-				

REFERENCES

[1] Vincent Kitio. ONU-Habitat. Séminaire National sur l'efficacité énergétique dans bâtiment et ville durable. Abidjan, 4 au 6 Juin 2015.

[2] UNEP Showcases New Green Buildings in Nairobi. Accessible at http://sdg.iisd.org/news/unep-showcases-new-green-buildings-in-nairobi/

[3] Building for the future: A United Nations showcase in Nairobi. Published February 2011 by United Nations Environment Programme. Downloadable at https://europa.eu/capacity4dev/file/11531/download?token=eS01KDaC

[4] Andrew Marsh Psychrometric Chart. Available at: https://drajmarsh.bitbucket.io/psychro-chart2d.html.

[5] Climate Consultant tool. Available at: https://climate-consultant.informer.com/6.0/

[6] Sustainability. Accessible at https://dcs.unon.org/sustainability-0

CASE STUDY 1-09: VILLAS DES CHERCHEURS | MOROCCO

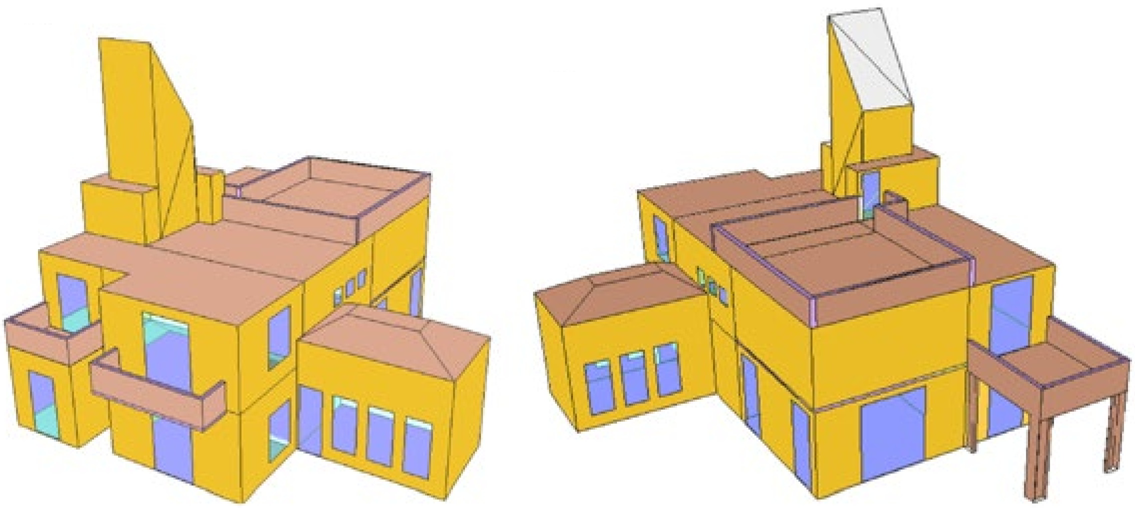
GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Ben Guerir, Morocco
Latitude; Longitude	32.214157096376795, -7.935813503615992
Climate zone (Köppen–Geiger classification)	BSh: Hot semi-arid steppe
BUILDING INFORMATION	
Building Type	Residential, Villas
Project Type	New construction
Completion Date	2016
Number of buildings	100 villas
Number of storeys	2 (Villa Zitoune)
Total Floor Area (m²)	330 (Villa Zitoune)
Net Floor Area (m²)	184 (Villa Zitoune)
Thermally conditioned space area (m²)	184 (Villa Zitoune)
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	184 (Villa Zitoune)
Total cost (€)	2 307 162 (24 000 000 MAD)
Cost /m² (€/m²)	125 (~1 304 MAD)
Performance Standards or Certification	None
Awards	COP 22 label
STAKEHOLDERS [1]	
Building Owner/ Representative	OCP
Architect / Designer	Elie Mouyal
Construction manager	CAP INGENIERIE
Environmental consultancy	JESA
Structural Engineer, Civil Engineer	CAP INGENIERIE

Product Manufacturer	-
Certification company	-
Others	-

PROJECT DESCRIPTION

Figure 139: Exterior view of the "Villas des Chercheurs"

The project is a collective residential zone for scientific researchers of the Mohammed VI Polytechnic University. There exist 4 kinds of villas depending on their architectures and areas: Villas Zitoune, Villas Limoune, Villas Roumane and Villas Kermous. The buildings walls are constructed with solid stone locally extracted. External walls and roof are insulated with hempcrete panels. Other bioclimatic concepts are applied. This report takes Villa Zitoune as case study for next descriptions. The 1st floor consists of one bedroom, two halls, a lobby and a kitchen; while the 2nd floor has two bedrooms.



(a) (b)

Figure 140: 3D architectural sketches of the studied house: (a) North-East sight, (b) South-East sight [2]

Figure 141 : Architectural plans of the studied house. The thermal zones as defined in TRNSYS are indicated [2].

SITE INTEGRATION

Figure 142 : Aerial view of the "Villas des Chercheurs" and its' surrounding

Located in a hot semi-arid steppe region, the project includes necessary facilities for living (school, market, club…). The construction of the 100 Villas is inspired from the architecture of traditional Moroccan Medina. Each villa has its own green space dedicated to urban agriculture activity.

CLIMATE ANALYSIS

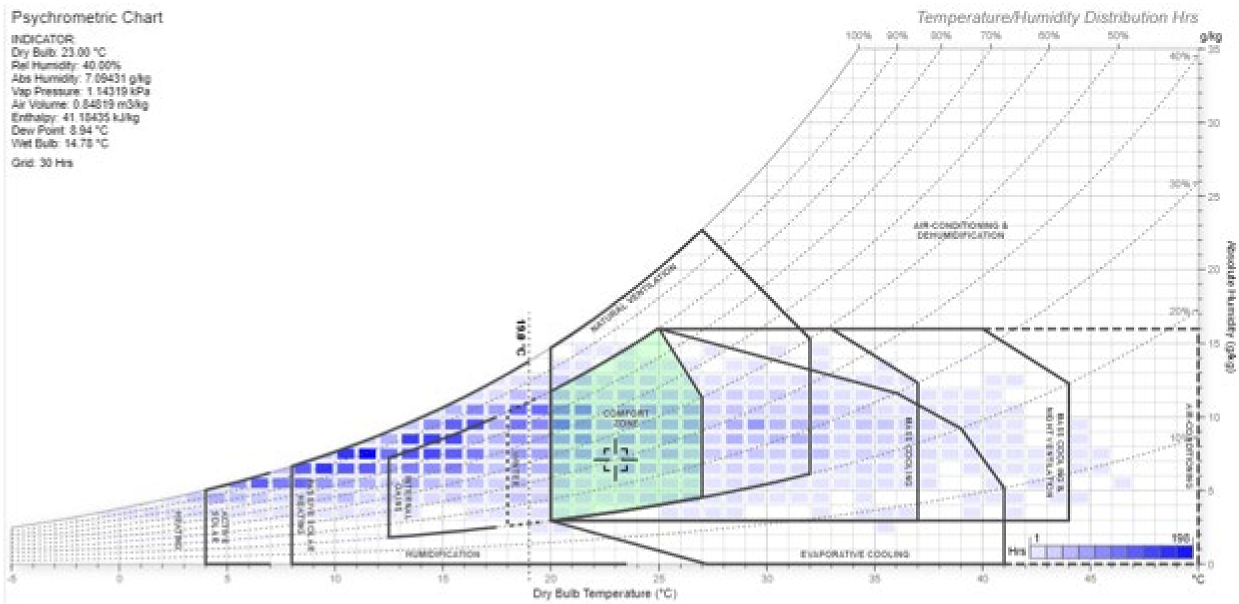


Figure 143: Givoni Bioclimatic Chart for the climate of Ben Guerir using Andrew Marsh online tool [3]. Climate data are extracted from https://climate.onebuilding.org/WMO_Region_1_Africa/MAR_Morocco/MS_Marrakech-Safi/MAR_MS_Ben.Guerir.AB.602051_TMYx.zip.

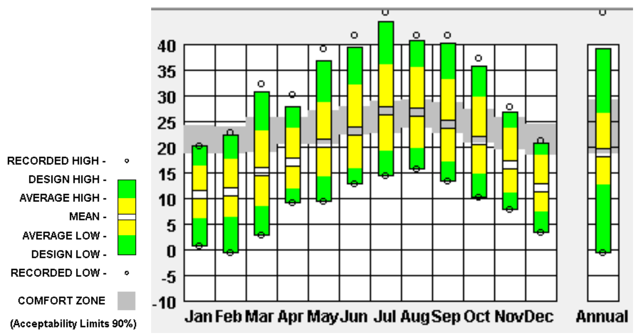


Figure 144: Temperature range by month for the city of Ben Guerir. Source: Climate consultant – Adaptative Comfort model [4]

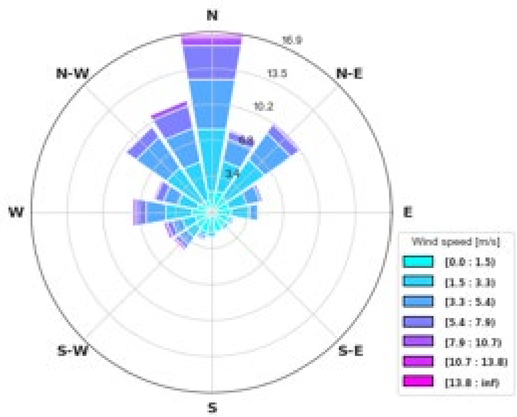


Figure 145: Annual Wind rose for Ben Guerir (Beaufort wind scale).

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **2530** Wh/m² (Dec) Max: **7573** Wh/m² (Jul) Mean: **4867,25** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **987** CDD 10°C: **3382**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **1263** CDD: **198**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **1100** CDD 26º: **380**

KEY BIOCLIMATIC DESIGN PRINCIPLES [1]	
Passive cooling strategy	▪ **Comfort ventilation:** Natural ventilation strategy is achieved through openings. ▪ **Nocturnal convective cooling:** Wind-tower coupled with a pebble foundation that serves as bioclimatic thermal mass for cooling. ▪ **Radiant cooling:** Insulated roofs, massive stone walls with high thermal resistance. ▪ **The soil as a cooling source:** Using ground thermal inertia.
Passive heating strategy	Use of wind-tower coupled with a pebble foundation that serves as bioclimatic thermal mass for heating.
Solar protection	Following the standards to have the shadowed portion of the glazed area should be as large as possible in summer and as low as possible in winter. External metallic venetian blinds and shutters
Building orientation	_
Insulation	The roof and the external walls are highly insulated with hempcrete material.
Vegetation	Each house owns a green space dedicated to urban agriculture activity.
Natural daylighting	Trough optimized glazed surfaces.
Use of local and embedded materials	Stone extracted from local quarries.
Water saving and heat recovery on hot water drain	Water collection from rain watering green spaces and private gardens.
Waste management	Wastewater treatment.
Others features	_

Figure 146: Key bioclimatic design principles of the « Villas des chercheurs »

Figure 147 : Digital model of the « Villa des chercheurs ».

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: **Unknown**
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: **No**
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	: **Yes**
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.: **No**

BUILDING FABRIC AND MATERIALS [2]	
Roof	Double slab of hempcrete (12 cm each)
	Overall R-value: **4.329** m².K/W
Windows	Double glazing: 6 mm thickness and 8 mm spacing filled with air
	Window-to-wall ratio (WWR): **21%**
	U-value: -
	Visual transmittance: -
Walls	Double wall with natural stone shaped on site (40 cm) Hempcrete insulation between the walls (10 cm) Porphyry rock hobs (10 cm)
	External walls: Overall R-value: **2.994** m².K/W Internal walls: Overall R-value: **2.267** m^{2}K/W

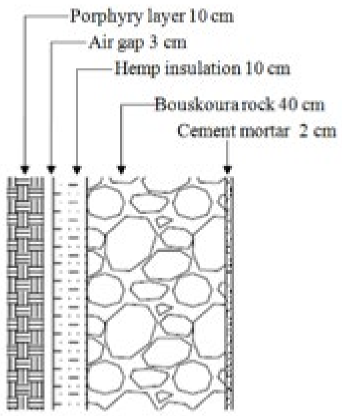


Figure 148 : External walls composition [2].

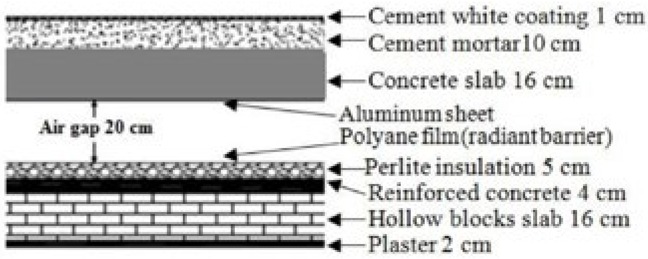


Figure 149 : Roof slab composition [2]

ENERGY EFFICIENT BUILDING SYSTEMS [1]	
Low-energy cooling systems	Two cooling systems are the most interesting ones: First: A Wind-tower that receives and blows air into a pebble-based foundation which serves as thermal mass. The pebble-based foundation is cooled using fresh air at night. Then, the air flow cooled is blowed using a network of ducts into the building rooms. Second: Small openings on the upper part overhanging the roof are designed, allowing the hot upward flow to escape. This creates an air movement that will cool the room.
Low-energy heating systems	The Wind-tower coupled with the pebble-based foundation serves for heating. The pebble-based foundation is heated using solar air collectors. Then, the air flow heated is blowed using a network of ducts into the building rooms.
Ceiling fans	Unknown
Mechanical ventilation / air renewal	Wind-tower
Domestic Hot Water	A solar air collector heats water ensuring the supply in bathrooms and from the kitchen.
Artificial lighting	High-efficiency LED lighting (3 W/m^2)
Control and energy management	None

Figure 150 : Wind Tower of the "Villa des chercheurs".

RENEWABLE ENERGY	
PV	None
Solar thermal	A solar air collector for water heating.
Wind	None
Geothermal	None
Biomass	None

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating: **9.4** [kWh/m^2/year]
	2. Energy needs for cooling: **23.2** [kWh/m^2/year]
	3. Energy use for lighting: - [kWh/m^2/year]
	4. Energy needs for sanitary hot water: - [kWh/m^2/year]
	5. Total Primary energy use: - [kWh/m^2/year]
	6. Renewable Primary energy generated on-site: - [kWh/m^2/year]
	7. Renewable Primary energy generated on-site and self-consumed: - [kWh/m^2/year]
	8. Renewable Primary energy exported to the grid: - [kWh/m^2/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): - %
	10. Delivered energy (from electricity bills) : - [kWh/m^2/year]
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
	1. Organic compound

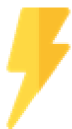
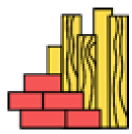
Indoor Air Quality indicators	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	-

LESSONS LEARNED AND RECOMMENDATIONS

Lessons learned	Bioclimatic principles have been considered in the early stages of the project, not only at the scale of the building itself but also at a larger scale with the arrangement of the buildings, the pathways and public spaces so as to provide shading and reduce the part of asphalt paving. This project required a comprehensive research approach, a certain degree of flexibility during the design process as well as a significant investment of time and additional construction costs.
Recommendations	▪ To increase the presence of vegetation ▪ To increase linkages with the surrounding context ▪ To diversify the sources of renewable energy

BUILDING STRENGTHS AND WEAKNESSES

Strengths

		
Passive Design	**Energy Efficiency**	**Local Materials**

Weaknesses

-

REFERENCES

[1] « Dix cas de bonnes pratiques au Maroc ». Available at: http://www.archi.ac.ma/images/publications/Catalogue%20web.pdf

[2] H. Mastouri, B. Benhamou, H. Hamdi, et E. Mouyal, « Thermal performance assessment of passive techniques integrated into a residential building in semi-arid climate », Energy Build., vol. 143, p. 1-16, mai 2017, doi: 10.1016/j.enbuild.2017.03.022.

[3] Andrew Marsh Psychrometric Chart. Available at: https://drajmarsh.bitbucket.io/psychro-chart2d.html.

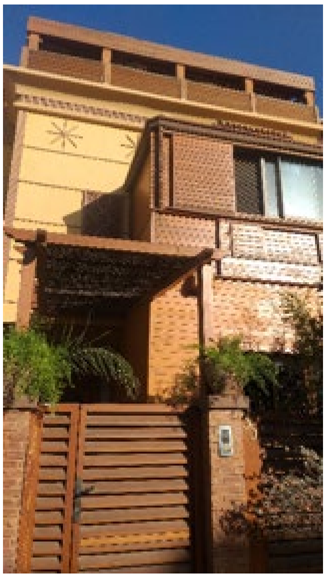
[4] Climate Consultant tool. Available at: https://climate-consultant.informer.com/6.0/

CASE STUDY 1-10: DAR NASSIM PROJECT | MOROCCO

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	35, Residence Nassim, Marrakech, Morocco
Latitude; Longitude	31.6497350, -8.0615803 Code Google Maps : JWXQ+V9 Marrakech
Climate zone (Köppen–Geiger classification)	BSh: Hot Semi-Arid
BUILDING INFORMATION	
Building Type	Terraced individual housing
Project Type	Renovation
Completion Date	2014
Number of buildings	1
Number of storeys	2
Total Floor Area (m²)	240m²
Net Floor Area (m²)	215 m²
Thermally conditioned space area (m²)	95 m²
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	The whole building is naturally ventilated
Total cost (€)	240.000
Cost /m² (€/m²)	1000
Performance Standards or Certification	Moroccan Thermal Regulation of Construction [1]
Awards	None
STAKEHOLDERS	
Building Owner/ Representative	Abderrahim BRAKEZ
Architect / Designer	Al Omrane Holding
Construction manager	Al Omrane Holding
Environmental consultancy	-
Structural Engineer, Civil Engineer	-

Product Manufacturer	-
Certification company	-
Others	Ministry of Housing and Urban Policy as a stakeholder

PROJECT DESCRIPTION



The house was built in 2002 on a floor area of 70 m² (8.86 m in the East-West direction and 7.90 m in the North-South direction). The South and North facades are attached to the walls of terraced houses of the same type and of the same surface.

the renovation of the house was carried out in 2014. A monitoring of the house was carried out before and after the renovation. This renovation aimed to improve the energy performance of the house and to carry out an extension by adding a solar hammam and a dining room as well as a bedroom [2].

Much of the energy consumed in this building is achieved through renewable energy systems. Indeed, a large part of the electricity used is produced by photovoltaic panels. Solar thermal panels are installed to provide domestic hot water and heating the floor of a hammam installed in the house after renovation [3].

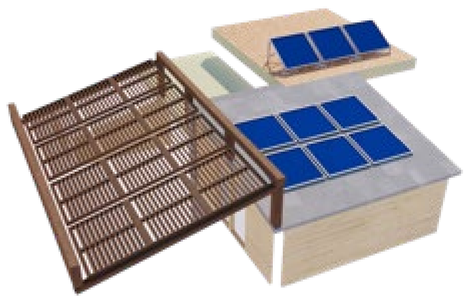
Ground floor

Vertical section of the house

First floor

West and East sides

Second floor



Roofs

Figure 151: Different views of the house after refurbishment

SITE INTEGRATION

The studied house, named Dar Nassim, is considered in the terminology of housing in Morocco as an „*economic villa* “. It is a new concept of habitat to qualify a product intended for the middle class. This product borrows its morphology to the model of the villa, with savings in surface area and quality of services.

The house is located in a closed residence composed of 120 houses designed according to the same plan but with different orientations. The building is built on a floor area of 70 m² overlooking gardens of 30.6 m² and 25.8 m² respectively.

The South and North facades are attached to the walls of terraced houses of the same type and of the same surface.

Figure 152 Aerial view of the residence and photo of the house in its close neighbourhood

Figure 153 : Situation of studied house inside the residence

ABC21 is funded by the EU's H2020 programme

CLIMATE ANALYSIS

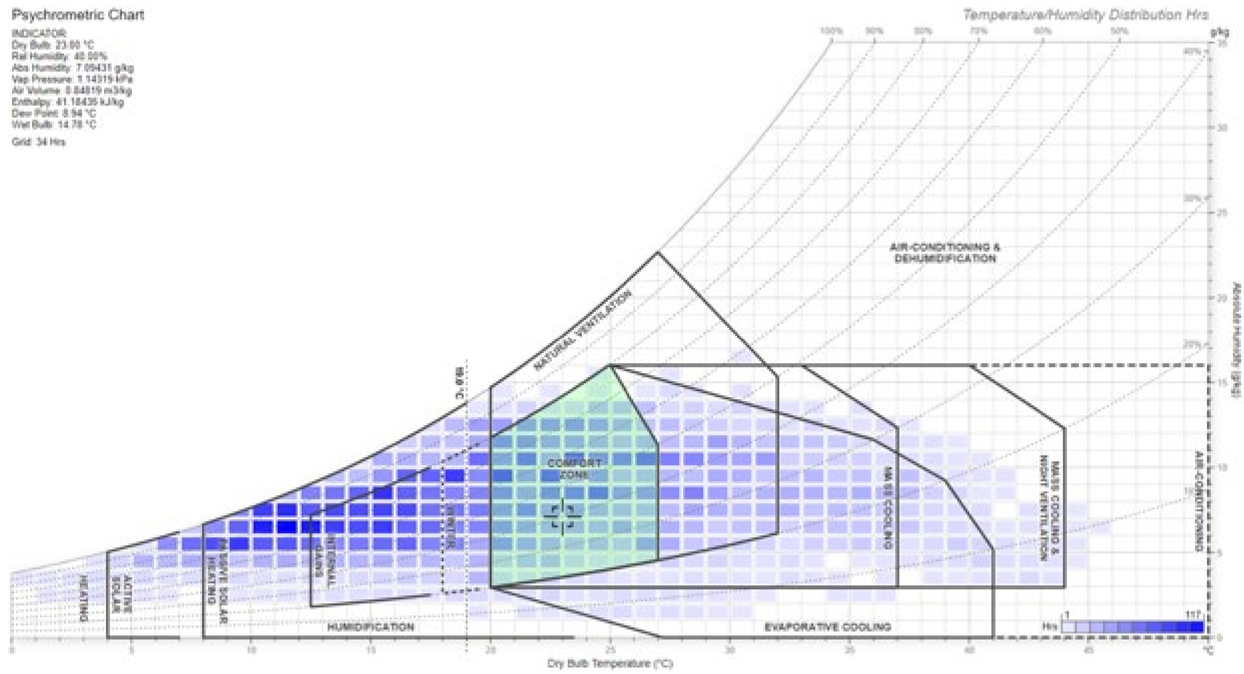


Figure 154: Givoni Bioclimatic chart for the climate of Marrakesh using Andrew Marsh online tool [4]. Climate data are extracted from http://climate.onebuilding.org/WMO_Region_1_Africa/MAR_Morocco/MS_Marrakech-Safi/MAR_MS_Marrakesh-Menara.AP.602300_TMYx.2004-2018.zip

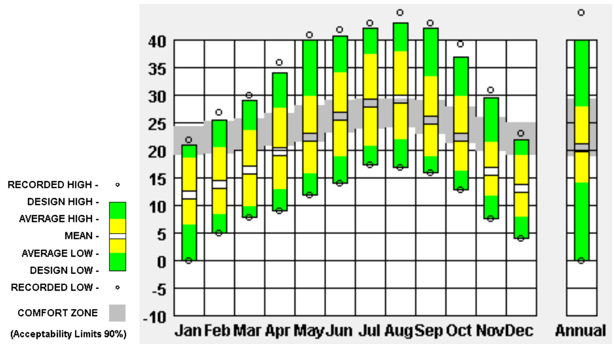


Figure 155: Temperature range by month for Marrakech. Source: Climate consultant – Adaptative Comfort model [5]

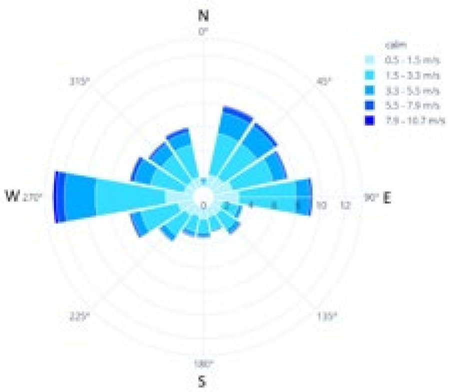


Figure 156: Annual Wind rose for Marrakech (Beaufort wind scale) [5]

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **2959** Wh/m² (Dec) Max: **7517** Wh/m² (Jul) Mean: **5237,42** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **768** CDD 10°C: **3896**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **1032** CDD: **245**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **863** CDD 26º: **498**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	**Comfort ventilation**: Natural ventilation strategy is activated through the manual opening of windows. **Nocturnal convective ventilation**: The natural ventilation (cross ventilation) is exploited during the night-time. Some of the techniques are already integrated the house (Insulation of facades by an air gap of 5 cm, ground coupling), while the others will be considered for retrofitting (thermal insulation of the roof and thermal insulation of external walls of west facade)
Passive heating strategy	Ground coupling on thermal load and double-glazed windows.
Solar protection	The shading of the west side of the roof is achieved by a mobile device. (Fig 3)
Building orientation	The main facades are East and West. The North and South walls are adjoining walls.
Insulation	The walls of East and West facades are insulated by an air gap of 5 cm. A thermal insulation by 4 cm extruded polystyrene (XPS) for the roof.
Vegetation	The main facades overlooked gardens of 30.6 m² and 25.8 m² respectively. The northwest-facing corridor of the 1st floor is shaded by the plants and trees of the west garden.
Natural daylighting	The house faces East-West. The street facade receives the sun in the afternoon. The back facade of the house is in the morning sun. This double exposure makes it possible to benefit from solar contributions all day long. The first challenge of the renovation was to create a layout with interior openings on each floor. This made it possible to create a natural light crossing to take advantage of the double East-West exposure of the house.
Use of local and embedded materials	N/A
Water saving and heat recovery on hot water drain	N/A
Waste management	N/A
Others features	N/A

Figure 157 : Mobile shading device of the west side 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	**No**
Ceiling fans	In every room, even those conditioned: **No**
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: **Yes**
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.:* **No** It is not necessary since the building is a detached residential house and the users are aware of how to correctly use the building.

BUILDING FABRIC AND MATERIALS	
Roof	• 1 cm of plaster • 16 cm hollow bricks with steel beams • 4 cm of reinforced concrete • 10 cm of cement mortar • 2 cm of ceramic tiles
	Overall R-value : 1.69 [m^2 K W^{-1}] U-Value : 0.59 [W m^{-2} K^{-1}]
Windows	Double glazing
	Window-to-wall ratio (WWR) (see Tableau 1)
	U-value = 2.95 [W m^{-2} K^{-1}], g-value =64 %
	Visual transmittance: -

Walls	• 1.5 cm of cement mortar • 10 cm red clay brick • 5 cm of air gap • 10 cm red clay brick • 1.5 cm of cement mortar
	U-value : 0.72 [W m^{-2} K^{-1}] Overall R-value : 1.388 [m^2 K W^{-1}]

Table 1 : Window-to-wall ratio of the Nassim house after renovation

Walls	Ground floor			1st floor		Terrace		
	West	East	South	West	East	West	East	South
Glass surface (m^2)	2.50	2.27	2.90	3.4	4.95	2.46	1.9	0.5
Total surface area of facades (m^2)	22.12	19.00	12.30	22.12	22.12	18.30	19.44	5.30
Overall rate of bay windows (%)	11.3%	11.9%	23.6%	15.4%	22.4%	13.4%	9.8%	9.4%

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	. **The soil as a cooling source:** The coupling between the building and the ground is very beneficial, especially in summer. Indeed, in an arid climate like that of Marrakech what matters most is the cooling load. Typically, the thermal inertia of the ground can reduce the annual heating / cooling thermal load by about 8%. . Smart reversible air conditioners equipped with Inverter technology allow 25% energy savings (all devices are in energy class A ++)
Low-energy heating systems	. Free solar gains are widely used in winter provided that the building is protected against excess gains in summer via shading systems, so as not to cause overheating inside the building. . Smart Inverter air conditioners with a high COP.
Ceiling fans	N/A
Mechanical ventilation / air renewal	The air renewal strategies are: ▪ Natural ventilation ▪ Nocturnal ventilation
Domestic Hot Water	Domestic hot water is produced by a closed-circuit solar water heater with a 200 liters storage tank. To maximize the self-consumption of the solar photovoltaic production we use a smart diverter to ensure deviation of surplus solar production electricity towards the resistance of the domestic hot water tank.
Artificial lighting	The whole building is equipped with high-efficiency LED lighting. (100 lumens/Watt)
Control and energy management	An advanced home automation system based on an open-source software can control temperature and lighting based on time of day and occupancy, reducing energy consumption around the home.

Individual thermostats in each room ensure the house is never over heated or over cooled and allow temperatures to be reduced when the room is not occupied (Figure 158).

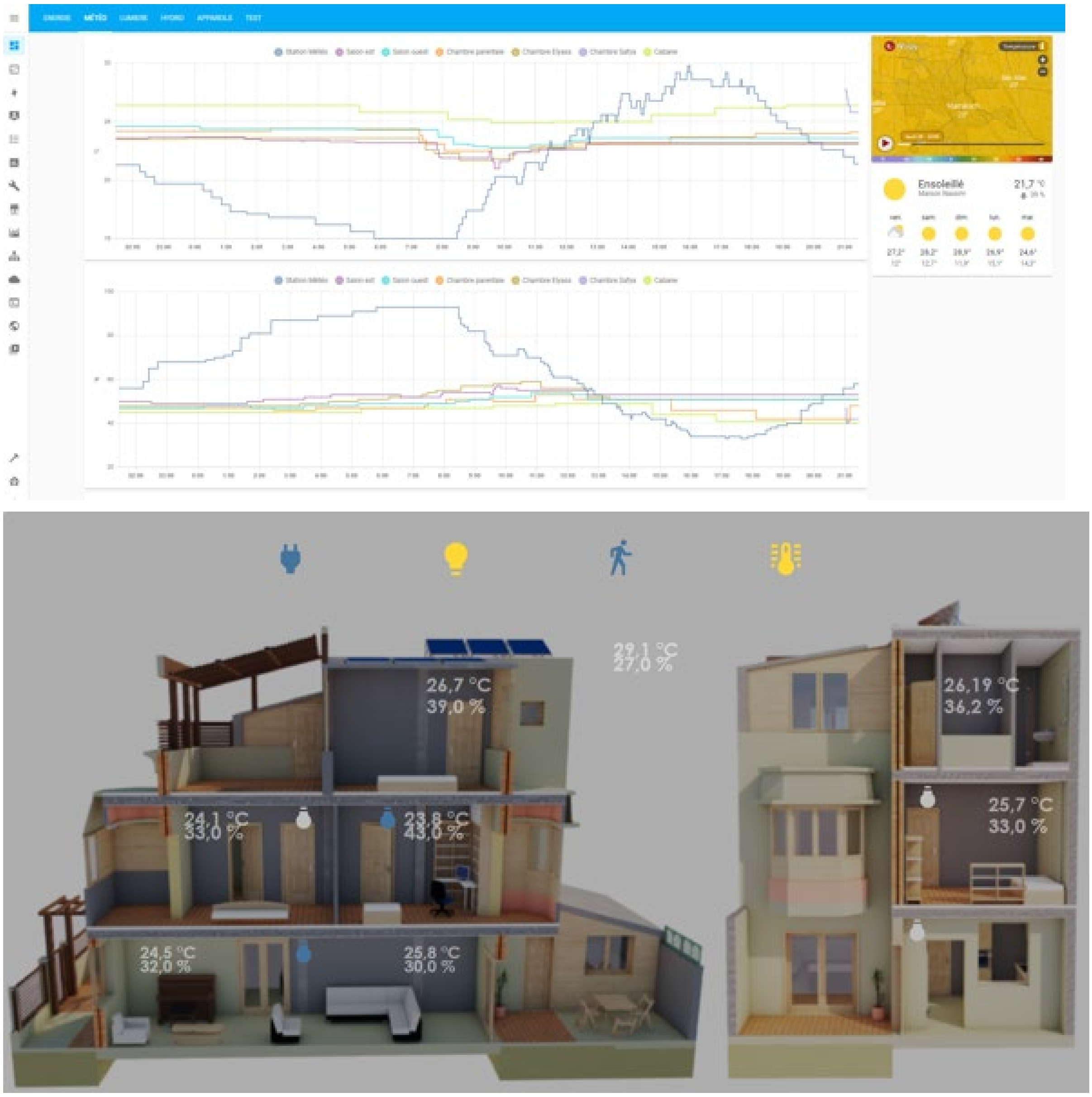


Figure 158 : Screenshots of the home automation management interface

RENEWABLE ENERGY

PV	. PV system (2 kW peak electric power) is installed in the south-orientated roof part of the building and on the sloped roof. The slope chosen for the solar panels is 15 degrees to promote summer photovoltaic solar production and for aesthetic reasons (Fig. 5). . The electricity production by the PV panels is continuously monitored and compared with the instantaneous energy use of the building and the delivered energy (from the grid).
Solar thermal	. A 1.6 square meter solar thermal panel with a 200 liters tank ensures the production of domestic hot water (Fig 5). . Two thermal solar panels of 2 square meters each (Fig. 5) to heat the floor of a Hammam installed in the terrace of the

	house. The system of solar floor heating mainly consists of flat-plate collectors, pump and an active layer (heating serpentine) integrated to the Hammam floor (Fig. 6 and Fig. 7).
Wind	N/A
Geothermal	N/A
Biomass	N/A

Figure 159 Solar thermal and photovoltaic panels installed on the roof of the house

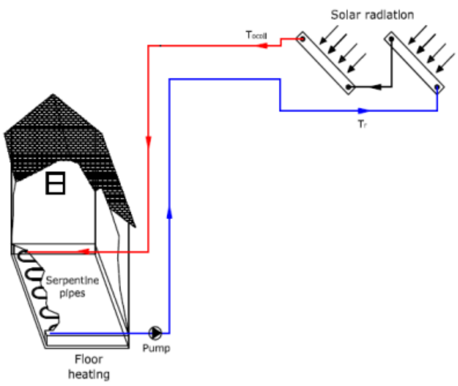


Figure 160 Scheme of the floor heating system

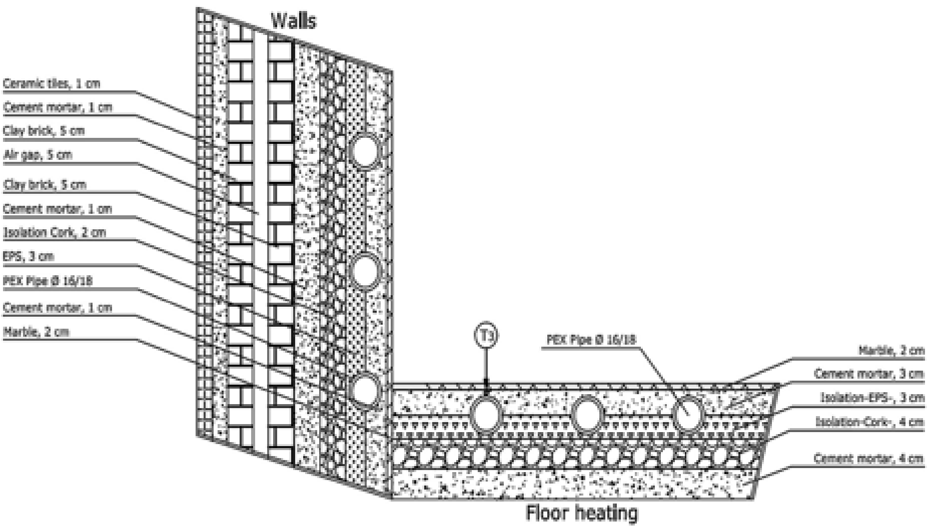


Figure 161 Floor and walls heating system (T3: temperature sensor)

ABC21 is funded by the EU's H2020 programme

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating: **2** [kWh/m^2/year]
	2. Energy needs for cooling: **3.5** [kWh/m^2/year]
	3. Energy use for lighting: **2** [kWh/m^2/year]
	4. Energy needs for Sanitary Hot water **1.5** [kWh/m^2/year] Unconsumed photovoltaic production (mainly during autumn and winter) is routed by a solar power diverter to the resistance of the solar water heater.
	5. Total Primary energy use: **28** [kWh/m^2/year] (Total Primary Energy Factor (PEF) equal to 2.63 for electrical energy from the grid)
	6. Renewable Primary energy generated on-site: **11.5** [kWh/m^2/year]
	7. Renewable Primary energy generated on-site and self-consumed: **7** [kWh/m^2/year]
	8. Renewable Primary energy exported to the grid: **4.65** [kWh/m^2/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): **25%**
	10. Delivered energy: **8** [kWh/m^2/year] (see Fig. 8)
Acoustic comfort indicators	1. Airborne sound insulation: N/A
	2. Equivalent continuous sound Level: N/A
	3. HVAC noise level: **28 dB**
	4. Reverberation time: N/A
	5. Masking/barriers: N/A
Visual comfort indicators	1. Light level (illuminance): YES
	2. Useful Daylight Illuminance (UDI): N/A
	3. Glare control: N/A
	4. Quality view: YES
	5. Zoning control: YES
Indoor Air Quality indicators	1. Organic compound: N/A
	2. VOCs: N/A
	3. Inorganic gases: YES (CO_2)
	4. Particulates (filtration): N/A
	5. Minimum outdoor air provision: N/A
	6. Moisture (humidity, leaks): No

ABC21 is funded by the EU's H2020 programme

	7. Hazard material: No
Users' feedback	The air temperature inside the building was decreased by 3 to 5 ° C, enhancing the thermal comfort of the occupants who are very satisfied with this renovation.

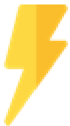
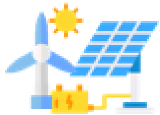
Figure 162: Monthly delivered energy of the house over one year (from November 2020 to August 2021)

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned	The analysis of temperature and humidity measurements inside and outside the building before renovation gave a general idea of the thermal behaviour of the house, as well as the strengths and weaknesses of its envelope. On the other hand, the measurements made after renovating the house with and without occupancy showed the positive effect of integrated systems on their thermal performance of the house. These bioclimatic solutions studied are: orientation of the building, thermal inertia, thermal insulation of the envelope with its thickness and its optimal position, double glazing, shading devices, natural ventilation, underfloor heating and the integration of renewable energy systems for the production of hot water and for heating the Hammam space of the house. An optimal combination was applied to the house and was the basis for the renovation. Faced with the East-West orientation of the house which is the most unfavourable and that cnnot be changed, we have played on other aspects which are summarized in the combination of roof insulation by 4 cm of extruded polystyrene, insulation of the walls with a 5 cm air gap, use of double glazing, use of mobile shading devices on the roof and windows, take advantage of natural night ventilation in summer. This combination has reduced the air temperature inside the building by 3 to 5 ° C, and it has increased the thermal comfort of the occupants who are very satisfied with this renovation.
Recommendations	To consume the maximum amount of photovoltaic energy produced instantly, in addition to the correct sizing of the installations, it is important to control and be able to predict production and consumption. Specialized regulations must emerge for thermal electrical equipment, in order to recover production predictions, analyse consumption, prioritize energy uses by being able to control devices, and finally, directing towards storage if necessary.

The IoT and controls can invrease the flexibility of energy demand, in order to increase self consumption of renewable energy generated on-site.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

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

Weaknesses

-

REFERENCES

[1] Moroccan Thermal Regulation for Construction, RTCM, https://www.amee.ma/fr/reglementation-thermique, Accessed October 20, 2021.

[2] Sobhy, I., Brakez, A., and Benhamou, B., 2017, "Analysis for Thermal Behaviour and Energy Savings of a Semi-detached House with Different Insulation Strategies in Hot Semi-arid Climate," J. Green Build., 12(1), pp. 78–106.

[3] Sobhy, I.; Brakez, A.; Benhamou, B. Energy performance and economic study of a solar floor heating system for a Hammam. Energy Build. 2017, 141, 247–261

[4] Andrew Marsh Psychrometric Chart. Available at: https://drajmarsh.bitbucket.io/psychro-chart2d.html.

[5] Climate Consultant tool. Available at: https://climate-consultant.informer.com/6.0/

CASE STUDY 1-11: DAR AMYS VILLA | MOROCCO

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Marrakech, Morocco
Latitude; Longitude	31.61685854559842, -8.033311845423265
Climate zone (Köppen–Geiger classification)	BSh: Hot semi-arid steppe

BUILDING INFORMATION	
Building Type	Terraced individual housing, Villas
Project Type	New construction
Completion Date	N/A
Number of buildings	1
Number of storeys	2
Total Floor Area (m²)	1st floor:167 m² 2nd floor: 117 m² [1]
Net Floor Area (m²)	284 m²
Thermally conditioned space area (m²)	284 m² (The whole building is thermally conditioned)
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m²)	284 m² (The whole building is naturally ventilated)
Total cost (€)	667 044 (7 000 000 MAD)
Cost /m² (€/m²)	2 348.8 (24 647 MAD/m²)
Performance Standards or Certification	-
Awards	-

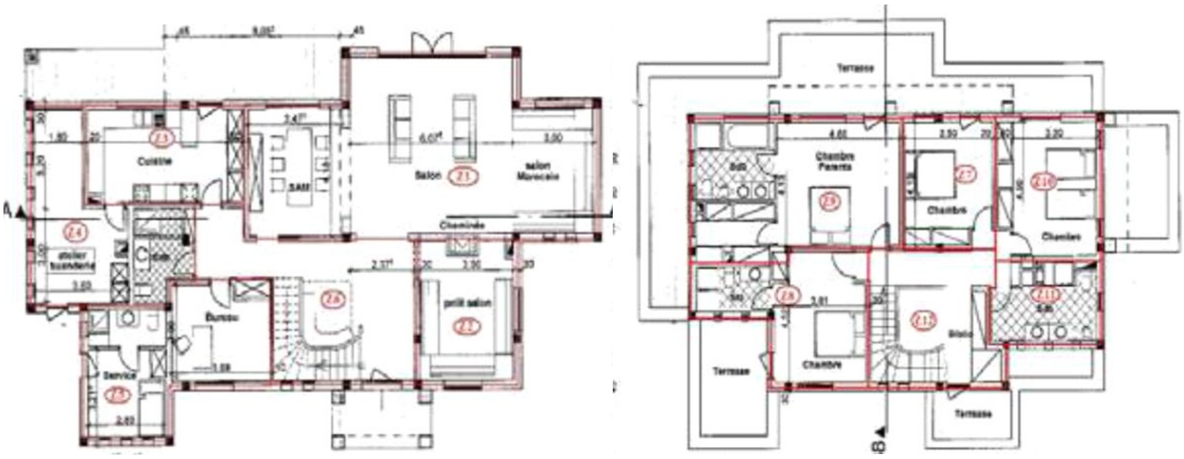
STAKEHOLDERS	
Building Owner/ Representative	Pr. Amine Bennouna
Architect / Designer	Mohamed El Anbassi
Construction manager	Mohamed El Anbassi
Environmental consultancy	Mohamed El Anbassi

Structural Engineer, Civil Engineer	Mohamed El Anbassi
Product Manufacturer	_
Certification company	_

PROJECT DESCRIPTION

Figure 163: Exterior view of the Dar Amys Villa

The building is a villa type house located in the Marrakech (Morocco). The house is constituted of two floors and was designed to be energy efficient by integrating some passive techniques: overhangs, an Earth-to-Air Heat Exchanger (EAHE), thermal insulation of the roof and external walls. Water is provided from an in-site well and managed with smart drip irrigation techniques. Biodegradable wastes are recycled and used as compost for fertilization. A solar water heater is installed on the roof of the building.



(b) (b)

Figure 164: Dar Amys plan view: (a) 1st floor level and (b) second floor level [2]

SITE INTEGRATION

Figure 165 : Aerial view of the Dar Amys Villa and its' surrounding

Dar Amys is a family detached house, located in a hot semi-arid steppe region. The villa is constructed in a green land of 300 m^2 area. The building is located in a suburb of Marrakesh constituted by luxury constructions villas.

CLIMATE ANALYSIS

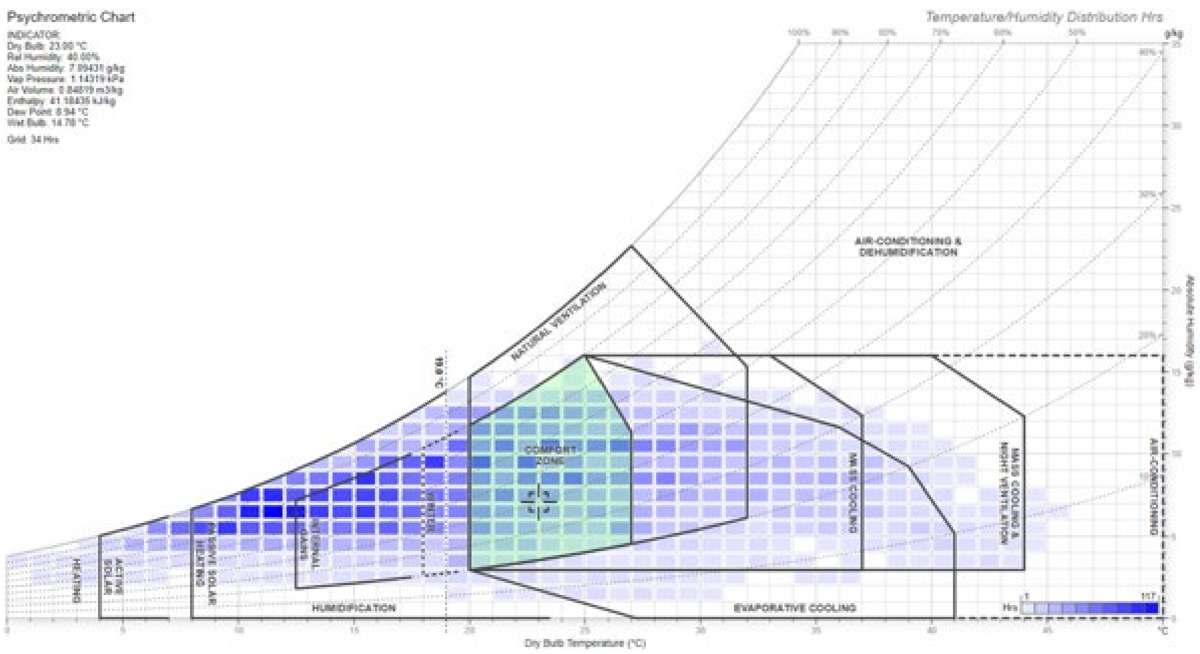


Figure 166: Bioclimatic chart for the climate of Marrakesh using Andrew Marsh online tool [3]. Climate data are extracted from http://climate.onebuilding.org/WMO_Region_1_Africa/MAR_Morocco/MS_Marrakech-Safi/MAR_MS_Marrakesh-Menara.AP.602300_TMYx.2004-2018.zip

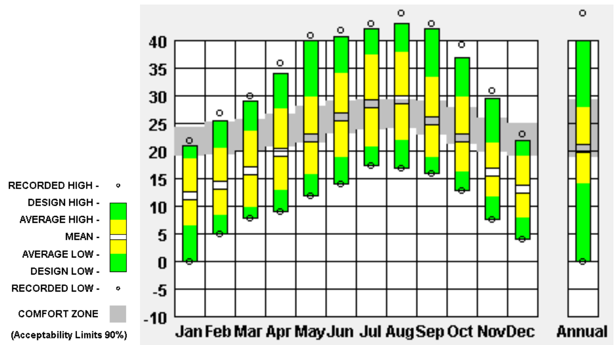


Figure 167: Temperature range by month for Marrakesh. Source: Climate consultant – Adaptative Comfort model [4]

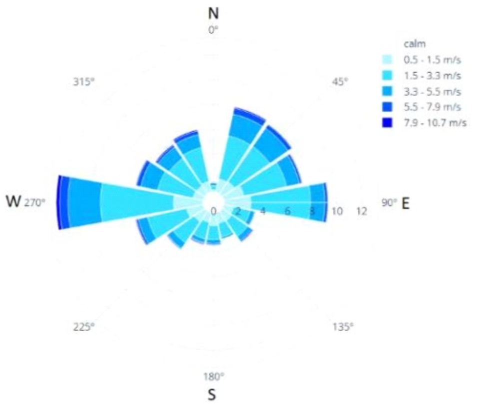


Figure 168: Annual Wind rose for Marrakesh (Beaufort wind scale) [4]

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **2959** Wh/m² (Dec) Max: **7517** Wh/m² (Jul) Mean: **5237,42** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **768** CDD 10°C: **3896**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **1032** CDD: **245**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **863** CDD 26º: **498**

KEY BIOCLIMATIC DESIGN PRINCIPLES	
Passive cooling strategy	**Comfort ventilation**: Natural ventilation strategy is achieved through the manual openings.
Passive heating strategy	High level of insulation of the roof and the walls. Double-glazed windows.
Solar protection	Overhangs and shadowing are following the standards to have the shadowed portion of the glazed area as large as possible in summer and as low as possible in winter. Horizontal solar protection of 1.20 m on the Southern façade.
Building orientation	Oriented east-west so that its large dimensions face south (a dis-alignment of 17 ° was tolerated) [1]
Insulation	The roof and the exterior walls of the villa are highly insulated. The different thermal resistances are given below: Envelope walls or exterior walls = 2,55 (m^2 K)/W Intermediate floor = 2,37 (m^2 K)/W Roof = 2,67 (m^2 K)/W
Vegetation	The villa is surrounded with planted trees, providing shadowing cool air to the house. Deciduous trees provide shading only when needed, i.e., in summer.
Natural daylighting	The house is provided with large glazed façade South-oriented which allows natural daylighting during the day.
Use of local and embedded materials	Fired earth bricks are used for the exterior walls.
Water saving and heat recovery on hot water drain	Water is provided from an in-site well and managed with smart drip irrigation techniques.
Waste management	Biodegradable wastes are recycled and used as compost for fertilization.
Others features	Line drying spaces are available.

Figure 169 : Passive principles set up: (a) Overhangs and shadowing and (b) Natural daylighting [2]

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**
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: **No**
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	In every room, even those conditioned: **Yes**
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.: **No** It is not necessary since the building is a detached residential house and the users are aware of how to correctly use the building.

BUILDING FABRIC AND MATERIALS [1]	
Roof	The roof is structured as follows (from inside to outside): 1. Plaster (1 cm) 2. “Hourdi” (16 cm) 3. Pre-stressed concrete (5 cm) 4. Polystyrene (6 cm) 5. Cement mortar (6 cm) 6. Ceramic tile (2 cm)
	Overall R-value: **2.67** [m^2K/W] U-value: **0.37** [W/m^2K]
1st floor slab	The 1st floor slab composition is similar to that of the roof without insulation.
	Overall R-value: **2.37** [m^2K/W] U-value: **0.42** [W/m^2K]
Walls	The **external walls** are structured as follows (from inside to outside): 1. Plaster (1 cm) 2. Concrete block (15 cm) 3. Glass wool (10 cm) 4. Earthenware brick (15 cm) 5. Cement mortar (1.5 cm)
	Overall R-value: **2.55** [m^2K/W] U-value: **0.39** [W/m^2K]
Windows	Tempered glass.
	Window-to-wall ratio (WWR): 1st floor | 2nd floor

	W	E	**S**	N	W	E	**S**	N
	7%	8%	**36%**	10%	2%	6%	**19%**	9%

U-value: -

Visual transmittance: -

ENERGY EFFICIENT BUILDING SYSTEMS	
Low-energy cooling systems	▪ **The soil as a cooling source**: The coupling between the building and the ground is very beneficial, especially in summer. Indeed, in an arid climate like that of Marrakech what matters most is the cooling load. ▪ Earth-to-Air Heat Exchanger (EAHX): The house is served by an EAHX formed of 3 tubes up to 3,50 m deep which provide 500 m³/h of air at 24 ° C in summer and 19 ° C in winter [1].
Low-energy heating systems	Free solar gains are widely used in winter provided that the building is protected against excess gains in summer via shading systems, so as not to cause overheating inside the building.
Ceiling fans	None
Mechanical ventilation / air renewal	**Natural ventilation.** Earth-to-Air Heat Exchanger (EAHX): The house is served by an EAHX formed of 3 tubes up to 3,50 m deep which provide 500 m³/h of air at 24 ° C in summer and 19 ° C in winter.
Domestic Hot Water	Two solar water heaters with exchanger (due to limestone and risk of frost) totalling 4 m² ensure the supply of hot water in bathrooms and from the kitchen
Artificial lighting	The whole building is equipped with high-efficiency LED lighting (3 W/m^2)
Control and energy management	N/A

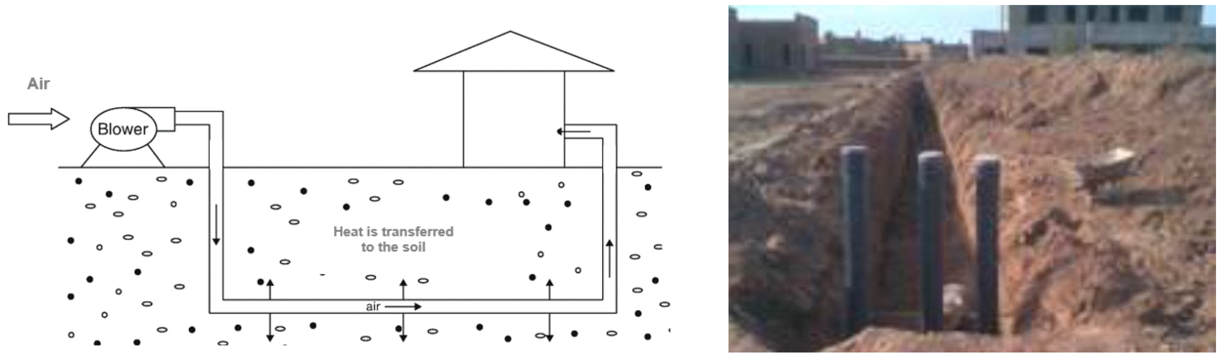


Figure 170: Earth-to-Air Heat Exchanger principle (a) and construction (b) [2]

RENEWABLE ENERGY	
PV	Not used

Solar thermal	Two solar water heaters with exchanger (due to limestone and risk of frost) totalling 4 m² ensures the supply of hot water in bathrooms and from the kitchen.
Wind	Not used
Geothermal	Earth-to-Air Heat Exchanger (EAHX): The house is served by an EAHX formed of 3 tubes up to 3,50 m deep which provide 500 m³/h of air at 24 ° C in summer and 19 ° C in winter
Biomass	Not used

Figure 171: Solar water heaters installed on the rooftop of the Dar Amys Villa.

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating: **15** [kWh/y/m^2]
	2. Energy needs for cooling: **23** [kWh/y/m^2]
	3. Energy use for lighting: - [kWh/m^2/year]
	4. Energy needs for sanitary hot water: - [kWh/m^2/year]
	5. Total Primary energy use: - [kWh/m^2/year]
	6. Renewable Primary energy generated on-site: - [kWh/m^2/year]
	7. Renewable Primary energy generated on-site and self-consumed: - [kWh/m^2/year]
	8. Renewable Primary energy exported to the grid: - [kWh/m^2/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): - %
	10. Delivered energy (from electricity bills) : - [kWh/m^2/year]
	1. Airborne sound insulation

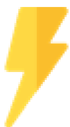
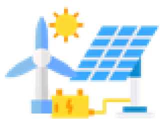
Acoustic comfort indicators	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators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

LESSONS LEARNED AND RECOMMENDATIONS [1][2]

Lessons learned	This case study shows that the passive features set up allowed to reach their main objectives: to reduce energy needs for heating and cooling while maintaining comfortable indoor conditions. The villa can not only accumulate solar heat gain when needed through the south-oriented windows but also regulate rooms temperature thanks to its high thermal inertia. The insulation of the roof and the external walls is a key performance measure to reduce heat loss and solar gain. The roof insulation allowed to reduce the cooling load by 42% and the energy needs for heating by 18%.
Recommendations	Roof insulation is highly recommended for the climate of Marrakech. Indeed, this passive feature has a great beneficial effect all year long.

BUILDING STRENGTHS AND WEAKNESSES

Strengths

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

Weaknesses

-

REFERENCES

[1] B. Benhamou et A. Bennouna, « Energy Performances of a Passive Building in Marrakech: Parametric Study », Energy Procedia, vol. 42, p. 624-632, janv. 2013, doi: 10.1016/j.egypro.2013.11.064.

[2] « Dix cas de bonnes pratiques au Maroc ». [En ligne]. Disponible sur: http://www.archi.ac.ma/images/publications/Catalogue%20web.pdf

[3] « Bioclimatic chart for the climate of Marrakesh ». [En ligne]. Disponible sur: http://climate.onebuilding.org/WMO_Region_1_Africa/MAR_Morocco/MS_Marrakech-Safi/MAR_MS_Marrakesh-Menara.AP.602300_TMYx.2004-2018.zip

[4] « Climate Consultant », Software Informer. https://climate-consultant.informer.com/6.0/ (consulté le nov. 03, 2021).

ABC21 is funded by the
EU's H2020 programme

CASE STUDY 1-12: SALAM CARDIAC SURGERY CENTRE | SUDAN

GEOGRAPHICAL AND CLIMATE INFORMATION	
Location	Soba, Khartoum, Sudan
Latitude; Longitude	15.509919818764784, 32.66305412641556
Climate zone (Köppen–Geiger classification)	BWh: Hot desert
BUILDING INFORMATION [1][2]	
Building Type	Hospital
Project Type	New construction
Completion Date	2010
Number of buildings	1
Number of storeys	1
Total Floor Area (m^2)	12.000
Net Floor Area (m^2)	-
Thermally conditioned space area (m^2)	9.300 (ground floor + basement)
Spaces with Natural Ventilation (with or without Ceiling Fans) Only (m^2)	2.700
Total cost (€)	15 920 960
Cost /m^2 (€/m^2)	1 137,2
Performance Standards or Certification	None
Awards	Aga Khan Award for Architecture
STAKEHOLDERS [1][2]	
Building Owner/ Representative	Emergency NGO - Pietro Parrino, Rossella Miccio
Architect / Designer	Studio Tamassociati - Raul Pantaleo, Simone Sfriso, Massimo Lepore, Sebastiano Crescini with Pietro Parrino and Gino Strada
Construction manager	-
Environmental consultancy	-
Structural Engineer	Francesco Steffinlongo
Mechanical/services engineering	Studio Pasquini with Jean Paul Riviere and Nicola Zoppi

Product Manufacturer	-
Certification company	-
Others	Franco Binetti (Operating Theatre design) Roberto Crestan with Alessandro Giacomello (Site engineer)

PROJECT DESCRIPTION

Figure 172: Reception area of the Salam Cardiac Surgery Centre

The Salam Cardiac Surgery Center is located in Soba Hill, 18 km from the city of Khartoum, in Sudan. It consists of a 63-bed hospital with 300 local staff, with a separate medical staff accommodation complex that can accommodate 66 people. This centre is built as a pavilion in a garden with the two main buildings organized around large courtyards. [1]
The design of the SALAM cardiac surgery centre followed three main guiding principles [3]:

- the idea of a "hollow" space and a pavilion-based system;
- the choice of the best possible technology given the context;
- the search for an ethical language for this type of architecture.

Figure 173: Salam Cardiac Surgery Centre exterior view

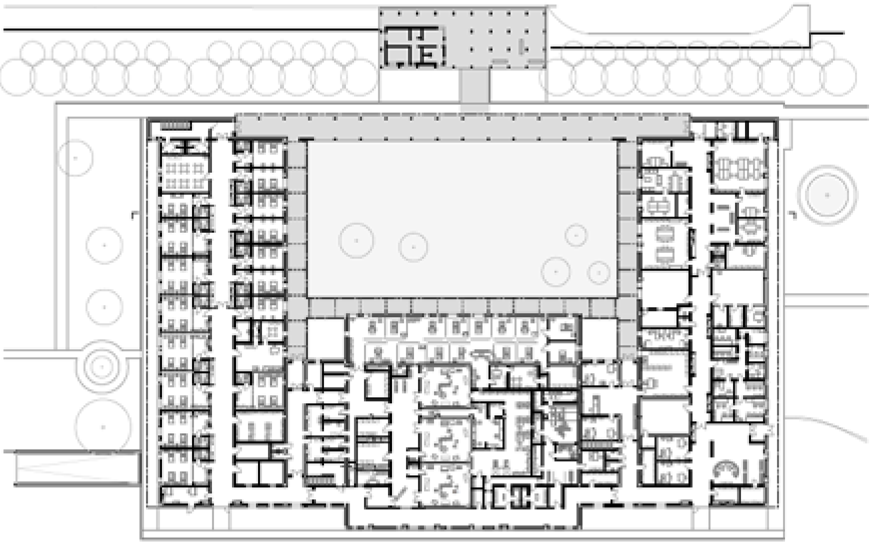


Figure 174: Floor plan of the building

SITE INTEGRATION

Figure 175 : Aerial view of the building and its' surrounding

The hospital surroundings are mainly desert areas, with no vegetation. The hospital was developed around an empty space, physically and ideally occupied by two huge mango trees, located in the center of the site (a plot on the banks of the Nile about 20 km from Khartoum). In keeping with traditional housing structures, the hospital is configured around a hollow space, creating angles, perspectives and sensations that change forever and are never monotonous.

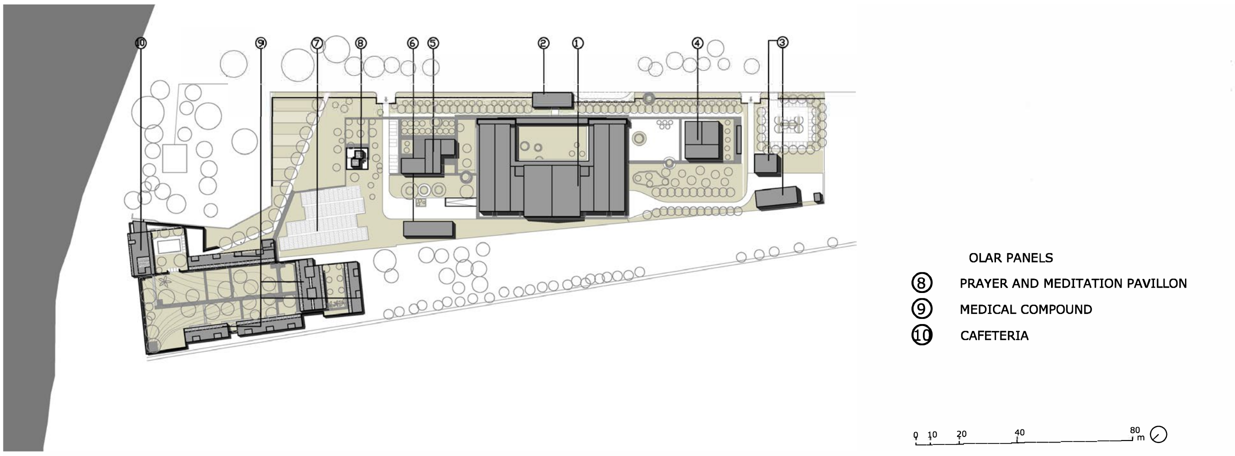


Figure 176: Site plan of the "Salam" centre [3]

CLIMATE ANALYSIS

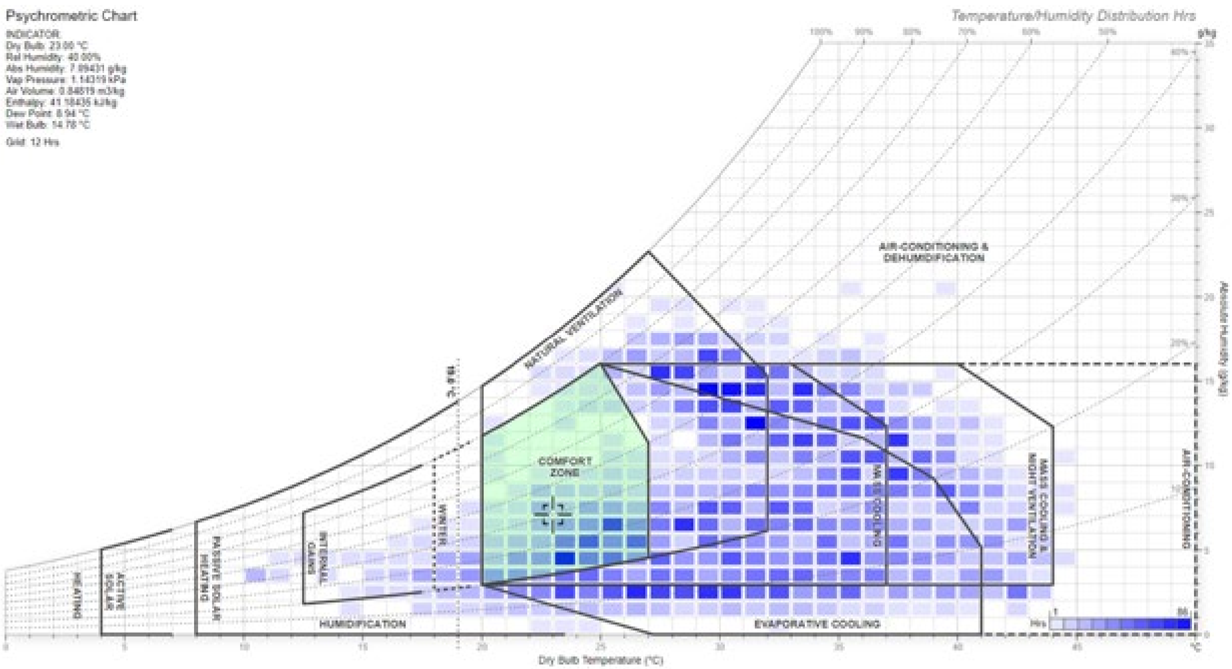


Figure 177: Bioclimatic chart for the climate of Khartoum using Andrew Marsh online tool [4]. Climate data are extracted from http://climate.onebuilding.org/WMO_Region_1_Africa/SDN_Sudan/KS_Kush/SDN_KS_Khartoum.Intl.AP.627210_TMYx.2004-2018.zip

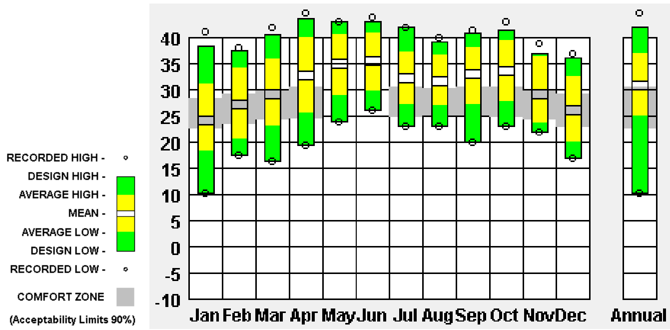


Figure 178: Temperature range by month of Khartoum. Source: Climate consultant – Adaptative Comfort model [5]

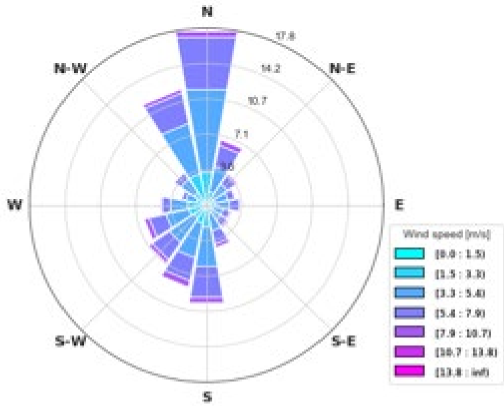


Figure 179: Annual wind rose for Khartoum (Beaufort wind scale) [5]

Global horizontal radiation (Avg daily total) Min (month) / Max (month)	Min: **5547** Wh/m² (Jan) Max: **7431** Wh/m² (May) Mean: **6532,33** Wh/m²
Annual Degree-Days for weather classification according to ASHRAE Standard 169-2020	HDD 18°C: **16** CDD 10°C: **7 607**
Annual Degree-Days for the Adaptive Comfort Base Temperature according to the ASHRAE 55-2017 for 80% of acceptability	HDD: **84** CDD: **810**
Annual Degree-Days for a static comfort temperature approach	HDD 18.6ºC: **21** CDD 26º: **2 033**

KEY BIOCLIMATIC DESIGN PRINCIPLES [3]	
Passive cooling strategy	Comfort ventilation: natural cross-ventilation Mass cooling (60 cm thick brick walls) Mixed modes of ventilation (NV & air conditioning) Thermal break windows Roof insulation
Passive heating strategy	NA
Solar protection	Bamboo blinds
Building orientation	The main facades of the building are oriented North/West
Insulation	A highly performing wall made of two layers of bricks separated by an insulating air cavity, with small windows. These windows are closed by highly performing glass panels with low emissions. The external walls are 58 cm thick and contain an insulated cavity that prevents the building from heating up. Insulation is also through an onion system of 5-centimetre internal insulating panels and an outer skin comprising a ventilated metal roof and bamboo blinds.
Vegetation	Shrubs and trees were used to protect the buildings from the heat and to mitigate the effects of the harsh climate.
Natural daylighting	All living spaces have natural light.

Use of local and embedded materials	Bamboo
Water saving and heat recovery on hot water drain	The production of hot water and heat are satisfied 100% by renewable energy without the need for recovery.
Waste management	The complete waste cycle is not managed internally.
Others features	A simple, mechanical solution was found to filter the large quantities of dust and sand in the air without having to rely on costly and complicated filtering devices. The air is designed to pass through a series of tunnels- a labyrinth like structure- before reaching the Air Handling Unit By doing so, the impact of the air on the walls of the tunnel will allow the sand to sediment while at the same time cooling the air and reducing its speed. A fine spray of water in the middle of the tunnels further eliminates the finer dust from the air and cools it down even more. The system needs very little maintenance work- limited to cleaning the tunnel-like structure- and allows the air to reach the conditioners filtered and 12°C cooler than when it enters the system.

Figure 180: Vegetation and shaded waiting area of the Salam Cardiac Surgery Centre Sudan

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): No
Protected bike parking and showers	Bikes are not used in Sudan. Ratio with number of users: NA
Ceiling fans	In every room, even those conditioned: No. Ceiling fans are only present in the canteen and the guest house.
Lighting system fractioned to allow using light only in zones occupied and where daylighting insufficient	In every room, even those conditioned: Yes. The lights circuit is divided for the different areas and can be manage according to the day light and the occupancy
Space and facilities for line drying clothes (especially important in residences, hotels, sport facilities…)	In every room, even those conditioned: Unknown
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.: Unknown

BUILDING FABRIC AND MATERIALS	
Roof	Insulated corrugated sheet Traditionally crafted thatched roofs for paths and areas for rest.
	Overall R-value:-
Windows	Windows aluminium 55 mm, Venetian blind inserted in the double glazing, 6+12+6 mm
	Window-to-wall ratio (WWR): -
	U-value: -
	Visual transmittance: -
Walls	Walls are made of two layers of bricks separated by an insulating air cavity, with small windows. Thickness: 58cm
	Overall R-value: -

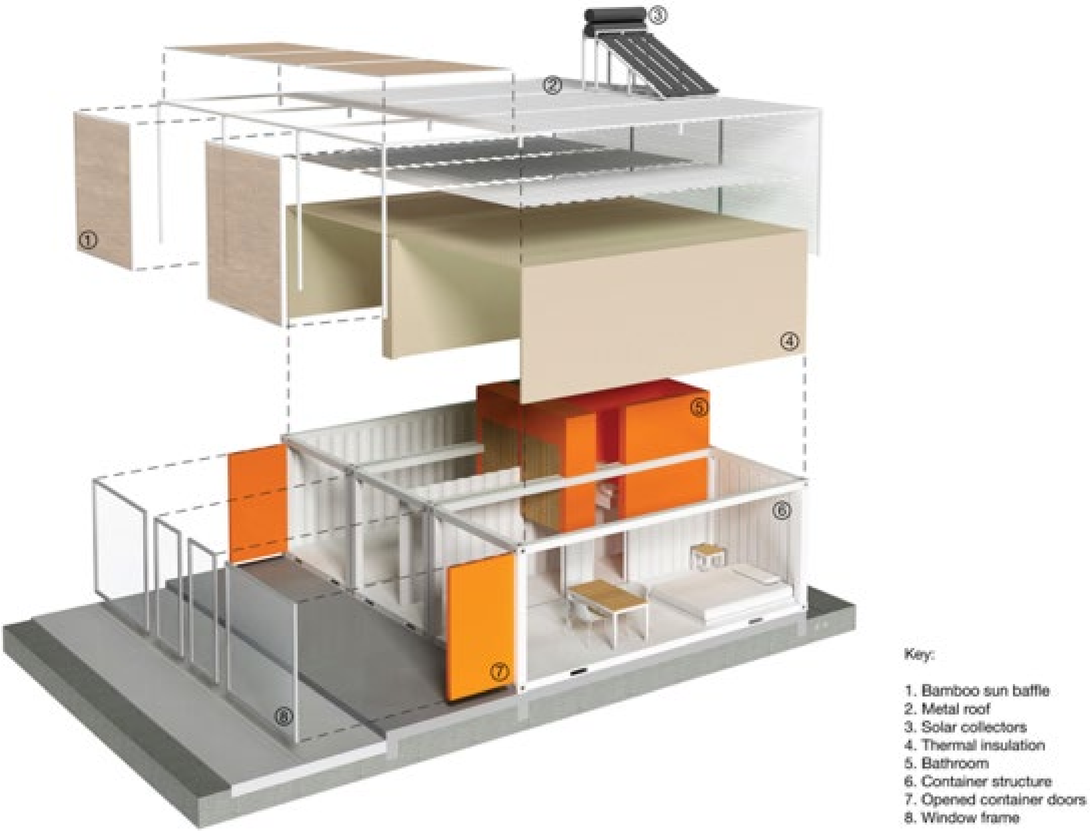


Figure 181 : Exploded view of the building fabric.

Figure 182: Bamboo sun and dust baffle

ENERGY EFFICIENT BUILDING SYSTEMS [3]	
Low-energy cooling systems	Solar collecting items are made up of a number of copper tubes that contain water; these are themselves placed in insulated glass tubes that allow the water inside the copper tubes to heat up. The water transfers the accumulated heat to an insulated 50 m^3 tank that keeps the water at 80-90°C. The heat is then used to produce cold fluid to 7°C in two "chilling" machines. [3] Solar power thus allows to produce cold without discharging any particles in the atmosphere and limiting the use of electric power to water circulation pumps. Two regular boilers have also been installed in case the solar power is not sufficient to run the two "chilling" machines. The cold water is used to lower the levels of heat in the rooms that need to be chilled for medical or other purposes. The machines used for this last part of the cooling circuit are called AHU (Air Handling Unit). There are 8, each one designed for a specific area of the hospital (surgery, administration, etc). The AHU draw air from outside and "force" it into a 7°C tube that cools it down. A second system of tubes subsequently transports the cool air to various hospital rooms according to need. [3]
Low-energy heating systems	NA
Ceiling fans	None
Mechanical ventilation / air renewal	Yes
Domestic Hot Water	The production of hot water is satisfied 100% by renewable energy. See next section.
Artificial lighting	Yes
Control and energy management	-

Figure 183: View of circulation pumps of chilled water [3]

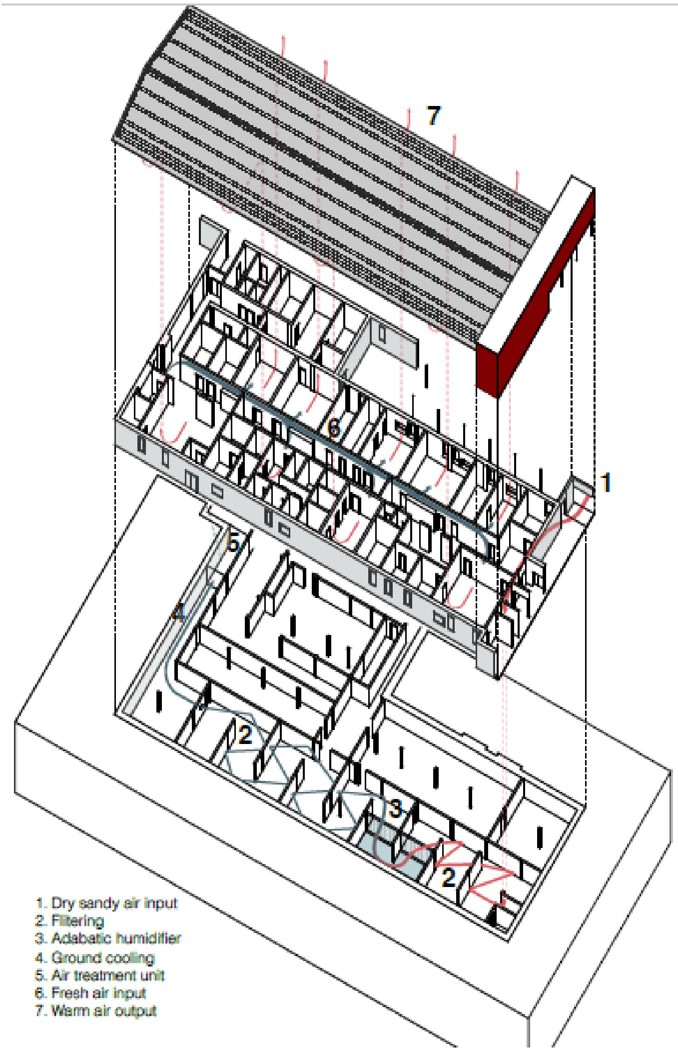


Figure 184: Principle of the cooling and filtering technological solutions

RENEWABLE ENERGY	
PV	None
Solar thermal	A solar farm, which contains 288 solar collecting items, powers the water-cooling system Surface: 1000 m^2 of solar panels Total power: 3 600 kW
Wind	None
Geothermal	None
Biomass	None

Figure 185: A solar farm of 1000 m^2 powers the water-heating system. [3]

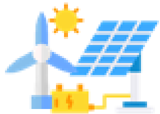
BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	1. Percentage of time outside an operative temperature range (Adaptive) : N/A
	2. Percentage of time outside an operative temperature range (Fanger) : N/A
	3. Degree-hours (Adaptive) : N/A
	4. Degree-hours (Fanger) : N/A
	5. Percentage of time inside the Givoni comfort zone of 1m/s: N/A
	6. Percentage of time inside the Givoni comfort zone of 0m/s: N/A
	7. Number of hours within a certain temperature range : N/A
Energy performance indicators	1. Energy needs for heating: - [kWh/m^2/year] : N/A
	2. Energy needs for cooling: - [kWh/m^2/year]: : N/A
	3. Energy use for lighting: - [kWh/m^2/year]: : N/A
	4. Energy needs for sanitary hot water: - [kWh/m^2/year]: : N/A
	5. Total Primary energy use: - [kWh/m^2/year]: N/A
	6. Renewable Primary energy generated on-site: - [kWh/m^2/year] : N/A
	7. Renewable Primary energy generated on-site and self-consumed: - [kWh/m^2/year]
	8. Renewable Primary energy exported to the grid: - [kWh/m^2/year] : : N/A

	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): - %
	10. Delivered energy (from electricity bills) : - [kWh/m^2/year]
Acoustic comfort indicators	1. Airborne sound insulation
	2. Equivalent continuous sound Level
	3. HVAC noise level
	4. Reverberation time
	5. Masking/barriers
Visual comfort indicators	1. Light level (illuminance)
	2. Useful Daylight Illuminance (UDI)
	3. Glare control
	4. Quality view
	5. Zoning control
Indoor Air Quality indicators	1. Organic compound
	2. VOCs
	3. Inorganic gases
	4. Particulates (filtration)
	5. Minimum outdoor air provision
	6. Moisture (humidity, leaks)
	7. Hazard material
Users' feedback	-

LESSONS LEARNED AND RECOMMENDATIONS	
Lessons learned & Recommendations	Temperatures often exceed 40°C in Sudan for long periods of time. It is this aspect of the Sudanese climate together with the presence of fine dust generated by the strong desert winds that has led to an in-depth study of the right type of insulation, cooling and filtering technologies. These technologies allow to reduce the energy consumption levels of the hospital while at the same time guaranteeing maximum levels of comfort [3]. The technological solutions that were sought were context-specific. In a country with very low levels of technology and with harsh climate conditions, the key features of the work were simplicity and innovativeness. Contrary to the practice of providing "third world" structures for "third world" countries, it was thus possible to prove that with innovation and low-cost technology we can guarantee the same standards of efficient health care as in any other Western health care centre [3].

BUILDING STRENGTHS AND WEAKNESSES

Strengths

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

Weaknesses

1. It could have been an interesting project more related with the near Nile river, useful for cooling effect and mobility issues.
2. There is a thermal solar farm of 1000 sqm, used to cool the large quantities of air needed for the entire building. However, the solar plant is not on the roof but on the floor and it occupies a green free area.
3. No reused/recycled materials were integrated in the design.

REFERENCES

[1] https://www.akdn.org/architecture/project/salam-cardiac-surgery-centre

[2] https://www.e-architect.com/africa/salam-centre-sudan

[3] https://www.archdaily.com/19061/salam-centre-for-cardiac-surgery-studio-tam-associati

[4] « Bioclimatic chart for the climate of Marrakesh ». [En ligne]. Disponible sur: http://climate.onebuilding.org/WMO_Region_1_Africa/MAR_Morocco/MS_Marrakech-Safi/MAR_MS_Marrakesh-Menara.AP.602300_TMYx.2004-2018.zip

[5] « Climate Consultant », Software Informer. https://climate-consultant.informer.com/6.0/ (consulté le nov. 03, 2021).

Part B

“Report on monitoring feedback of selected case studies”.

CONTENTS

ABC21 is funded by the EU's H2020 programme

1. Introduction

1.1 Scope and objectives

The ABC21 project has highlighted the difficulty to collect performance data.
There is a real lack of measured data and monitoring feedback in African buildings.

Only a few buildings are fully monitored in terms of energy and global comfort and the majority of them are located in Europe. Measurement campaigns have been conducted on site so as to address this lack of data and verify acceptable level of comfort, especially for the case studies located in Africa.
The monitoring activities have thus focused on the evaluation of the indoor thermal comfort.

We present in this report only the case studies that have been monitored during the ABC 21 project with measured data that are reliable. They are identified by green dots in Figure 2.

1.2 Document Structure

The document is structured as follows:

- Section 2 describes the methodology used;
- Section 3 gives the list of selected case studies and contact person for each monitored case studies
- Section Annex presents the results by case studies, the guidelines for the thermal comfort measurements and the questionnaire used for the Post 0ccupancy Evaluation.

ABC21 is funded by the EU's H2020 programme

2. Methodology - Measurement campaign for the assessment of indoor thermal comfort

The methodology for the measurement campaign has consisted in :`

- Design of experiment and identification of the levels of monitoring function of the location (La Reunion and PoliMI);
- Selecting measurement equipment for indoor measurements with careful balance of accuracy and cost (PoliMI and La Reunion);
- Selection of outdoor weather stations able to deliver accuracy, robustness to a harsh environment, availability of a maintenance service in Africa (PoliMI);
- Acquisition of measuring equipment and weather stations (PoliMI);
- Shipment of sensors and meteo stations to the buildings to be monitored (PoliMI) ;
- Training and assistance to local teams in charge of the measurements and Post Occupancy Evaluation (La Reunion for Senegal, Kenya and PoliMI for Burkina).

Three different levels of monitoring strategies have been planned (see Figure 1) according to the availability in terms of sensors and human resources. Due to the limited budget, human constraints, quality of network, it was not possible to install the same level of monitoring in all the selected case studies.

Three different levels of monitoring strategies have thus been defined (see Figure 1) :

- The first level is a basic monitoring level with sensors capable of measuring the indoor air temperature and relative humidity in selected spaces inside the building. Outdoor conditions are limited to air temperature and RH measured with the same kind of sensor that are protected from solar radiation with a naturally ventilated shield;
- The second level is the same as level one with an additional weather station on site. The weather station has to measure at least global horizontal solar radiation, wind speed/wind direction, temperature and relative humidity;
- The third one is a more detailed monitoring with, in addition of level 2, the measurement of all indoor thermal environment parameters (i.e. the air temperature, the relative humidity, the black globe temperature and the air velocity). The measurements will last at least 2 or 3 months during the hottest period. The position and number of measurement points will be selected so to get representative and scientific based values. The measurement instrumentation and the protocol used for the evaluation of the thermal environment will meet the requirements given in the European Standard "NF EN ISO 7726: Ergonomics of the thermal environment- Instruments for measuring physical quantities".

ABC21 is funded by the
EU's H2020 programme

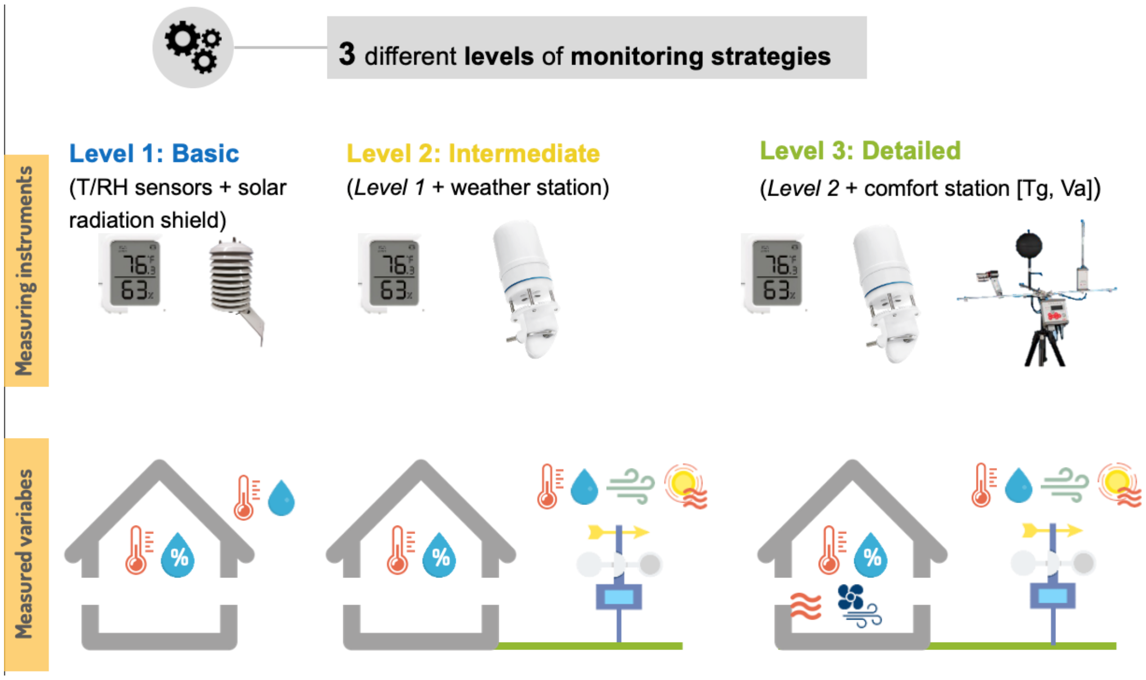


Figure 1 : The 3 levels of monitoring in ABC21 project

As mentioned before, different levels of monitoring have been set coherently to budgetary and human resources availability.
The first level of monitoring focuses only on the measurements of air temperature and relative humidity. It was performed in the buildings where the level of technical assistance was limited and/or where the installation of a comfort station for long term measurements was found to be more difficult.
For the second level of monitoring, the case studies in Africa have been given priority due to the lack of reliable and accessible weather data and thanks to a partnership established with The Trans-African Hydro-Meteorological Observatory (TAHMO), which aims to develop a vast network of weather stations across Africa. For the other case studies located in Europe and in La Reunion, weather data were obtained from weather stations close to each respective case study.
The third level of monitoring is the more detailed one and the one to be favoured when possible since it considers the main variables influencing thermal comfort. We note that air velocity is an essential element of comfort in bioclimatic buildings, where comfort ventilation and natural night ventilation are among the main passive strategies. Hot sphere anemometers should be used in this context since they are sensitive to air velocity from all directions and are more robust compared to the more common hot wire anemometers.

POE questionnaires have also been carried out in order to track occupants' general satisfaction with the indoor environment. Due to the difficulty of managing the process, only of few POE could have been conducted.

The lessons learned from the different case studies have helped developing the final technical guidelines for future-proof bioclimatic and passive design in warm climates.

ABC21 is funded by the
EU's H2020 programme

Figure 2 gives the description of the level of monitoring for each of the 24 buildings of Phase 1 and Phase 2. We thus have:

- 4 buildings with level 1;
- 3 buildings with level 2;
- 12 buildings with level 3;
- 5 buildings with no monitoring.

Among the monitored buildings, some of them were instrumented before the start of ABC 21. The partners of the project kindly accepted to share their measured data (PoliMi, UR/PIMENT Laboratory and ESIROI, Izuba energies consulting company, Prof. Abderrahim Brakez of Cadi Ayyad University for Dar Nassim project in Morocco). Those data and the experimental feedback are reported in deliverable D3.9A. They are identified in the figure below with red dots.

The case studies with green and blud dots have been monitored during ABC 21. The sensors and weather stations have been financed by ABC21 except the buildings in La Reunion (ENERPOS, ESIROI and Moufia Lecture theatre) : for those case studies, the University of La Reunion has monitored the buildings with its own sensors/weather stations at level 3 and has kindly given the measured and analysed data at the disposal of ABC 21.

Figure 2 : Description of the level of monitoring by building for Phase 1 and Phase 2. The case studies with red dots have been monitored before ABC21. Measured data and experimental feedback for those buildings are presented in D3.9A. The ones with green dots have been monitored during ABC 21 with reliable data and are presented in this report. The ones with blue dots have been monitored during ABC 21 but the quality of the measured data was not sufficient and enough reliable to be presented in this report.

3. Selection of monitored case studies and contact persons by country and building project

Due to the difficulties encountered to install the sensors in the different buildings and to find the right people to collect and to analyse the data, as well as the limited time to finalize the deliverable, some choices have been made to select priority case studies and to present reliable data.
Table 2 presents the selected buildings and the people responsible of the monitoring phase.

Table 1 : Selected buildings and contact person by country for the monitoring phase during the ABC21 project.

Overall structure of the monitoring reports	Contact person	Institution	Email address
	Silvia Erba Virginie Grosdemouge	PoliMi UR	silvia.erba@polimi.it Virginie.grosdemouge@univ-reunion.fr
Project Name/Country	Contact person	Institution	Email address
EUROPE			
Patio house/ Italy	Alessio Battistella François Garde Lorenzo Pagliano Andrea Sangalli	PoliMi UR PoliMi	alessio.battistella@polimi.it francois.garde@univ-reunion.fr lorenzo.pagliano@polimi.it andrea.sangalli@polimi.it
Ruinha House/ Portugal	Alessio Battistella Virginie Grosdemouge	PoliMi UR	alessio.battistella@polimi.it Virginie.grosdemouge@univ-reunion.fr
LA REUNION			
ESIROI Building/ France (La Réunion)	Virginie Grosdemouge François Garde	UR	Virginie.grosdemouge@univ-reunion.fr francois.garde@univ-reunion.fr
Aimé Césaire School / France (La Réunion)			
Ilet du Centre / France (La Réunion)			
AFRICA			
Mbakadou primary School/Senegal	Virginie Grosdemouge Alessio Battistella Ernest Dione Silvia Erba	UR PoliMi DEEC	Virginie.grosdemouge@univ-reunion.fr alessio.battistella@polimi.it ernest.dione@gmail.com silvia.erba@polimi.it
Lycée Mermoz /Senegal	Ernest Dione François Garde	UR DEEC	ernest.dione@gmail.com francois.garde@univ-reunion.fr
CFP Nioro, Senegal	Ernest Dione François Garde	UR DEEC	ernest.dione@gmail.com francois.garde@univ-reunion.fr
UNON Building Kenya	Gian Luca Brunetti François Garde Vincent Kitio Andrea Sangalli	PoliMi UR UN Habitat	gianluca.brunetti@polimi.it francois.garde@univ-reunion.fr vincent.kitio@un.org
BIT building, Burkina	Andrea Sangalli, Silvia Erba, Humera Mughal	PoliMi PoliMI	andrea.sangalli@polimi.it silvia.erba@polimi.it mughalhumera2@gmail.com

ABC21 is funded by the EU's H2020 programme

	Lorenzo Pagliano Kossi Imbga Arnaud Valea	PoliMI PoliMI UNZ UNZ	lorenzo.pagliano@polimi.it kossiimbga@yahoo.fr watival2@gmail.com

ANNEX Part B

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

- Patio house (Italy);
- Ruinha House (Portugal);
- ESIROI Building (La Réunion);
- Aimé Cézaire primary school (La Réunion) ;
- Mbakadou primary School (Senegal) ;
- CFP Nio*ro* (Senegal) ;
- Lycée Mermoz (Senegal) ;
- UNON Building (Kenya) ;
- Burkina Institute of Technology (Burkina);
- *Ilet du Centre (La Réunion)*.*

STRUCTURE OF THE MONITORING TEMPLATE

THERMAL COMFORT MEASUREMENTS GUIDELINES AND POE QUESTIONNAIRE

**Ilet du Centre is a case study located in La Reunion that is presented in this document because of its specific features in terms of passive design. The monitored results presented do not follow the template of the other case studies. It seemed relevant to the authors to include the monitored results to highlight the efficiency of innovative passive strategies (buffer space, effect of vegetation).*

Africa-Europe Bioclimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

PATIO HOUSE - ITALY

ABC21 is funded by the
EU's H2020 programme

Authors

Name	Email	Institution
Alessio Dionigi Battistella	alessio.battistella@polimi.it	PoliMi

Revision

Version	Date	Author	Description of changes
V1	18.05.2023	Virginie Grosdemouge	Revision and modification
V2	03.01.2024	Lorenzo Pagliano	Revision and modification

CONTENTS

ABC21 is funded by the
EU's H2020 programme

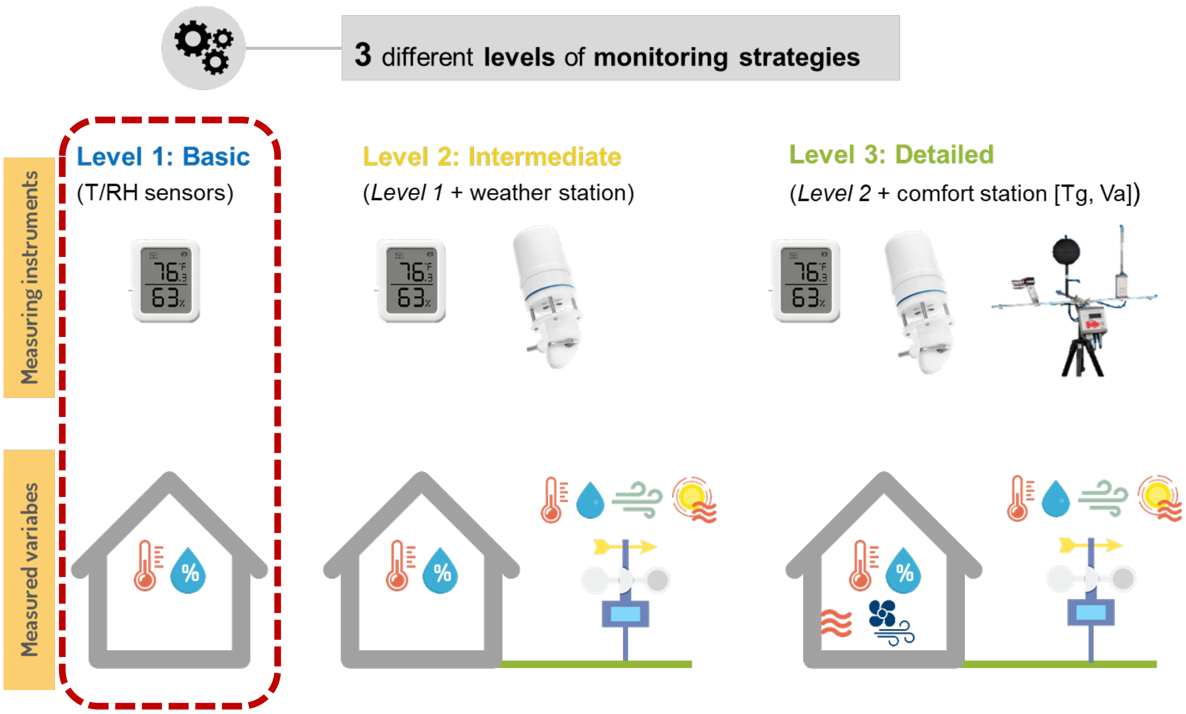
1. Presentation of the case study

This section gives a short description of the project

Name	Patio House
Architect / Designer	Arch. Michele Ricci, Ing. Giovanna Nardini
Location	39.217703, 8.374674
City	Portoscuso, (Sardinia)
Country	Italy
Building type	Residential
Climate zone (Köppen–Geiger)	CSA
Description	The project stems from the desire to create a sustainable and innovative building, in energy class A+ suitable for the Sardinian Mediterranean climate, made with natural materials. A safe, healthy and comfortable home: the client immediately requested a straw house. The architectural design was therefore based on choices that would optimize not only the quality of the spaces but also energy efficiency and environmental sustainability. The biggest problem was to create a building which, even if placed within a plot subdivision and therefore, an urbanized area, managed to maintain its privacy. The fulcrum of the project becomes the desire to create a private, intimate outdoor space. The traditional Sardinian house, especially that of the Sulcis area, had a courtyard, an external but private space, hence, the intention of resuming a classic typology typical of warm Mediterranean countries: the house with an internal courtyard. The patio is supposed to favor natural ventilation in summer.
Main bioclimatic strategies	Natural cross ventilation, nocturnal ventilative cooling, high level of insulation, inner courtyard for the formation of cool areas, optimal shape and optimized solar protection. External solar protection with movable slats are optimal for regulating light and solar access and for allowing ventilation while protecting from intrusion.

2. Material and method

2.1 Monitoring campaign level : Level 1



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: start date: 19/07/2022 End date: 09/01/2023

Collection of weather data:

- ✓ National weather station close to the site: distance from the site: 2.7 km
- ☐ TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield

Issues encountered:

- ✓ Missing data: 6%
- ☐ Shortage
- ☐ Wifi connection
- ☐ Others:

2.2.1 Sensors and weather station location

This section gives information about the location of the sensors inside the building.

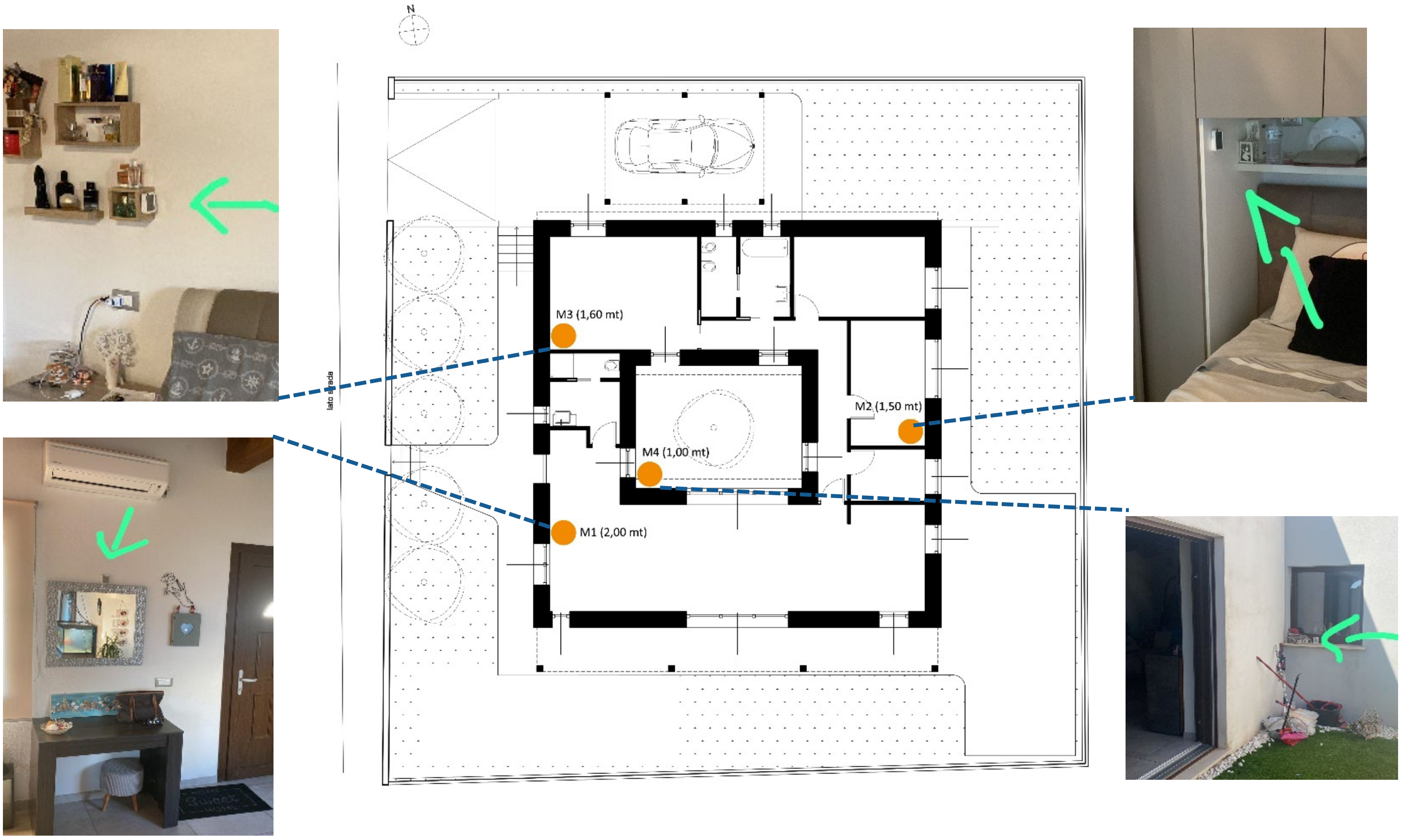


Figure1 : Sensors location for the Patio House (M1-Living Room, M2-Bedroom East, M3-Bedroom West, M4-Patio)

2.2.2 Sensors specification

Details about the sensors are given below:

Datasheet SHTC3

Humidity and Temperature Sensor IC

- Ultra-low power consumption
- Full battery supply voltage range (1.62 - 3.6 V)
- Small DFN package: 2 × 2 × 0.75 mm3
- Typical accuracy: ±2 %RH and ±0.2 °C
- Fully calibrated and reflow solderable
- Power-up and measurement within 1 ms
- NIST traceability

3. Results and discussion

3.1 Boxplot

Figure 2 and 3 below presents the boxplots of air temperature for all the studied rooms over the total period of measurements as well as the one for the outdoor conditions from the T/RH sensors. Figure 2 presents the boxplots in summer whereas Figure 3 presents the ones in winter. In both periods, one can see that the indoor conditions are very stable either in winter (median temperatures are around 22°C) and in summer (median indoor temperatures around 27°C).

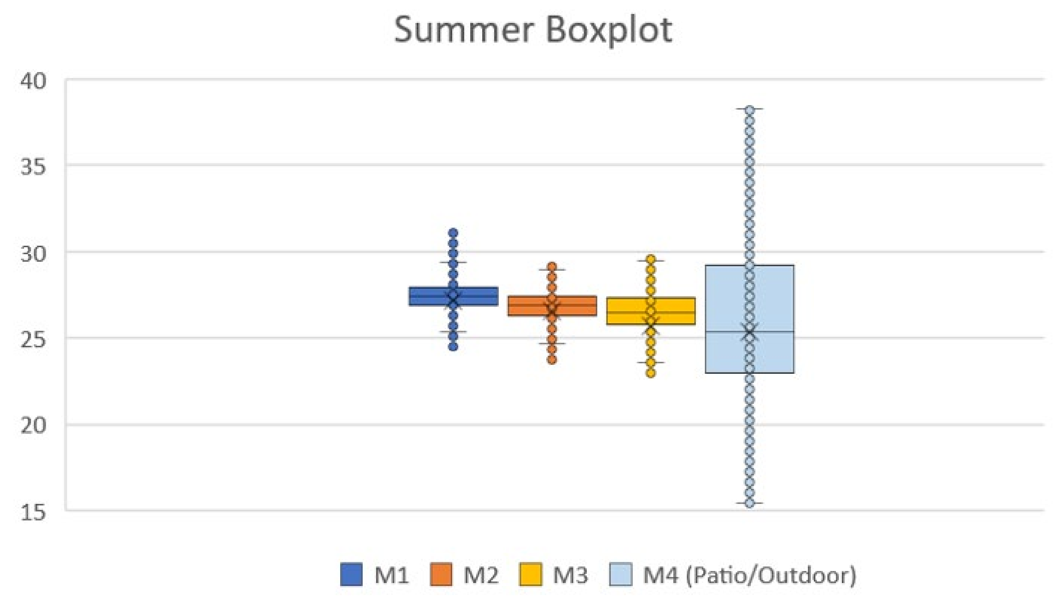


Figure 2 : Boxplot of the air temperature for the indoor and outdoor conditions from the 19th of July to the 30th of September for the Patio House (M1-Living Room, M2-Bedroom East, M3-Bedroom West, M4-Patio)

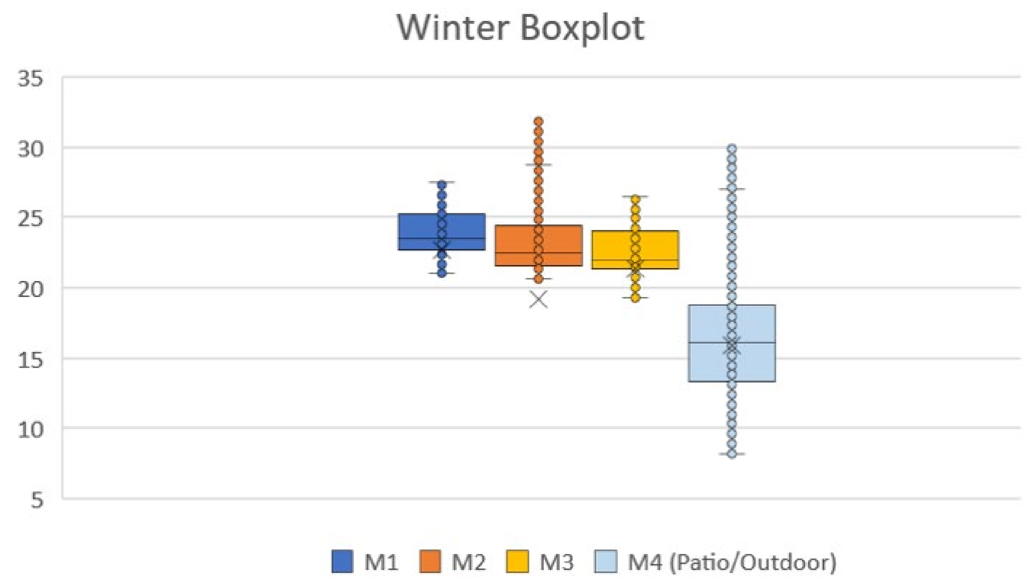
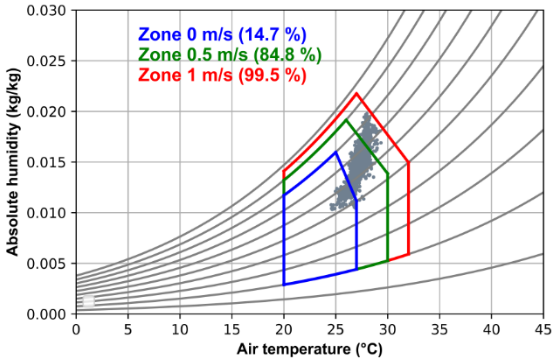


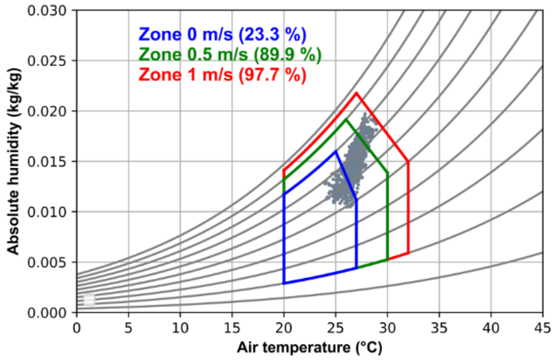
Figure 3: Boxplot of the air temperature for the indoor and outdoor conditions from the 1st of October to the 9th of January for the Patio House (M1-Living Room, M2-Bedroom East, M3-Bedroom West, M4-Patio)

3.2 Givoni comfort zone

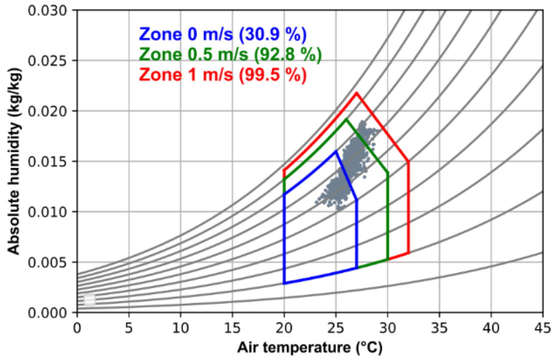
Figure 4 below shows the Givoni comfort zone for each room over the total period of measurements as well as the one for the outdoor conditions over the same period during the occupied hours.



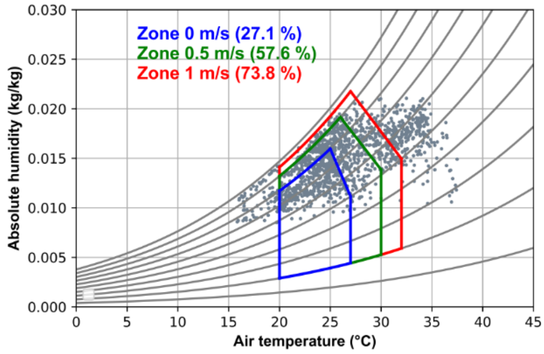
(a) M1-Living Room



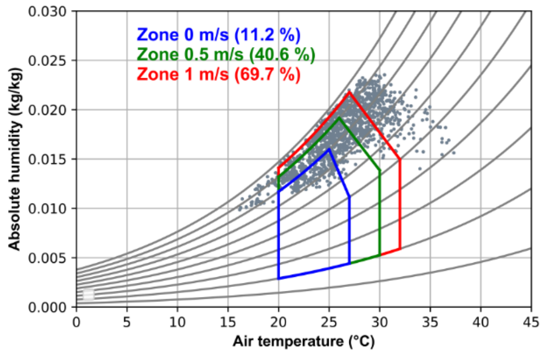
(b) M2-Bedroom East



(c) M3-Bedroom West



(d) M4-Patio



(e) Weather station

Figure 4: Givoni comfort zones for the conditions for the sensor (a) M1, (b) M2 ,(c) M3 ,(d) M4 (e) Weather Station from the 1st of August to the 30th September for the Patio House

Figures 4 (a), (b) and (c) point out that the comfort conditions are satisfying in all the spaces inside the house, with 99% of the air temperature and relative humidity pairs inside the Givoni comfort zone with air velocity at 1 m/s. That means that the occupants can be in comfort with an air velocity of 1 m/s in the spaces that can be created by opening the windows and generating a natural cross ventilation that we assume possible thanks the constant and strong prevailing wind (see Figure 5). In windless hours, and or indoor temperature higher than outdoor we suggest to install and use ceiling fans in all spaces (one fan/bedroom and two fans for the living room).
The outside conditions in the patio are very similar to the airport with hot and humid conditions, certainly because of the proximity of the Mediterranean See. The patio does not act as a buffer space, certainly because of the lack of solar shading. We suggest to

install in the patio retractable solar shades in textile and/or plant a native tree in the patio, as planned in the original project, see renderings and preliminary drawings in the project description.

Number of hours / frequency within a certain temperature range

The table below lists the frequency (Fq) within a certain temperature range calculated for all the monitored rooms and for the outdoor conditions during the occupied hours. One can observed positively that the air temperature does not exceed 30°C in any of the rooms, despite the hot conditions in the patio (100 hours observed above 30°C).

Hot period (1st Aug. to 30th Sep. 2022) Occupation time: 6:00pm to 8:00pm	M1 (Living room)		M2 (bed East)	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<22°C	**0**	0%	**0**	0%
22°C≤Ta<24°C	**0**	0%	**0**	0%
24°C≤Ta<26°C	**86**	8,3%	**176**	17,2%
26°C≤Ta<28°C	**801**	77,8%	**798**	77,8%
28°C≤Ta<30°C	**143**	13,9%	**52**	5,1%
30°C≤Ta<32°C	**0**	0%	**0**	0%
32°C≤Ta<34°C	**0**	0%	**0**	0%
34°C≤Ta<36°C	**0**	0%	**0**	0%
Ta≥36°C	**0**	0%	**0**	0%
Hot period (1st Aug. to 30th Sep. 2022) Occupation time: 6:00pm to 8:00pm	M3 (bed West)		M4 (Patio)	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<22°C	**0**	0%	**209**	20,6%
22°C≤Ta<24°C	**11**	1,1%	**206**	20,3%
24°C≤Ta<26°C	**283**	27,8%	**269**	26,5%
26°C≤Ta<28°C	**692**	68%	**136**	13,4%
28°C≤Ta<30°C	**32**	3,1%	**85**	8,4%
30°C≤Ta<32°C	**0**	0%	**60**	5,9%
32°C≤Ta<34°C	**0**	0%	**36**	3,5%
34°C≤Ta<36°C	**0**	0%	**14**	1,4%
Ta≥36°C	**0**	0%	**1**	0,1%

Hot period (1st Aug. to 30th Sep. 2022) Occupation time: 6:00pm to 8:00pm	OUTDOOR (weather station)	
Range	Nb of Hours	Frequency
Ta<22°C	**167**	16,3%
22°C≤Ta<24°C	**138**	13,5%
24°C≤Ta<26°C	**284**	27,8%
26°C≤Ta<28°C	**251**	24,6%
28°C≤Ta<30°C	**130**	12,7%
30°C≤Ta<32°C	**42**	4,1%
32°C≤Ta<34°C	**9**	0,9%
34°C≤Ta<36°C	**1**	0,1%
Ta≥36°C	**0**	0%

3.3 Number of hours / frequency by relative humidity range (all level of monitoring)

The table below lists the frequency by bins of 10% of RH for all the monitored rooms and for the outdoor conditions during the occupied hours. As already observed in section 2, the outdoor conditions in the patio are very humid compared to the bedroom ones.

Hot period (1st Aug. to 30th Sep. 2022) Occupation time: 6:00pm to 8:00pm	M1		M2	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
[0,10%[	**0**	0%	**0**	0%
[10,20%[	**0**	0%	**0**	0%
[20,30%[	**0**	0%	**0**	0%
[30,40%[	**0**	0%	**0**	0%
[40,50%[	**8**	0,8%	**8**	0,8%
[50,60%[	**189**	18.1%	**146**	13,7%
[60,70%[	**538**	51.6%	**542**	50,9%
[70,80%[	**295**	28.3%	**356**	33,5%
[80,90%[	**12**	1.2%	**12**	1,1%
[90,100%[	**0**	0%	**0**	0%
Hot period (1st Aug. to 30th Sep. 2022) Occupation time: 6:00pm to 8:00pm	M3		M4	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
[0,10%[	**0**	0%	**0**	0%
[10,20%[	**0**	0%	**0**	0%
[20,30%[	**0**	0%	**0**	0%
[30,40%[	**0**	0%	**3**	0,3%
[40,50%[	**0**	0%	**24**	2,4%
[50,60%[	**79**	7,4%	**120**	11,8%
[60,70%[	**526**	49,1%	**222**	21.8%
[70,80%[	**458**	42,8%	**283**	27,8%
[80,90%[	**8**	0,7%	**279**	27,4%
[90,100%[	**0**	0%	**88**	8.6%

Hot period (1st Aug. to 30th Sep. 2022) Occupation time: 6:00pm to 8:00pm	OUTDOOR	
Range	Nb of Hours	Frequency
[0,10%[	**0**	0%
[10,20%[	**0**	0%
[20,30%[	**0**	0%
[30,40%[	**0**	0%
[40,50%[	**1**	0,1%
[50,60%[	**10**	1%
[60,70%[	**62**	5,9%
[70,80%[	**269**	25,7%
[80,90%[	**438**	41,9%
[90,100%[	**265**	25,4%

3.4 Analysis of a representative week

3.4.1 Solar radiation profile

Data is not available.

3.4.2 Wind profile

Wind speed measured by the weather station has been plotted for the selected typical hot week and is represented in Fig.5. We can see how the wind velocity reaches significantly high values and presents a certain variability. This observation is consistent with the case study being very close to the sea. It might provide an important driver for diurnal *comfort ventilation* and *nocturnal ventilative cooling.*

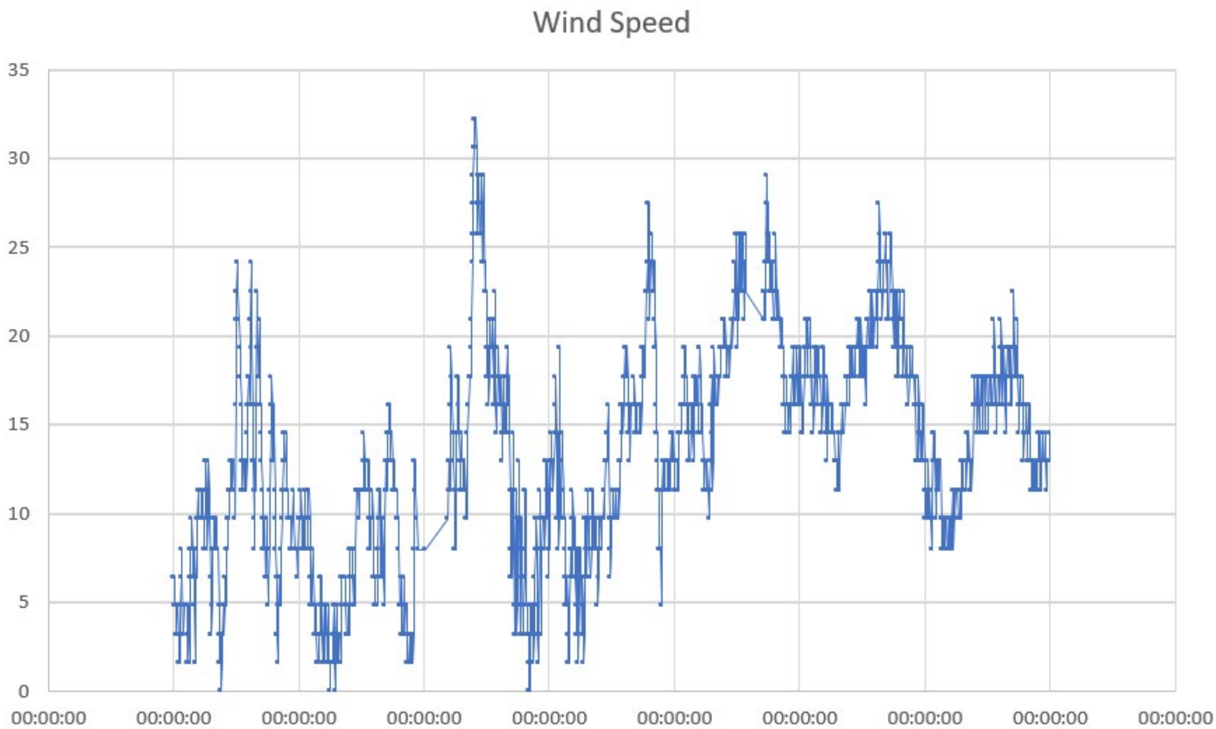


Figure 5 : Wind speed profiles in km/h from the 15th August to 21th August 2022.

3.4.3 Air temperature profile

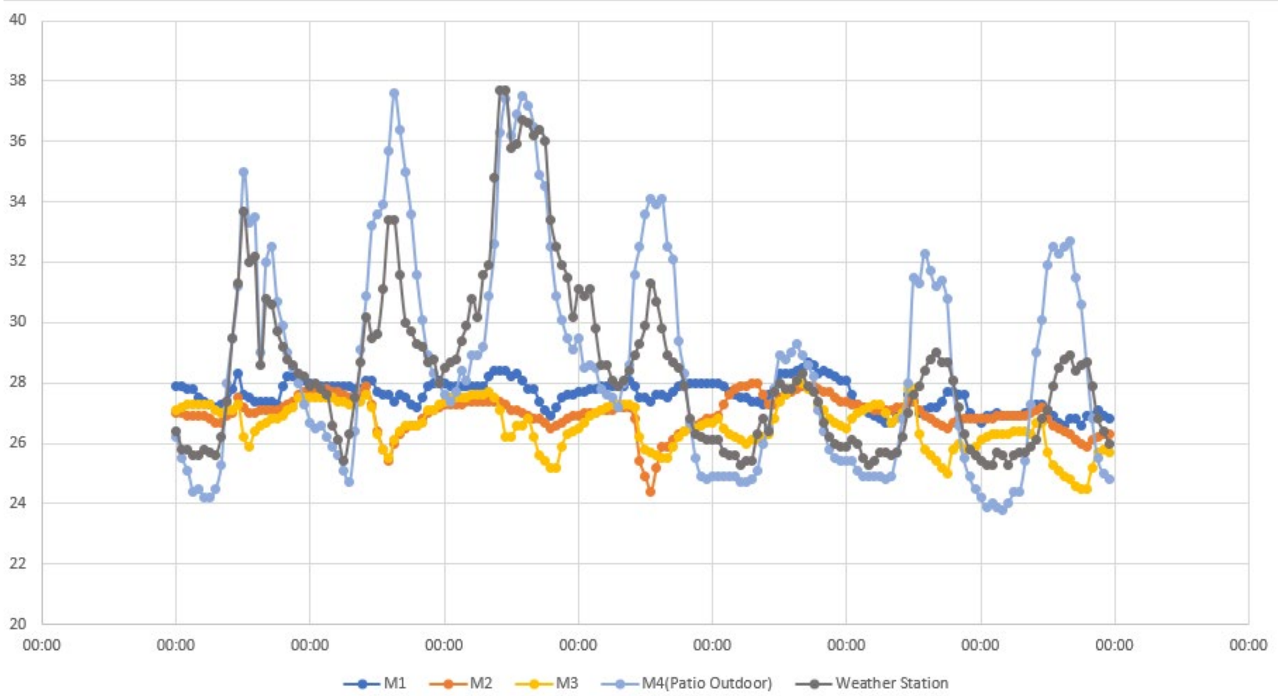


Figure 6 : Air temperature profiles for the Patio House from the 15th August to 21th August 2022 M1-Living Room, M2-Bedroom East, M3-Bedroom West, M4-Patio

From Figure 6, it can be observed that the temperatures inside the rooms are on average, fluctuating by a maximum of 3 degrees during different times of the day. In the patio, however, we can see a peculiar situation, where the microclimate generated by the space often reaches higher temperatures than those measured by the weather station.

The differences between outdoor and indoor temperatures can reach considerable peaks over 9 degrees at certain times of the day.

In this graph, it can also be seen that between 1 p.m. and 6 p.m. an air conditioner is turned on in the bedrooms.

4. Lessons learnt and recommendations.

The monitoring was initially planned for situations where AC would be of. This did not prove possible since the week of measurements coincided with a particularly hot period, with a couple of days with minimum temperatures at night of 28 °C. Hence AC was turned on between 1 p.m. and 6 p.m in the bedrooms.

Consequently it is difficult to disentangle the effect of the envelope and passive techniques from the one of the active AC. We notice anyway that the air conditioning is activated just for a few hours, even in a challenging weather condition, with outdoor max reaching 34-38 °C and night temperature never falling below 25-26 °C. Passive features appear able to attenuate the impact of the heat wave. PV on the roof might supply energy for the few hours when AC is turned on, during the hot hours of the afternoon.

On the contrary the patio does not seem to play its role of buffer space in summer as initially planned by the architects, probably because of the lack of solar shading systems. The outdoor conditions inside the patio are very similar to the airport ones,. We would point out, however, that in the original design a tree was planned on the patio.

Recommendations:

Patio: we recommend lowering the outdoor temperature in summer by planting a tree (deciduous tree, pergola with wine tree), and to install a retractable shading system in textile or pergola with fixed or rotating louvres (see pictures below). A tree in the courtyard was indeed foreseen in the project.

Insert connection to a cold sink: earth to air heat exchanger, ground at 5 m depth (temperature of the soil at 5-6 m depth is stable and equal to the average air temperature over the year, in this area between 16 and 17 °C; if a ground exchanger would be situated at a lower depth, the temperature of the soil can be kept low by shading and by watering periodically the surface, to benefit of evaporative cooling), evaporative cooling being hindered by humidity.

Pergola with fixed slats

Sun shade sails

Retractable awning

Bioclimatic pergola with rotating louvres

Patio with tree

Patio with green pergola

Figure 1 : Suggested solutions for shading the patio.

Bedrooms and living room: to avoid or to reduce the use of AC, we recommend to install ceiling fans in all indoors spaces (one for each bedroom and 2 for the living room). The ratio is one ceiling fan/ 10 m^2. Once the courtyard would be shaded it would be useful to have a ceiling fan also there.
External solar protection with movable slats are optimal for regulating light and solar access and for allowing ventilation while protecting from intrusion. In case absent on some of the openings they should be added, and an effective operating strategy should be integrated by the users of the house.

Increase the inertia of the straw wall: by increasing the thickness of the interior clay-based plaster or even through a single-row brick wall.

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

RUINHA HOUSE - PORTUGAL

ABC21 is funded by the EU's H2020 programme

Authors

Name	Email	Institution
Alessio Dionigi Battistella	alessio.battistella@polimi.it	PoliMi
Lorenzo Pagliano	lorenzo.pagliano@polimi.it	PoliMI

Revision

Version	Date	Author	Description of changes
V1	18.05.2023	Virginie Grosdemouge	Revision and modification
V2	15.09.2023	Alessio Battistella, Lorenzo Pagliano	Revision and modification
V3	05.01.2024	Alessio Battistella, Lorenzo Pagliano	Revision and modification

CONTENTS

ABC21 is funded by the
EU's H2020 programme

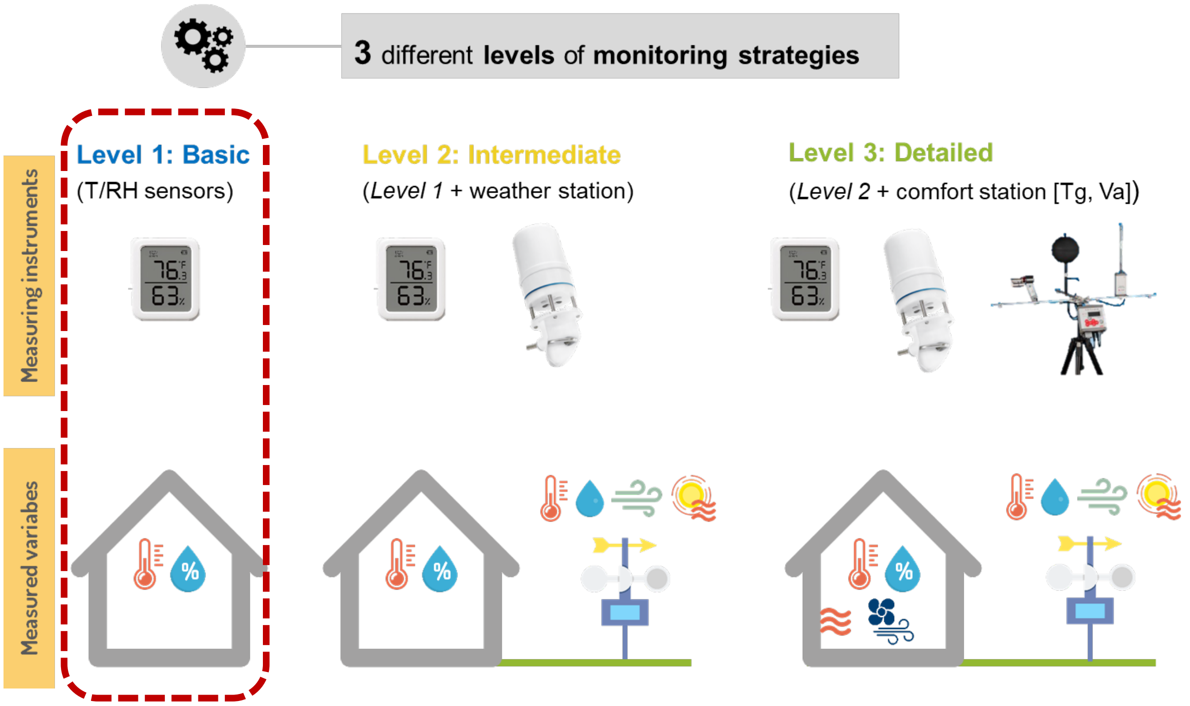
1. Presentation of the case study

Name	Ruinha House
Architect / Designer	Tania Teixeira/ CRU Atelier
Location	37.64812, -8021353
City	Montemor-o-Novo
Country	Portugal
Building type	Residential, isolated or semi-detached house, Terraced individual housing, Villas (row house in city center)
Climate zone (Köppen–Geiger)	Cwa
Description	Is a self built refurbishment. The house with a floor area around 100 m^2 is located in a very old and narrow street, an entrance patio was predicted to function as a buffer zone articulating exterior and interior, public and private zones. The rusted metal doors and window allow light and wind to cross. The patio catches the south light and brings it in all day long, in a house that is oriented east-west. In the patio there is an outdoor kitchen and storage space. The patio leads to the main room. The high windows help cross ventilate the room and release hot air.
Main bioclimatic strategies	Winter: thermal inertia provided by thick rammed earth walls and earth lime plasters; thick thermal insulation of the roof (16 cm thick mat made of recycled cotton tissues); solar gains complement

	the radiant floor heating, with hot water supplied by a heat pump and from time to time by a wood stove. Summer: thermal inertia provided by thick rammed earth walls and earth lime plasters; thick thermal insulation of the roof; external shading of glazed surfaces, cross ventilation between the façade on patio and the one facing the garden allows *nocturnal ventilative cooling* (and *comfort ventilation* during daytime when outdoor conditions are favorable).

2. Material and method

2.1 Monitoring campaign level: level 1



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: start date: 22/06/2022 end date: 26/04/2023

Collection of weather data: (please tick the right option)

- ✓ National weather station close to the site, at around 27,2 km, in Evora.
- ☐ TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield

Issues encountered: (please tick the right option and complete if needed)

- ✓ Missing data: 12% (add information)
- ☐ Shortage
- ☐ Wifi connection
- ☐ Others:

2.2.1 Sensors and weather station location

This section gives information about the location of the sensors inside and outside the building.

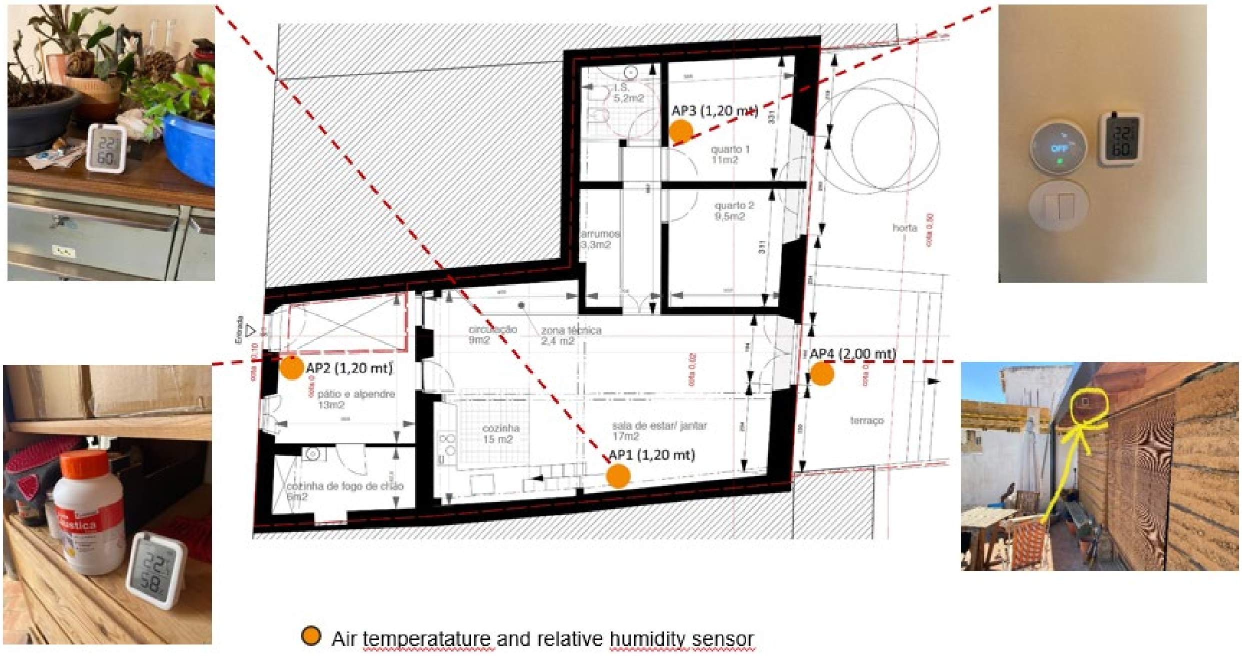


Figure 1: Sensors location for the Ruinha House.

2.2.2 Sensors specification

Details about the sensors are given below:

Datasheet SHTC3
Humidity and Temperature Sensor IC

- Ultra-low power consumption
- Full battery supply voltage range (1.62 - 3.6 V)
- Small DFN package: 2 × 2 × 0.75 mm3
- Typical accuracy: ±2 %RH and ±0.2 °C
- Fully calibrated and reflow solderable
- Power-up and measurement within 1 ms
- NIST traceability

2.3 Post Occupancy Evaluation Surveys

The surveys were conducted from 06/09/2022 until 17/10/2022. They were usually done in the morning around 10 am or around 10 pm for a total of 7 responses.
They were made mainly by the family living in the building (one man and one woman around 38 years old).

3. Results and discussion

3.1 Boxplot

Figures 2 and 3 below presents the boxplots of air temperature for all the studied rooms over the total period of measurements as well as the one for the outdoor conditions from the T/RH sensors. Figure 2 presents the boxplots in summer whereas Figure 3 presents the ones in winter. In both periods, one can see that the indoor conditions are very stable either in winter (temperatures are around 20°C) and in summer (indoor temperatures around 25°C).

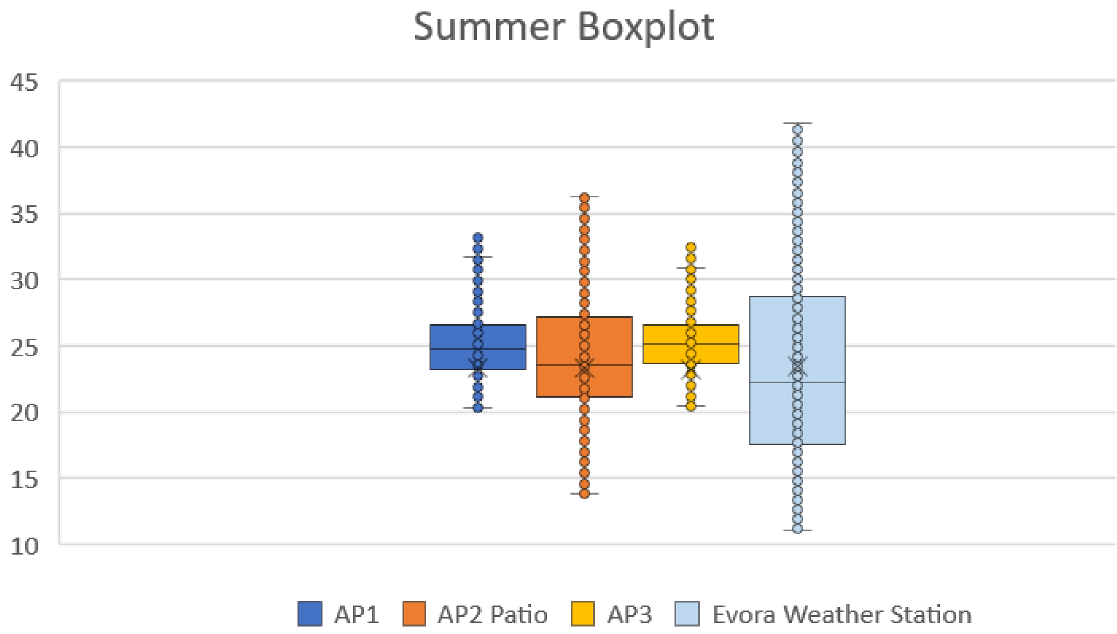


Figure 2: Boxplot of the air temperature for the indoor and outdoor conditions from the 26th of June to the 30th of September for the Ruinha House (AP1-Living room, AP2-Patio, AP3-Bedroom, Evora Weather Station)

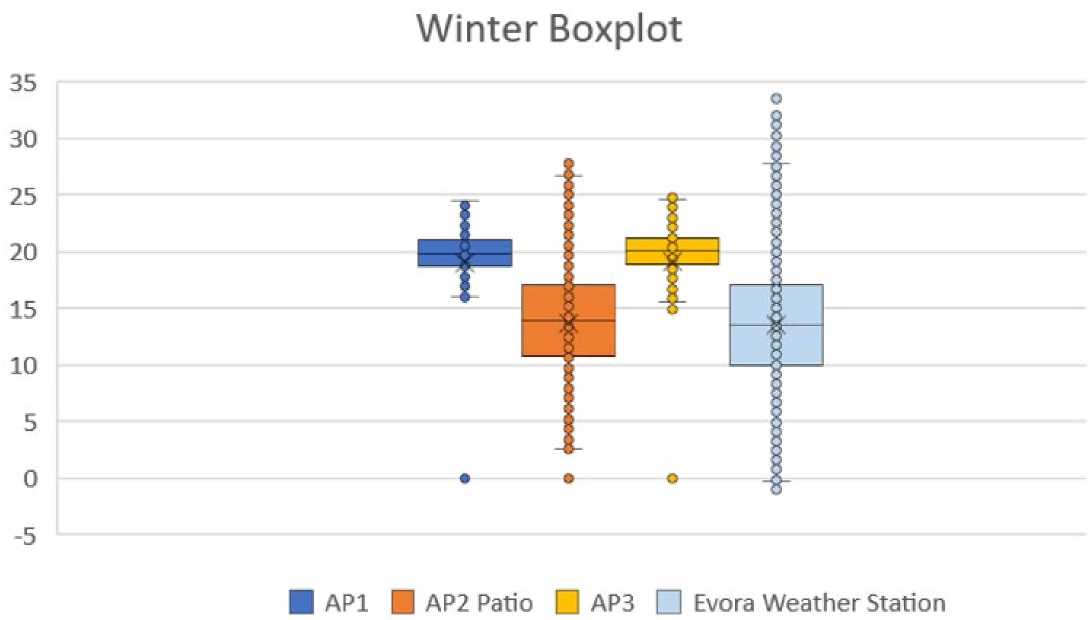
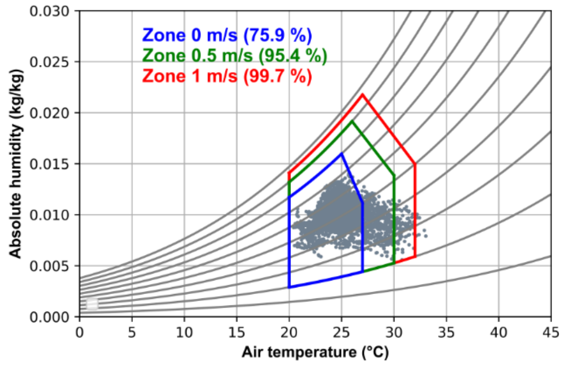


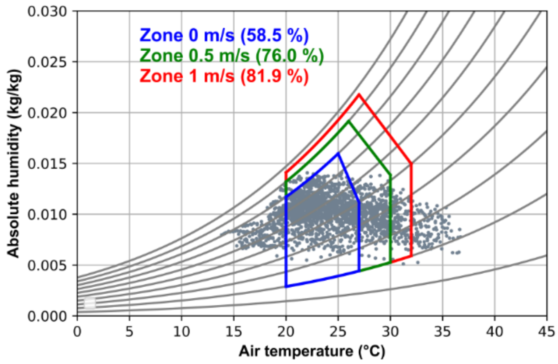
Figure 3: Boxplot of the air temperature for the indoor and outdoor conditions from the 1st of october to the 26th of April for the Ruinha House (AP1-Living room, AP2-Patio, AP3-Bedroom, Evora Weather Station)

3.2 Givoni comfort zone (Level 1, 2 & 3)

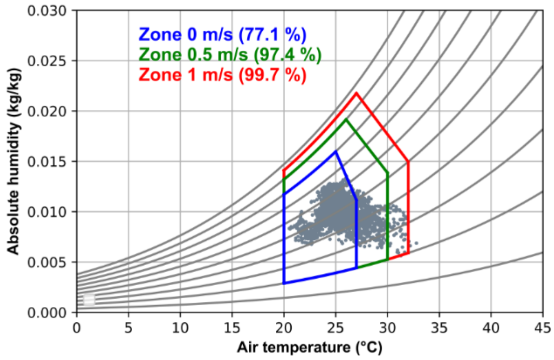
Fig. 4 below shows the Givoni comfort zone for each room for the summer period as well as the one for the outdoor conditions over the same period during the occupied hours.



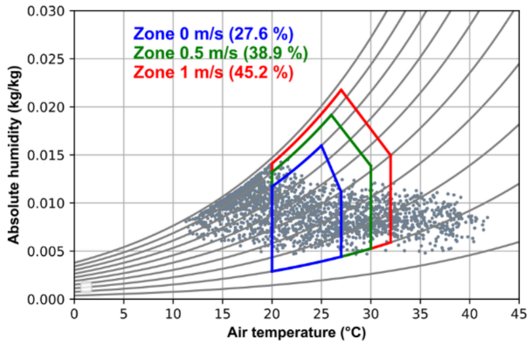
(a) AP1-Living Room



(b) AP2-Patio



(c) AP3-Bedroom



(d) Evora Weather Station

Figure 2: Givoni comfort zones for the conditions for the sensor (a) AP1, (b) AP2,(c) AP3 ,(d) Weather Station from the 28ht of June to the 30th September for the Ruinha House

3.3.1 Number of hours / frequency within a certain temperature range

The table below lists the frequency (Fq) within a certain temperature range calculated for all the monitored rooms and for the outdoor conditions during the occupied hours. It can be observed that the temperature is on average regular below 30 degrees. Outdoors, temperatures above 36 degrees are also reached, while in the building the temperature drop is considerable, as highs are around 32 degrees.

Hot period (28th Jun.to 30th Sep. 2022) Occupation time: 6:00 pm to 8:00am	AP1 (Living room)		AP2 (Patio)	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<22°C	**87**	5.3%	**554**	34.1%
22°C≤Ta<24°C	**392**	24,1%	**328**	20,2%
24°C≤Ta<26°C	**587**	36%	**240**	14,8%
26°C≤Ta<28°C	**292**	17.9%	**174**	10,7%
28°C≤Ta<30°C	**186**	11.4%	**156**	9,6%
30°C≤Ta<32°C	**78**	4.8%	**88**	5,4%
32°C≤Ta<34°C	**7**	0.4%	**55**	3,4%
34°C≤Ta<36°C	**0**	0%	**26**	1,6%
Ta≥36°C	**0**	0%	**6**	0,4%

Hot period (28th Jun.to 30th Sep. 2022) Occupation time: 6:00 pm to 8:00am	AP3 (Bedroom)		OUTDOOR (Weather station)	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<22°C	**51**	3.1%	**986**	59%
22°C≤Ta<24°C	**262**	16.1%	**150**	9%
24°C≤Ta<26°C	**687**	42.1%	**106**	6,3%
26°C≤Ta<28°C	**415**	25.5%	**110**	6,6%
28°C≤Ta<30°C	**179**	11%	**83**	5%
30°C≤Ta<32°C	**35**	2.1%	**75**	4,5%
32°C≤Ta<34°C	**1**	0%	**59**	3,5%
34°C≤Ta<36°C	**0**	0%	**41**	2,5%
Ta≥36°C	**0**	0%	**61**	3,7%

3.3.2 Number of hours / frequency by relative humidity range

The table below lists the frequency by bins of 10% of RH for all the monitored rooms and for the outdoor conditions during the occupied hours. It can be observed, the outdoor conditions, in the patio and in weather station measurements, are very humid compared to the internal ones.

Hot period (28th Jun.to 30th Sep. 2022) Occupation time: 6:00 pm to 8:00am	AP1 (Living room)		AP2 (Patio)	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
[0,10%[	**0**	0%	**0**	0%
[10,20%[	**0**	0%	**4**	0.2%
[20,30%[	**53**	3.2%	**96**	5.8%
[30,40%[	**263**	15.9%	**216**	13.1%
[40,50%[	**519**	31.3%	**293**	17.8%
[50,60%[	**637**	38.4%	**355**	21.6%
[60,70%[	**185**	11.2%	**411**	25%
[70,80%[	**2**	0.1%	**236**	14.3%
[80,90%[	**0**	0%	**35**	2.1%
[90,100%[	**0**	0%	**0**	0%

Hot period (28th Jun.to 30th Sep. 2022) Occupation time: 6:00 pm to 8:00am	AP3 (Bedroom)		OUTDOOR (weather station)	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
[0,10%[	**0**	0%	**0**	0%
[10,20%[	**0**	0%	**43**	2.6%
[20,30%[	**24**	1.4%	**189**	11.3%
[30,40%[	**251**	14.9%	**250**	14.9%
[40,50%[	**707**	42%	**160**	9.6%
[50,60%[	**570**	33.9%	**158**	9.4%
[60,70%[	**131**	7.8%	**134**	8%
[70,80%[	**0**	0%	**171**	10.2%
[80,90%[	**0**	0%	**197**	11.8%
[90,100%[	**0**	0%	**372**	22.2%

3.4 Analysis of a representative week

3.4.1 Solar radiation profile

Global solar radiation measured by the closest weather station has been plotted **for a typical hot week. The selected days were sunny days with a peak of around 1000W/m².**

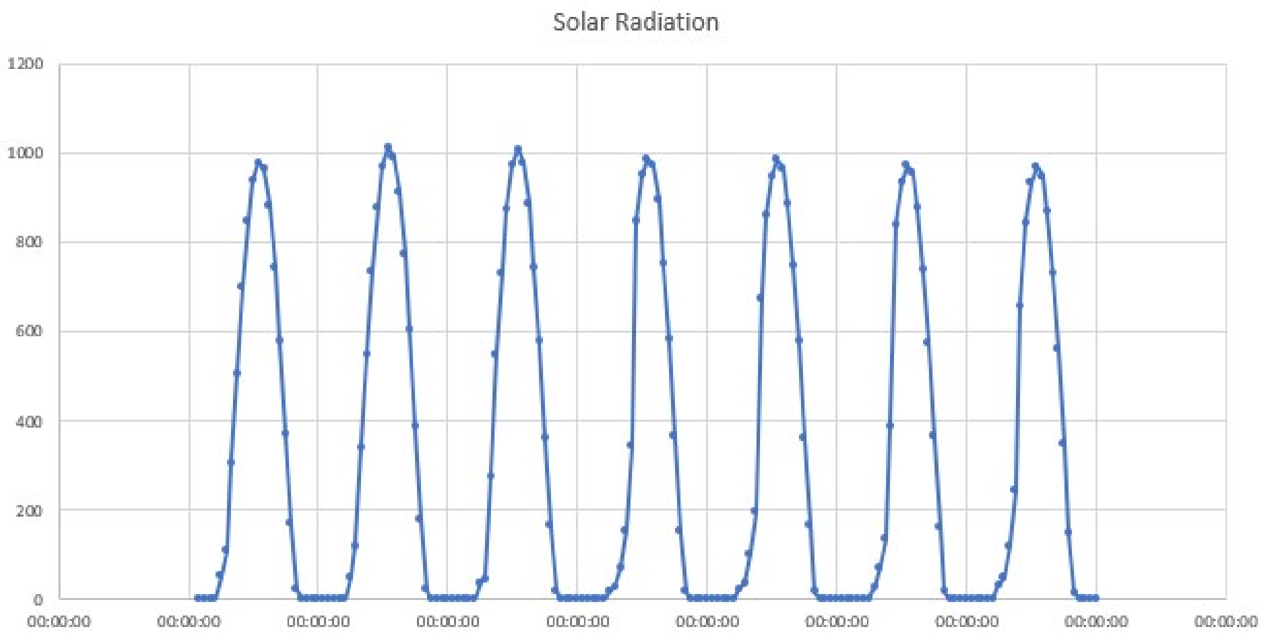


Figure 5: Solar radiation profiles (in W/m²) for the Ruinha House from the 1st August. to 7th August 2022.

3.4.2 Wind profile

Wind speed measured by the weather station on site has been plotted for the same typical hot week than section before. It can be observed how the wind was at a constant and almost always optimal speed throughout the entire week. It is not a very strong wind but given its constancy and intensity we can infer that it might positively affect the indoor comfort of the building.

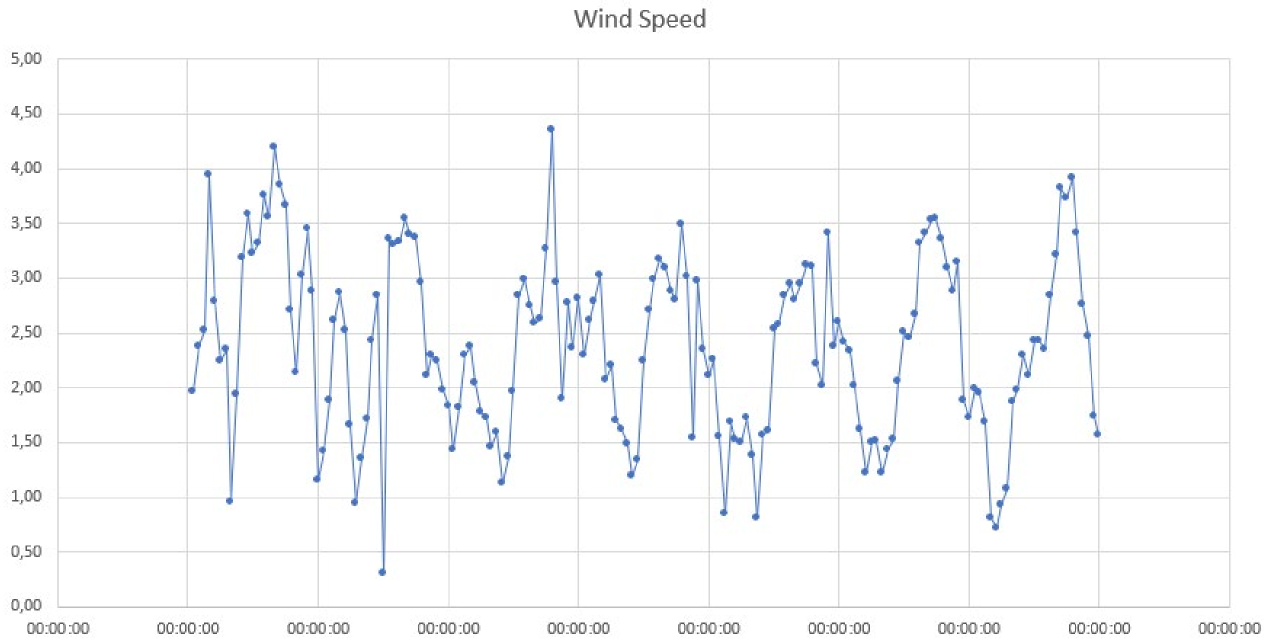


Figure 6: Wind speed profiles in m/s from the 1st Augst. to 7th Aug 2022.

3.4.3 Air temperature profile

From Fig. 7, it can be observed that the temperatures inside the rooms are on average regular with fluctuations between 3/5 degrees during different times of the day.

The patio, on the other hand, shows partial mitigation of temperatures, with a difference of approximately 3 degrees during the hot times of the day and a greater difference during the night-time hours.

Differences between outdoor and indoor temperatures can reach considerable peaks over 8 degrees at some times of the day during the daytime part and as much as 12 degrees during the night-time hours.

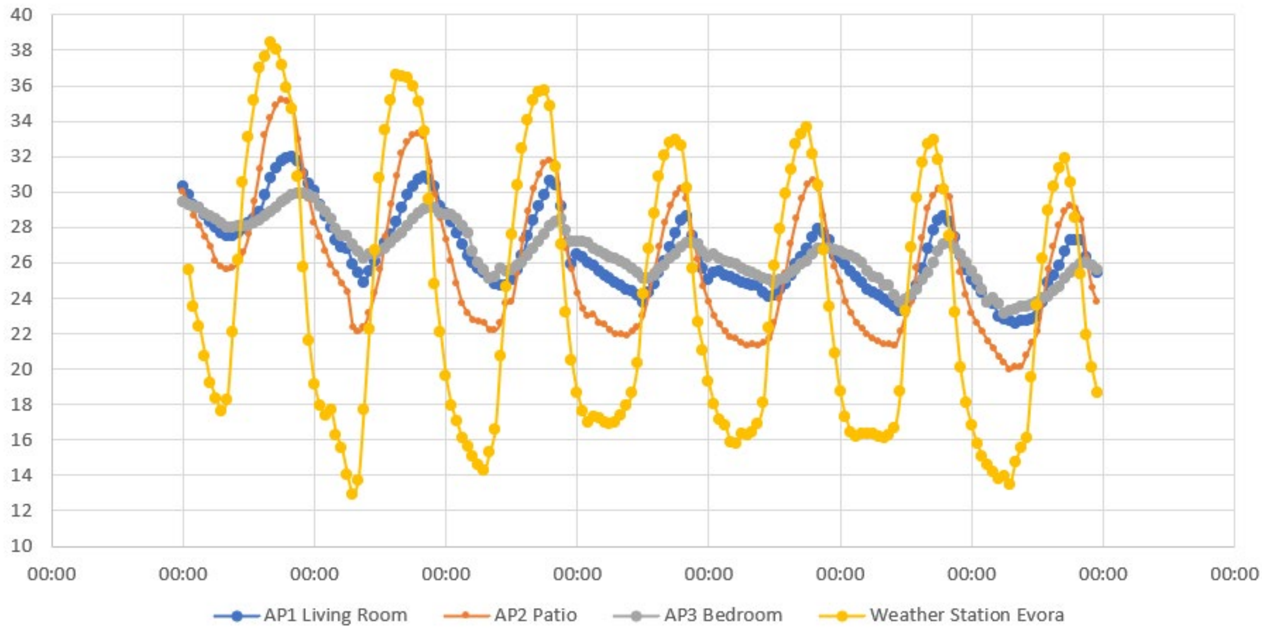


Figure 7: Air temperature profiles for the Ruinha House from the 1st August. to 7th Aug 2022. AP1-Living Room, AP2-Patio, AP3-Bedroom, Evora Weather Station

4 Lessons learnt and recommendations

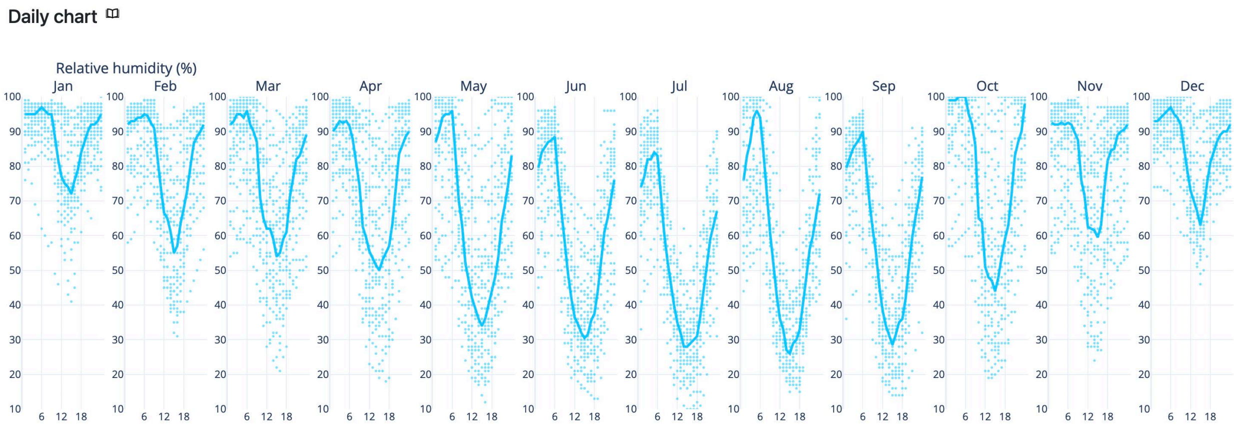
Thanks to the bioclimatic design (large thermal capacity of walls, external shading, thermal buffer of the patio, thermal insulation of the roof) and passive techniques (night ventilative cooling) summer comfort conditions are within the Adaptive or Givoni comfort range; during the hottest hours of the day comfort conditions can be met if an air velocity of 1 m/s can be achieved

We did not measure air velocity indoor, but it is possible that this velocity might not be achievable all the time by cross ventilation and/or it would be counterproductive (by bringing indoor air too hot) with respect to the benefits of *night ventilative cooling*.

An easy improvement of the passive cooling strategy, in hot hours of the day, would hence be to close windows to limit the intake of hot air and achieve air velocity of around 1 m/s by installing and using ceiling fans appropriately sized and positioned, and thus complete the *comfort ventilation strategy.*

Complementary strategies which might additionally ameliorate summer conditions at hot daytime hours are:

- Additional shading of the garden and patio by deciduous trees or climbing plants on trellises
- A ground exchanger for pre-cooling intake air during the day
- Evaporative cooling, e.g. in the patio, during the hot hours of the day, when relative humidity is at low level, might create a cool space.



.

Africa-Europe Bioclimatic Collaboration 21

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

ESIROI – LA REUNION

ABC21 is funded by the EU's H2020 programme

Authors

Name	Email	Institution
Virginie Grosdemouge	Virginie.grosdemouge@univ-reunion.fr	UR
François Garde	francois.garde@univ-reunion.fr	UR

Revision

Version	Date	Author	Description of changes
V0	09.05.2023	Virginie Grosdemouge and François Garde	Draft version
V1	30.05.2023	Virginie Grosdemouge and François GARDE	Updated version

CONTENTS

ABC21 is funded by the
EU's H2020 programme

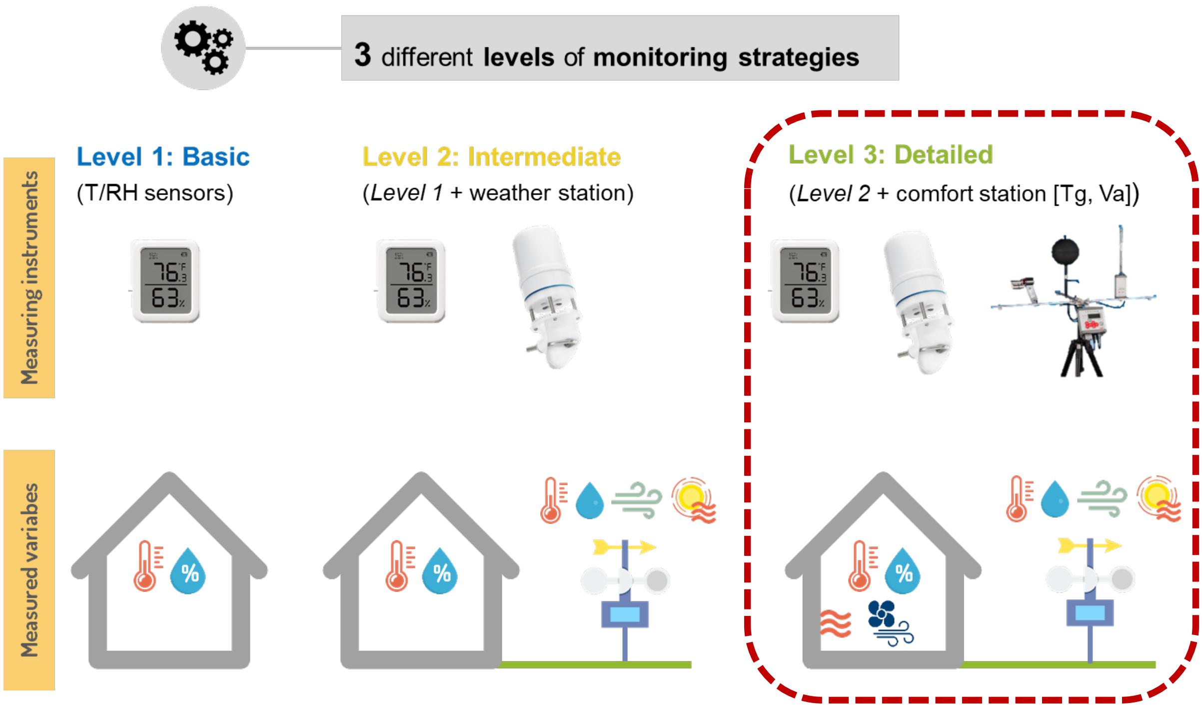
1. Presentation of the ESIROI building

Name	ESIROI building
Architect / Designer	LAB Réunion
Location	-21.340, 55.491
City	Saint-Pierre
Country	La Reunion, France
Building type	Educational
Climate zone (Köppen–Geiger)	Aw
Description	The new building of the ESIROI (Ecole Supérieure d'Ingénieurs Réunion Océan Indien) is a bioclimatic Net Zero Energy Building located at the Terre-Sainte university campus, in the city of Saint-Pierre of Reunion Island. It offers innovative architectural solutions that cope with the vagaries of a humid tropical climate, while being as environmentally friendly as possible, and ensuring a working environment at the forefront of innovation and comfortable for these new users. The main feature of this building is that the wind has been the main source of inspiration for its design. Thanks to a weather station installed on site, the trade winds during the working hours and during the three hottest months could have been identified. Thus, the building has a "C" shape that faces the eastern trade winds, which creates a high pressure zone inside it and low pressure around the main facades. Thanks to this design, there is always a difference of pressure in all the spaces that are naturally cross ventilated and that created a constant air velocity that can be adjusted thanks to large vertical glass louvers. The vertical louvers are opened or closed by the users during day-time function on the comfort conditions. This design influenced by the wind has been validated and optimized in thanks to studies conducted in the wind tunnel testing facility "Laboratoire aérodynamique Eiffel". The choice of a mixed metal / light wall structure as an alternative to all-concrete, and the importance of vegetation within the project are examples of solutions that demonstrate the strong desire to reduce its environmental impact. Like the future engineers who will be trained there, ESIROI demonstrates the local know-how in terms of bioclimatic design in tropical areas.
Main bioclimatic strategies	A design inspired by the trade winds and the traditional creole architecture. There is a thermal zoning of spaces function of the design strategy : All bioclimatic spaces are naturally cross ventilated with low inertia materials, vertical louvers, large and solar blades detached from the openings to encourage natural light. Air conditioned spaces are located at the ground floor to minimize the solar gains. At this level, all conditioned spaces are made with concrete walls with high inertia. Dense vegetation is planted around the building. Ceiling fans are installed in all spaces. A 100 kWp Builgin Integrated PV plant balances the low consumption of the building.

ABC21 is funded by the EU's H2020 programme

2. Material and method

2.1 Monitoring campaign level



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: Start date: 01/03/2022 - End date: 01/03/2023

Collection of weather data:

- ☐ National weather station close to the site - distance from the site: …km
- ☐ TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield
- ☒ Other: University weather station on site

Issues encountered: NONE

- ☐ Missing data: Please specify period of missing data or percentage of missing data.
- ☐ Shortage
- ☐ Wifi connection
- ☐ Others: ……………………..

2.2.1 Sensors and weather station location

This section gives information about the location of the sensors inside the building and outside for the weather station. Five differents rooms have been monitored with T/RH sensors for one year, i.e 3 classroms and 2 offices, located at different storeys. The sensors were installed at the middle of the room or on a partition walls, protected from direct solar radiation and at a height of 2 meters above the floor. Ponctual measurements were also done in the classrooms for different day and time using the Testo Kit (please see the sensors specifications in the next section).
Weather data were extracted from a weather station installed on site.

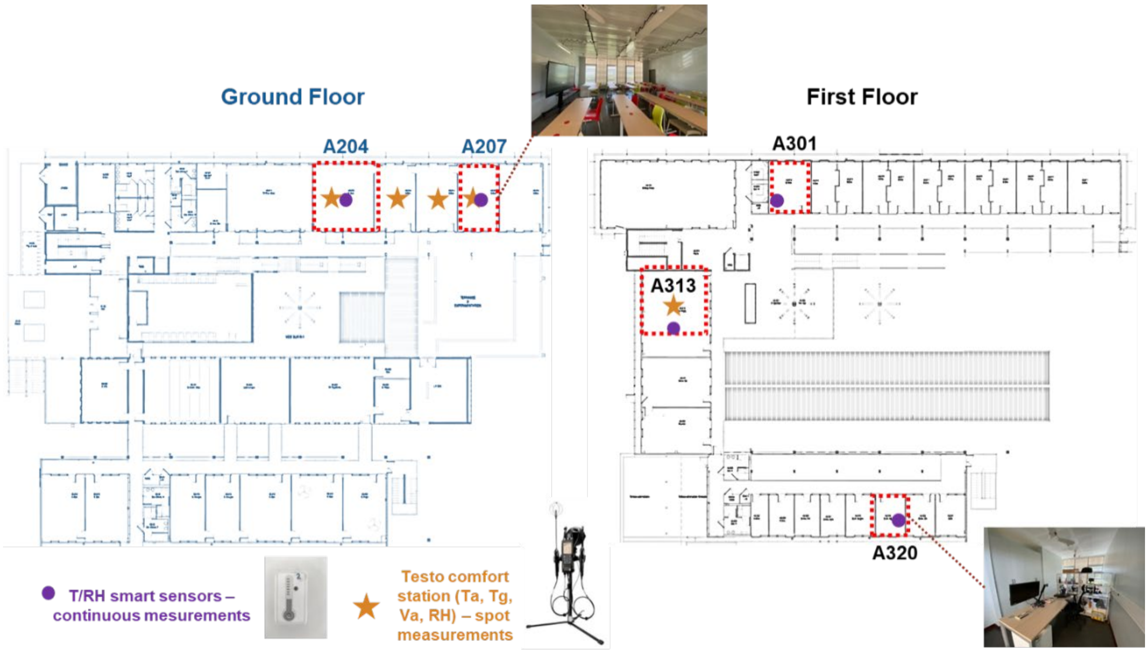


Figure 1: Location of the sensors for the ESIROI building

★ PIMENT weather station *(precipitation, solar radiation, relative humidity, air temperature, wind direction, wind speed)*

Figure 2: Location of the weather station.

2.2.2 Sensors specification

Details about the sensors are given in the table below

Sensor name	Code in Fig. 1	Measured variables	Accuracy	Resolution	Operating/ measuring range
LoRaWan Class A smart sensors	●	Air temperature (T)	±0.3 °C	0.01 °C	-40 to +125 °C
		Relative humidity (RH)	±3 %RH	0.04 %RH	0 to 100%
Testo 440 - Air velocity and IAQ measuring instrument	★	Air temperature (T)	±0.5 °C	0.1 °C	0℃ to 50℃
		Relative humidity (RH)	±3 %RH (10 to 35 %RH) ±2 %RH (35 to 65 %RH) ±3 %RH (65 to 90 %RH) ±5 %RH (other range)	0.1 %RH	5 to 95 %RH
		Air velocity (Va)	±(0.03 m/s + 4 % of mv)	0.01 m/s	0 to 5 m/s
		Black globe temperature (Tg)	Class 1: ±1,5°C or 0,40%	0.1 °C	0 to +120 °C

2.3 Post Occupancy Evaluation Surveys

This section includes general information concerning the POE surveys.

Measurements and questionnaires were done in 5 different classrooms over 7 different days in the hot period and for different time of the day, i.e morning and afternoon. The respondents were mainly students from the engineering school ESIROI.

Date	Time	Room	Number of responses	Respondents information				
				category	Mean clo value at the beginning	Mean clo value at the end	Mean metabolic activity at the beginning	Mean metabolic activity at the end
14/02/2022	8:30–12:30 am	A205	57	Students and 1 professor	0.36	0.36	1.86	1.17
	1:30-4:30 pm	A313	29		0.37	0.37	1.31	1.32
17/02/2022	8:30–12:30 am	A207	60		0.37	0.35	1.69	1.20
	1:30-4:30 pm	A207	45		0.36	0.37	1.38	1.47
18/02/2022	8:30–12:30 am	A205	39		0.36	0.36	1.65	1.08
	1:30-5:30 pm	A313	48		0.41	0.42	1.38	1.20
22/02/2022	8:30–12:30 am	A205	35		0.45	0.41	1.55	1.13
	1:30-3:30 pm	A204	43		0.43	0.40	1.41	1.13
23/02/2022	8:30–10:30 am	A204	78		0.42	0.42	1.48	1.70
24/02/2022	8:30–12:30 am	A206	20		0.38	0.35	1.62	1.18
10/03/2022	8:30–12:30 am	A206	40		0.35	0.34	1.90	1.18
Total			**494**					

ABC21 is funded by the EU's H2020 programme

3. Results and discussion

3.1 Boxplot

Figure 3 below presents the boxplot of air temperature for all the studied rooms over the total period of measurements as well as the one for the outdoor conditions.

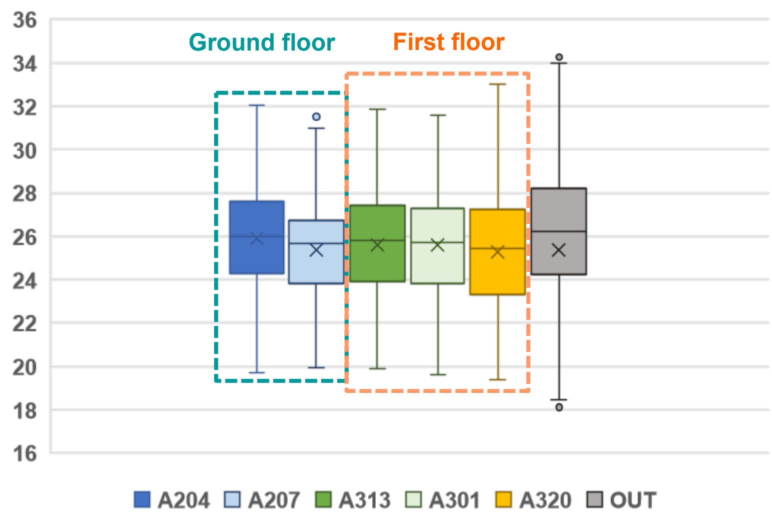


Figure 3: Boxplot of the air temperature for the indoor and outdoor conditions from the 1st March 2022 to the 1st March 2023 for the ESIROI building.

The repartition of the air temperatures is almost the same for all the studied rooms, regardless of the floor concerned. The mean value of air temperature is between 25 and 26°C. The maximum of air temperature does not exceed 32°C (or only a few times).

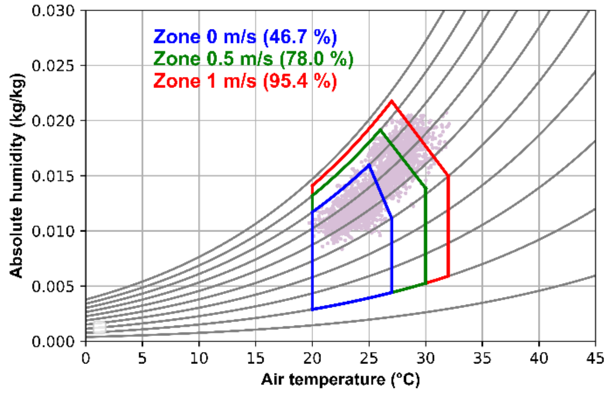
3.2 Givoni comfort zone

Figure 4 below shows the Givoni comfort zone for each room over the total period of measurements as well as the one for the outdoor conditions over the same period during the occupied hours.
It can be observed that the percentage of time (in terms of number of hours) is equal or superior to:

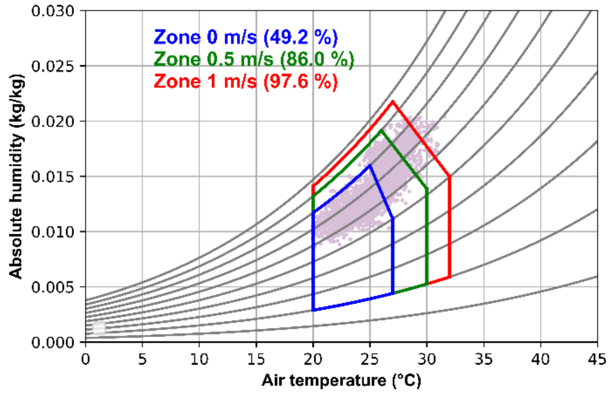
- 78% in the 0.5m/s Givoni comfort zone for all the studied rooms
- 95% in the 1m/s Givoni comfort zone for all the studied rooms.

Comfortable indoor conditions could be achieved in the majority of the occupied hours, with an air velocity of 1m/s combining natural ventilation and the use of ceiling fans.

GROUND FLOOR LEVEL

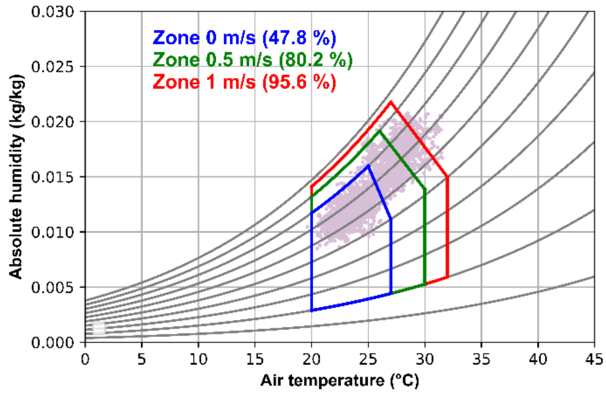


A204 – Classroom (N)

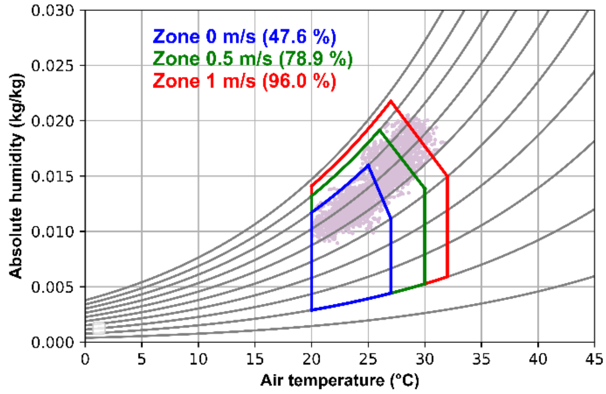


A207 – Classroom (N)

FIRST FLOOR LEVEL

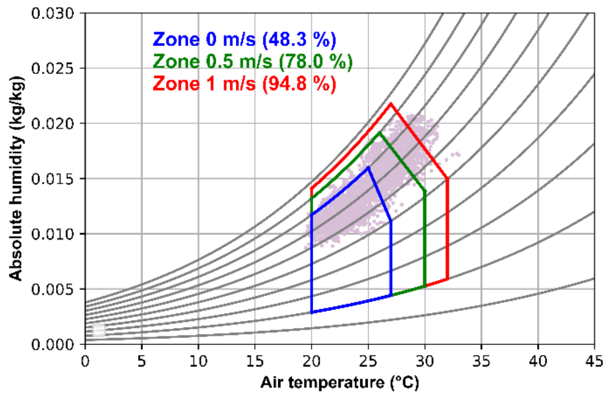


A301 – Office (N)



A313 – Classroom (W)

FIRST FLOOR LEVEL



A320 – Office (S)

OUTDOOR CONDITIONS

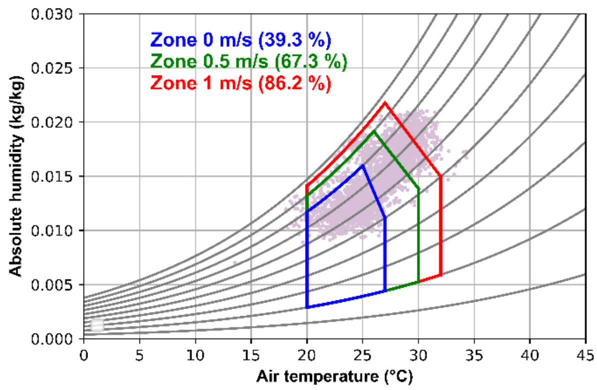


Figure 4: Givoni comfort zones obtained for each room of the ESIROI building and for the outdoor conditions from the 1st March 2022 to 1st March 2023 during the occupied hours.

3.3 Number of hours / frequency within a certain temperature range

This section presents the number of hours and the frequency of air temperature by bins of 2°c for the different monitored rooms during the occupied hours only and for the outdoor conditions.

1st March 2022 to 1st March 2023 Occupation time: 8:00am to 5:00pm	GROUND LEVEL				FIRST FLOOR LEVEL						OUTDOOR CONDITIONS	
	A204		A207		A301		A313		A320		University weather station	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
T<20°C	2	0%	4	0%	1	0%	1	0%	22	1%	66	2%
20°C≤T<22°C	116	4%	249	8%	246	8%	153	5%	332	11%	140	5%
22°C≤T<24°C	527	17%	572	19%	547	18%	676	22%	669	22%	439	15%
24°C≤T<26°C	876	29%	835	28%	775	26%	787	26%	750	25%	785	26%
26°C≤T<28°C	901	30%	1001	33%	896	30%	893	30%	746	25%	768	25%
28°C≤T<30°C	536	18%	330	11%	510	17%	450	15%	454	15%	640	21%
30°C≤T<32°C	61	2%	29	1%	45	1%	60	2%	44	1%	170	6%
32°C≤T<34°C	1	0%	0	0%	0	0%	0	0%	3	0%	9	0%
34°C≤T<36°C	0	0%	0	0%	0	0%	0	0%	0	0%	3	0%
T≥36°C	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%

For all the studied rooms, the air temperature is mostly below 30°C and only exceeds 30°C a few time (1-2% of the occupied time).

3.4 Number of hours / frequency by relative humidity range

This section presents the number of hours and frequency of air relative humidity by bins of 10% RH for the different monitored rooms during the occupied hours only and for the outdoor conditions.

1st March 2022 to 1st March 2023 Occupation time: 8:00am to 5:00pm	GROUND LEVEL				FIRST FLOOR LEVEL						OUTDOOR CONDITIONS	
	A204		A207		A301		A313		A320		University weather station	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
[0,10%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[10,20%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[20,30%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[30,40%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[40,50%[	7	0%	2	0%	3	0%	2	0%	3	0%	21	1%
[50,60%[	348	12%	243	8%	244	8%	191	6%	132	4%	406	14%
[60,70%[	1510	50%	1340	44%	1480	49%	1534	51%	1246	41%	1357	45%
[70,80%[	973	32%	1266	42%	1085	36%	1130	37%	1308	43%	918	31%
[80,90%[	181	6%	169	6%	190	6%	163	5%	325	11%	215	7%
[90,100%]	1	0%	0	0%	18	1%	0	0%	6	0%	80	3%

The relative humidity inside the rooms ranges between 60 to 80 % for the majority of the occupied hours but can exceeds 80% during some hours.

3.5 Analysis of a representative week

3.5.1 Solar radiation profile

Global solar radiation measured by the weather station on site has been **plotted for a typical hot week** in Saint-Pierre, La Réunion**, with a peak around 1000W/m^2.**
The four first days were cloudy while the three last days were sunny days.

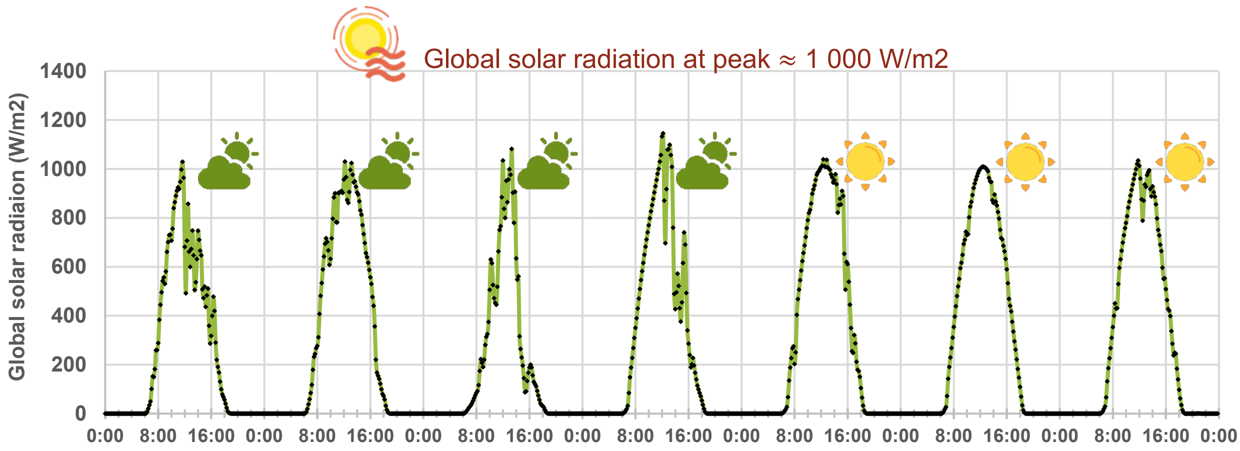


Figure 5 : Solar radiation profiles from the 6th of March to the 12th of March 2022. Data were extracted from the weather station on site.

3.5.2 Wind profile

Wind speed measured by the weather station on site has been **plotted for the same typical hot week than section before.**
During the four first days that were cloudy, the mean wind speed ranges between 1.7 and 2.7m/s during the occupied hours while during the three last days (that were sunny days), the mean wind speed was higher, with 5m/s.

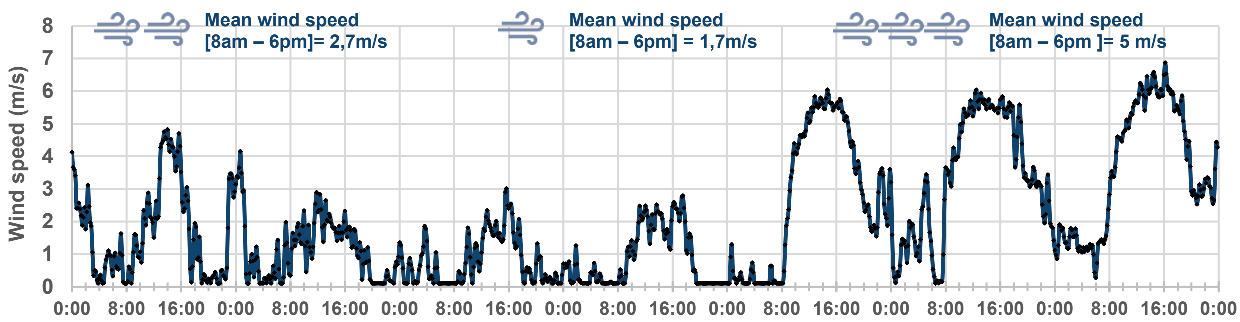


Figure 6 : Wind speed profiles from the 6th of March to the 12th of March 2022. Data were extracted from the weather station on site.

3.5.3 Air temperature profile

Air temperature profiles inside selected rooms have been plotted for the same typical hot week along with the outdoor air temperature (obtained from the weather station on site). In terms of operation, all the monitored spaces are naturally cross ventilated. The users can adjust the openings thanks to manual vertical large glasse louvers, function of the comfort conditions.
At night, the staff in charge of the security systematically close the louvers in the end of the day to avoid animals, birds etc. to enter in the spaces.

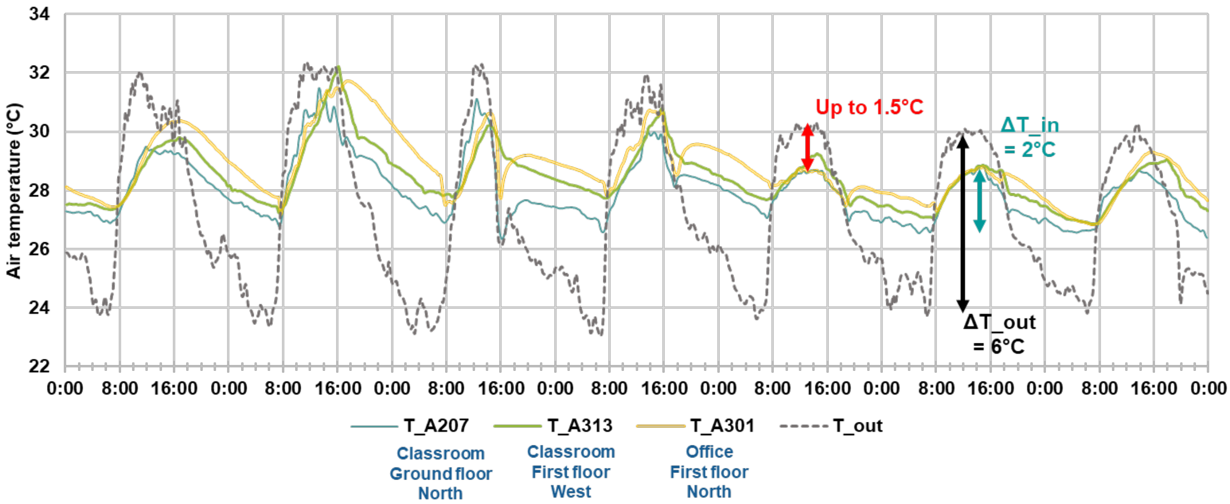


Figure 7: Air temperature profiles for the selected rooms of the ESIROI building from the 6th of March to the 12th of March 2022.

From Figure 7, it can be observed that the air temperature inside all spaces remains below the outdoor air temperature, with a difference at peak that can reach 1.5°C during the days with higher wind speed. Air temperature inside the rooms does not exceed 32°C, contrary to the outside temperature. This is a good indicator that the bioclimatic strategies work well.
The air temperature of the office located at the first floor with a North orientation is 1°C higher than the air temperature of the other rooms most of the time. This can be explained that this office is closer to mineral surfaces (asphalt).
Besides, the diurnal air temperature variation inside ranges between 2 to 4°C, which is lower than the one for the outside air temperature that ranges between 6 to 9°C.
The indoor air temperature at night is 3°C above the outdoor air temperature because all the spaces are closed at night. This does not have a bad influence during day time because the users open the louvers and the coupling effect of low inertia materials with cross natural ventilation rapidly reduce the indoor air temperature during working hours.

3.6 POE results

7 sessions of POE surveys were conducted during the hot season, and essentially during the month of February 2022. 494 responses were collected and are analysed in the sections below.

3.6.1 Thermal sensation, thermal comfort judgement and thermal preference

Figure 8 below presents the results obtained in terms of thermal sensation, thermal comfort judgement and thermal preference.

As it can be observed in Fig. 8.a, during the different surveyed dates, people mostly feel neutral (50% of the respondents) or slightly warm (31%). Only 11% of the respondents felt warm and 3% hot. Besides, people mostly find their thermal environment to be comfortable (56%) or slightly uncomfortable (34%). Only 10% of the respondents find the conditions either uncomfortable or very uncomfortable.

Finally, even if 49% of the people surveyed would prefer no change, 46% of them would rather prefer to be cooler.

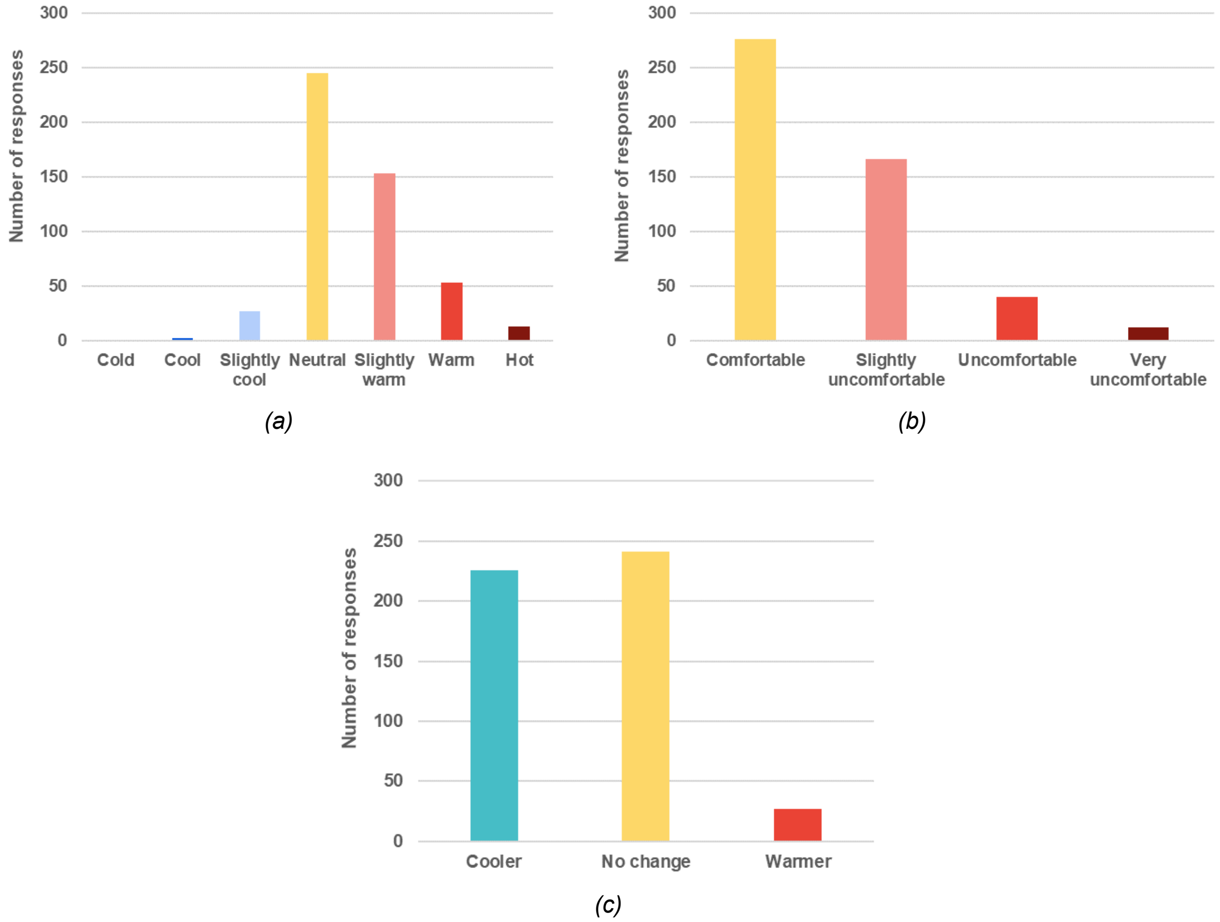
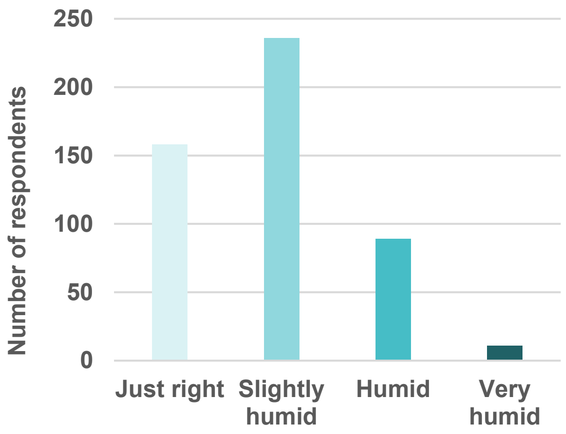


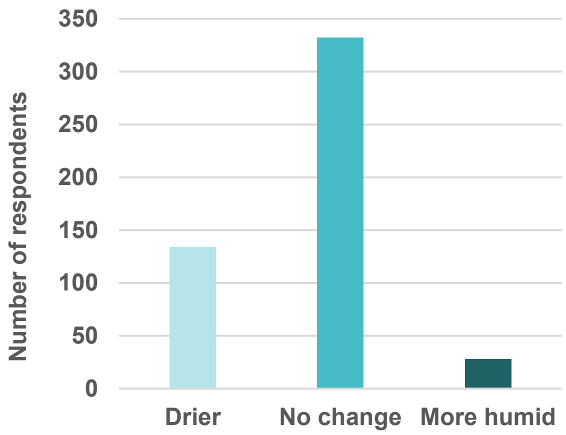
Figure 8: (a) Thermal sensation, (b) thermal comfort judgment and (c) thermal preference of the surveyed people of the ESIROI building during the hot period.

3.6.2 Sensation and preference for the air humidity

Figure 9 below presents the results obtained for the sensation and preference in terms of air humidity. It can be observed that the majority of the votes range between the categories "just right" with 32% of the votes, slightly humid with 48% of the votes and humid (18%). The people surveyed would rather prefer the air humidty to be the same (67%) or drier (27%).



(a)

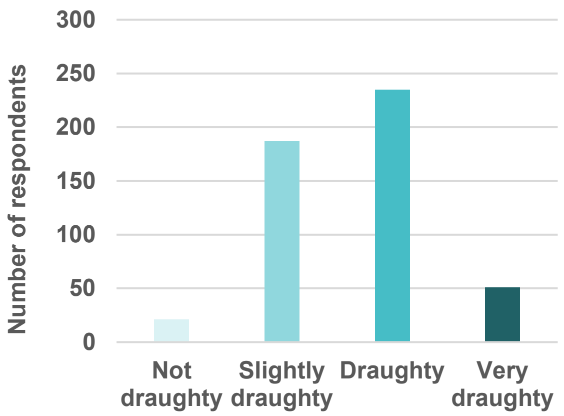


(b)

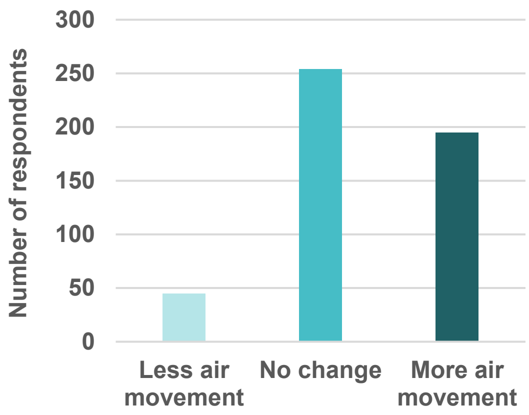
Figure 9: (a) Sensation and (b) preference in terms of air humidity inside the surveyed rooms of the ESIROI building.

3.6.3 Sensation and preference for the air velocity

Figure 10 below presents the results obtained for the sensation and preference in terms of air velocity.



(a)



(b)

Figure 10 : (a) Sensation and (b) preference in terms of air velocity inside the surveyed rooms of the ESIROI building.

The majority of the people surveyed found that the air velocity was slightly draughty (38%) to draughty (48%) during the POE surveys. In addition, more than 50% of the respondents would prefer no change whereas 39% of them would prefer to feel more air movement.

4. Lessons learnt and recommendations

The measurements conducted inside the building point out that the indoor thermal conditions remain overall comfortable with air temperatures inside the spaces that are below the outdoor air temperature and do not exceed 32°C during the majority of the occupied hours, provided that the air velocity reaches 1 m/s. This is a good indicator that the bioclimatic strategies work well.
Users are happy to control their own thermal comfort thanks to adjustable vertical louvers and ceiling fans in the case of windless day.

Users are overall satisfied with the thermal comfort conditions in summer even if during the POE surveys, some people would have prefered more air movement, especially in classrooms where some of the ceiling fans were not working properly.

This study and its findings not only emphasize the importance of the role of natural ventilation but also the one of ceiling fans for buildings located in similar climate. The maintenance of the equipment installed inside the buildings also plays a pivotal role in achieving comfortable thermal conditions inside.

Another point to behighlighted is that the users are not satisfied with the thermal comfort conditions in winter, and feel that there is too much wind and that they feel too cold.

By way of conclusion, the management of natural ventilation is not only required in summer but also in winter to ensure people feel comfortable all year long.

ABC21 is funded by the
EU's H2020 programme

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

AIME CEZAIRE SCHOOL (LA RÉUNION)

ABC21 is funded by the
EU's H2020 programme

Authors

Name	Email	Institution
Virginie Grosdemouge	Virginie.grosdemouge@univ-reunion.fr	UR
François Garde	francois.garde@univ-reunion.fr	UR

Revision

Version	Date	Author	Description of changes
V0	19.05.2023	Virginie Grosdemouge and François GARDE	Draft of the document
V1	30.05.2023	Virginie Grosdemouge and François GARDE	Updated version

CONTENTS

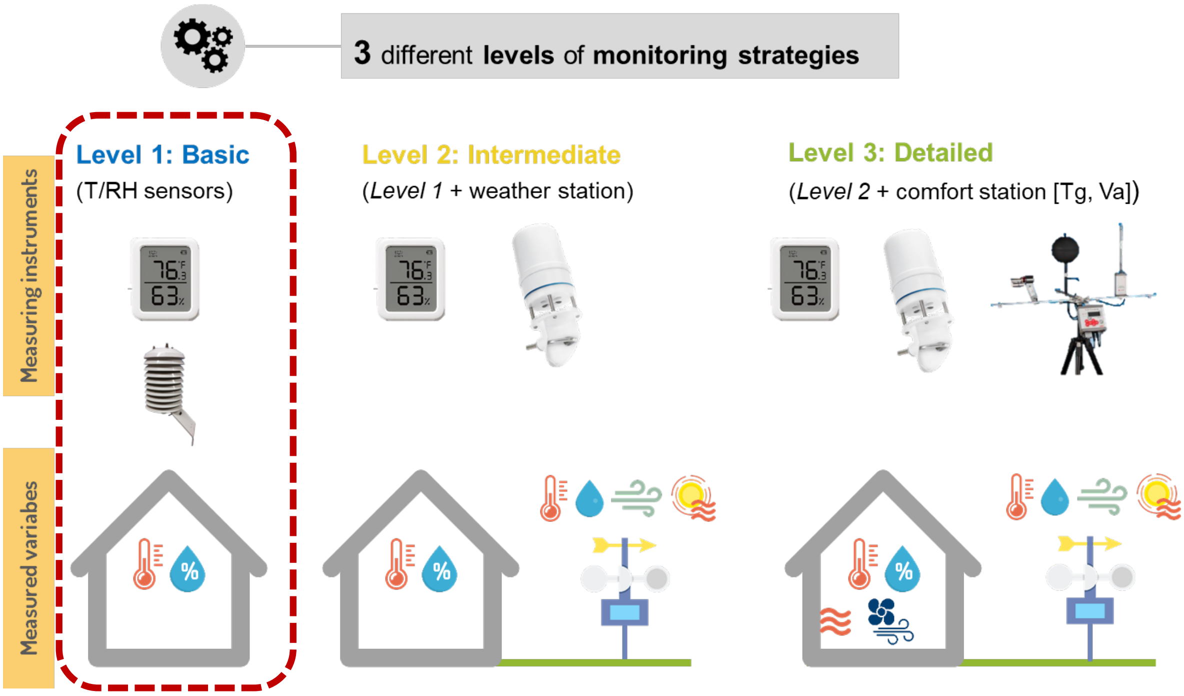
1. Presentation of the Aime Cesaire primary school

Name	Aimé Césaire Primary School
Architect / Designer	Antoine Perrau Architectures
Location	-21.296, 55.460
City	Saint-Pierre
Country	La Reunion, France
Building type	Educational
Climate zone (Köppen–Geiger)	Aw
Description	The school is composed of 12 classrooms (5 nursery classrooms and 7 elementary classrooms). It was designed according to two differentiated inscriptions: one protecting the spaces to the point of covering them with a unifying shade, this is the space of the children; the other, opening its courtyards and its playgrounds around and under the buildings, this is the space of the elementary school. The project proposes a very sober volumetric impact deployed by making the best use of the site effects and natural slopes, slightly embedded upstream and on piles downstream.
Main bioclimatic strategies	Cross natural ventilation, large unit roof umbrella, reflective and specific sun protection, gardens, insulated roofs, green roof, management of rainwater. Ceiling fans installed in all spaces.

ABC21 is funded by the EU's H2020 programme

2. Material and method

2.1 Monitoring campaign level



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: start date: 26/02/2022 End date: 27/03/2023

Collection of weather data:

- ☒ National weather station close to the site. Distance from the site: 5 km
- ☐ TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield

Issues encountered: NONE

- ☐ Missing data
- ☐ Shortage
- ☐ Wifi connection
- ☐ Others: ……………………..

ABC21 is funded by the EU's H2020 programme

2.2.1 Sensors and weather station location

This section gives information about the location of the sensors inside the building (and outside in case of a weather station).
All T/RH sensors have been installed in the middle of the rooms at a height of 2m.
One T/RH sensor (named E3)has been installed at a covered corridor level. It is supposed that this sensor measures the outdoor conditions.

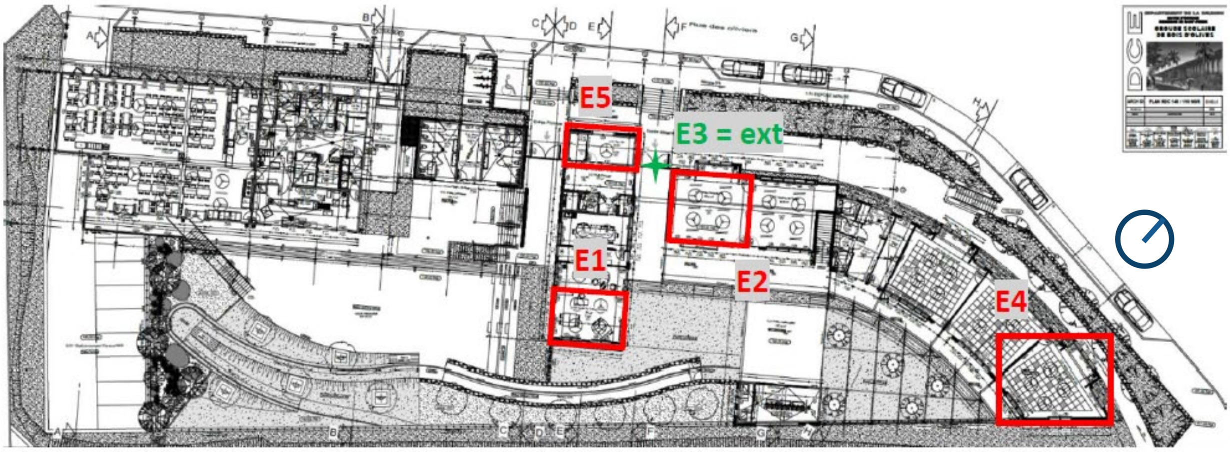


Figure 1: Location of the T/Rh sensors at the ground floor level of the Aimé Césaire primary school.

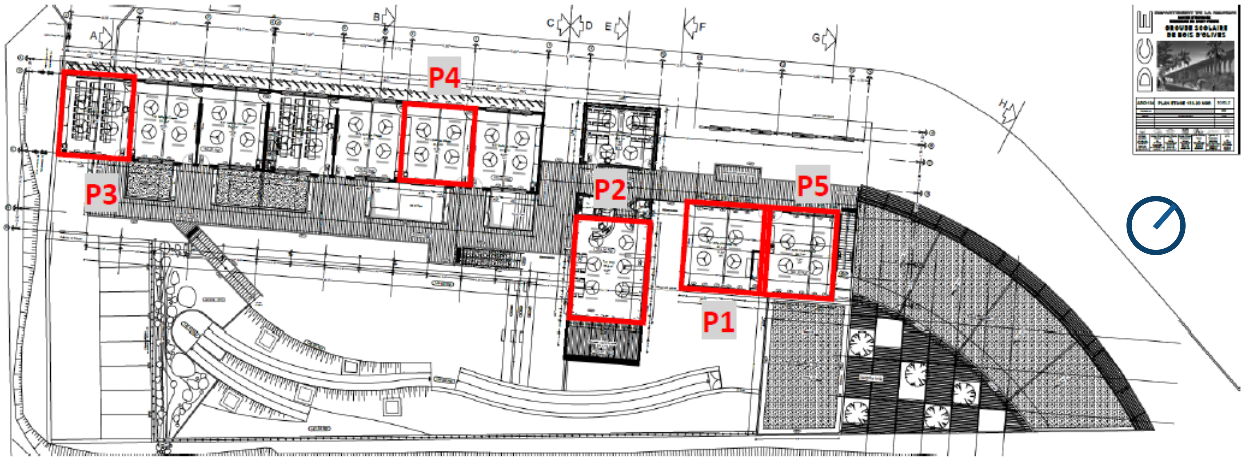


Figure 2 : Location of the T/Rh sensors at the first floor level of the Aimé Césaire primary school.

South-East Facade (one can note that sensors P1 and P5 have been placed in classrooms without any solar shadings)

Eastern outdoor corridor (First floor)

North-West Facade

Figure 3 : Some pictures to locate the sensors

ABC21 is funded by the EU's H2020 programme

2.2.2 Sensors specification

Details about the sensors are given in the table below

Table 1 : Sensors' specifications (the time step for data acquisition was 20')

Sensors	Code in Figure 1 & 2	Measured variables	Accuracy	Resolution
Testo 174H	E & P	Air temperature (T)	±0,5 °C (-20 to +70 °C)	0,1 °C
		Relative humidity (RH)	±3 %RH (2 to +98 %RH) at +25°C ±0,03 %RH/K ±1 Digit	0,1 %RH

2.3 Post Occupancy Evaluation Surveys

No questionnaire surveys were conducted for this case study.

ABC21 is funded by the
EU's H2020 programme

3. Results and discussion

The monitored period was conducted during one month in the hot and humid season, from the 26th of February 2022 to the 27th of March 2022

3.1 Boxplot

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

Figure 4 below presents the boxplot of air temperature for all the studied rooms over the total period of measurements as well as the one for the outdoor conditions.

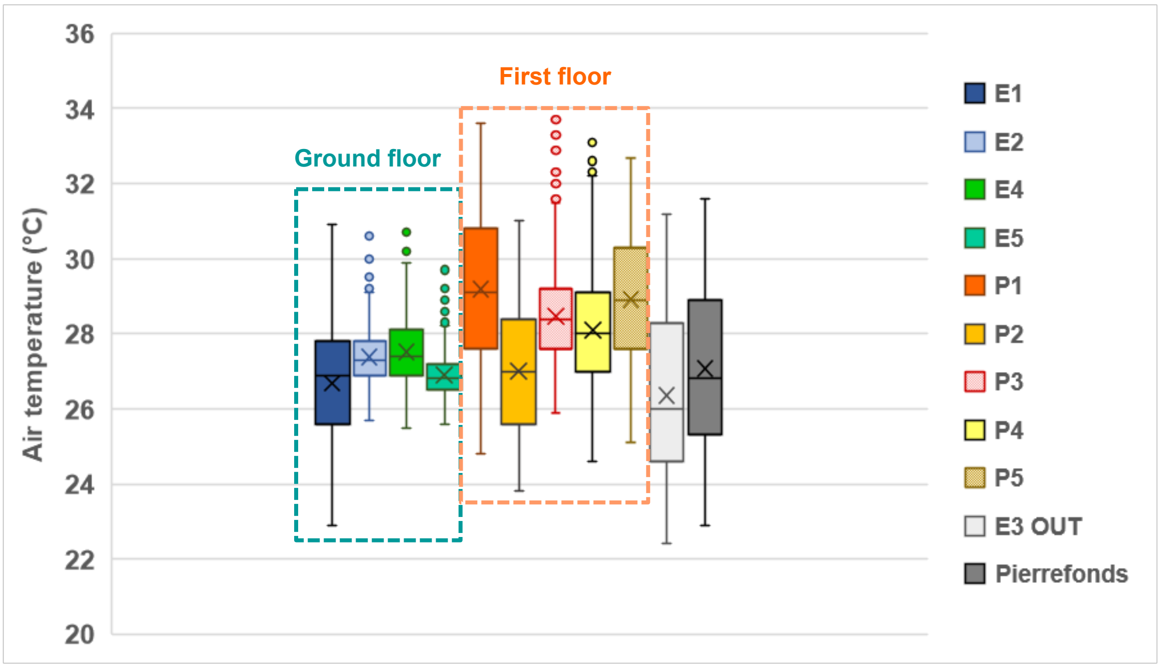


Figure 4: Boxplot of the air temperature for the indoor and outdoor conditions from the 26h of Feb. to the 27th of March for the different monitored rooms of the Aimé Césaire school.

The analysis of the box plots highlights the following remarks :

- The local outdoor temperature measured by E3 is one degree below the outdoor conditions of the airport;
- The comfort conditions measured at the upper level are worse than the classrooms located on the ground level. The mean temperature is around 28°C/29°C whereas on the ground level, it is around 27°C; This can be probably explained by a bad insulation / solar shading of the roof;
- The most uncomfortable classrooms are P1 and P5, because of the combined effect of a bad insulation of the roof and no solar protection on the West façade (see Figure 3).

3.2 Givoni comfort zone

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

Figure 4 below shows the Givoni comfort zone for each room over the total period of measurements as well as the one for the outdoor conditions over the same period during the occupied hours.

Ground Floor Level

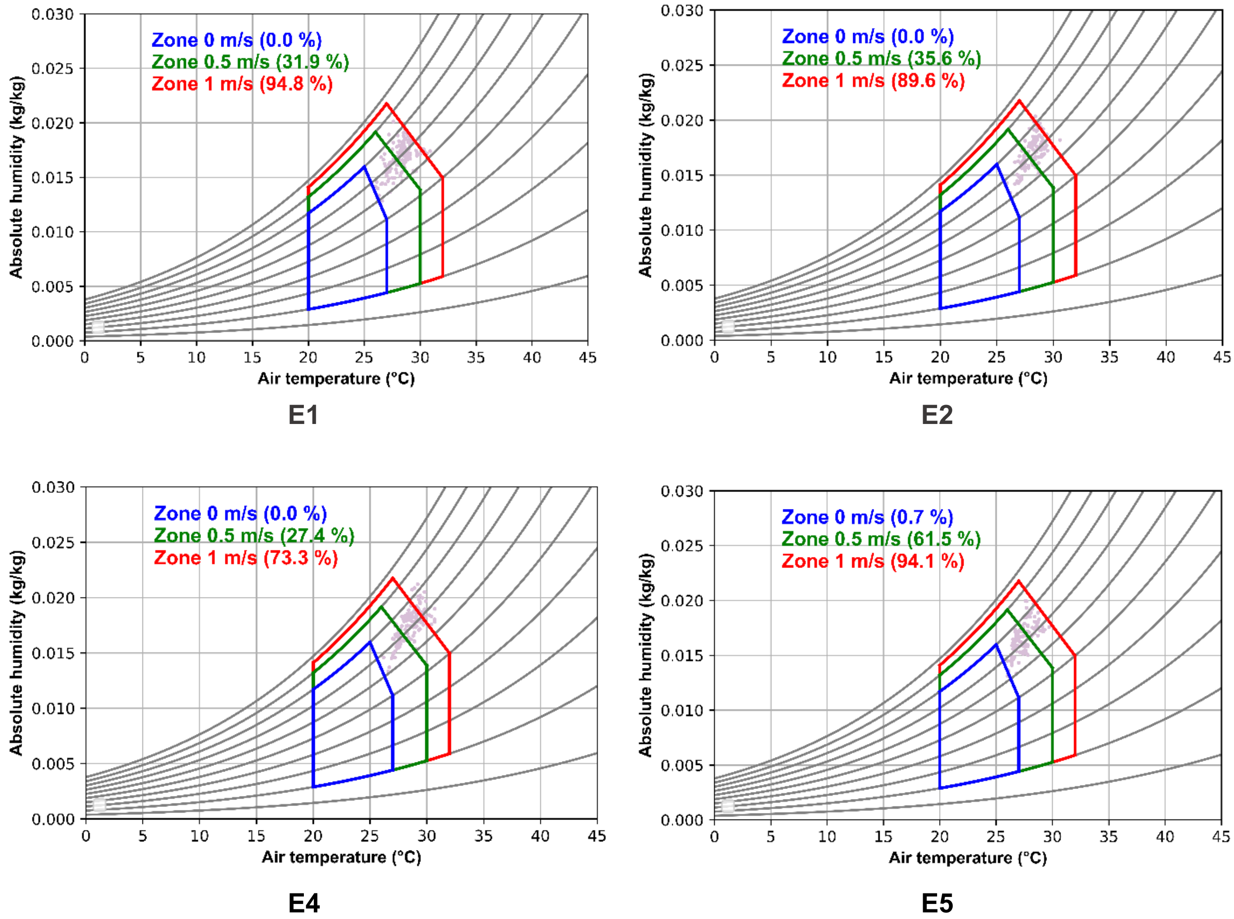
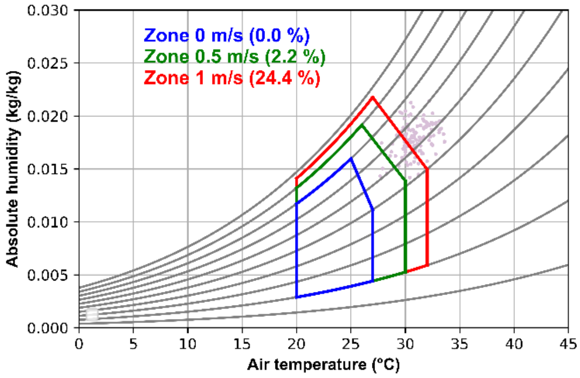


Figure 5 : Givoni comfort zones of all the monitored rooms at the ground level

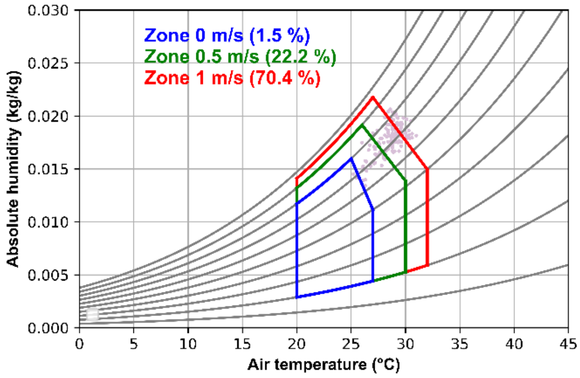
The Givoni diagrams of the classrooms located on the ground floor show that the comfort conditions are acceptable with an air velocity of 1m/s. As the air velocity has not been measured, we assume that the installed ceiling fans generate this speed.

Sensor E4 points that the comfort conditions are a little bit hot (some dots are outside the zone of 1m/s), probably because of the green roof which is not as efficient as planned (there is not upper level above this classroom).

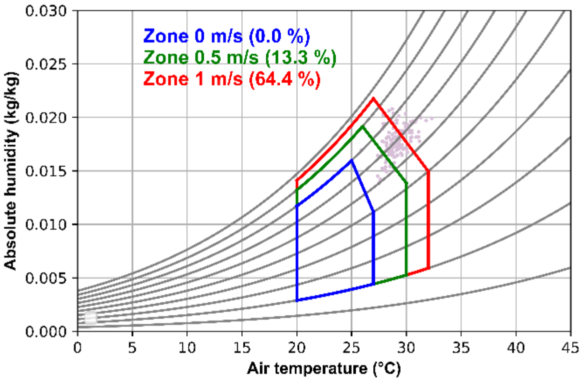
First Floor Level



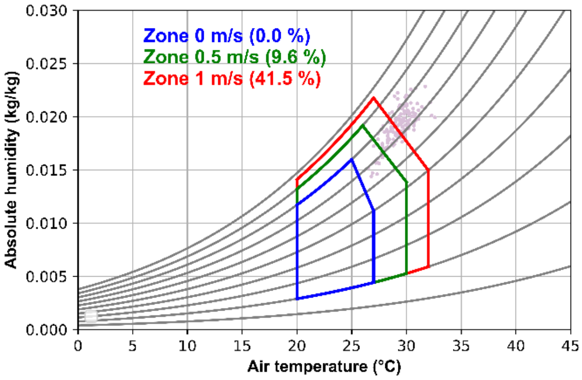
P1



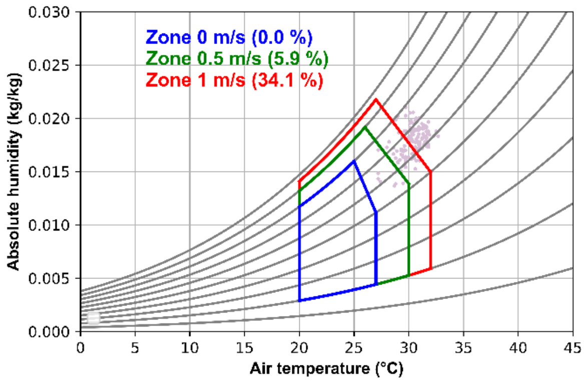
P2



P3

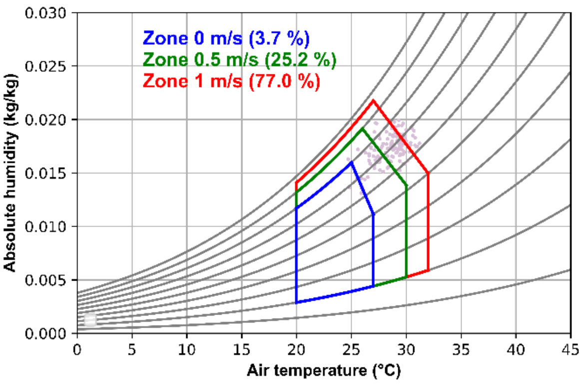


P4

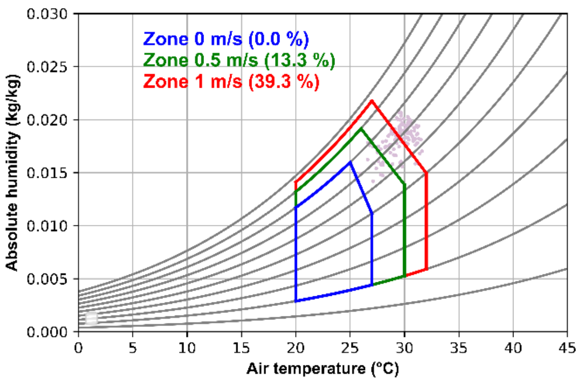


P5

OUTDOOR CONDITIONS



E3 - Covered and well ventilated area



Pierrefonds airport weather station

Figure 6: Givoni comfort zones of all the monitored rooms at the first floor and of the outdoor conditions during the occupied hours for the Aimé Césaire school.

The analysis of the Givoni diagrams of Figure 6 points out that :

- The outdoor conditions measured by sensor E3 are acceptable ;
- All the classrooms of the first floor are uncomfortable;
- The worst classrooms in terms of thermal comfort are P1, P4 and P5.

3.3 Number of hours and frequency within a certain temperature range

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

Table 2 below lists the frequency (Fq) within a certain temperature range calculated for all the monitored rooms and for the outdoor conditions during the occupied hours.

Table 2 : Number of hours within a 2°C temperature range for all classrooms and for outdoor conditions. One can note that all the classrooms at the first floor are very hot, more specifically P1 and P5

Hot period (26th Feb. to 12th March 2022) Occupation time: 8:00am to 4:00pm	GROUND LEVEL								OUTDOOR CONDITIONS			
	E1		E2		E4		E5		E3 - Covered and well-ventilated area		Pierrefonds weather station	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
T<22°C	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
22°C≤T<24°C	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
24°C≤T<26°C	1	1%	1	1%	0	0%	2	1%	9	7%	1	1%
26°C≤T<28°C	45	33%	55	41%	43	32%	102	76%	31	23%	20	15%
28°C≤T<30°C	85	63%	78	58%	86	64%	31	23%	82	61%	63	47%
30°C≤T<32°C	4	3%	1	1%	6	4%	0	0%	13	10%	51	38%
32°C≤T<34°C	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
34°C≤T<36°C	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
T≥36°C	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%

Hot period (26th Feb. to 12th March 2022) Occupation time: 8:00am to 4:00pm	FIRST LEVEL									
	P1		P2		P3		P4		P5	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
T<22°C	0	0%	0	0%	0	0%	0	0%	0	0%
22°C≤T<24°C	0	0%	0	0%	0	0%	0	0%	0	0%
24°C≤T<26°C	0	0%	3	2%	1	1%	0	0%	0	0%
26°C≤T<28°C	3	2%	34	25%	15	11%	23	17%	5	4%
28°C≤T<30°C	32	24%	**88**	65%	**94**	70%	**82**	61%	42	31%
30°C≤T<32°C	**72**	53%	10	7%	**24**	18%	27	20%	**85**	63%
32°C≤T<34°C	**28**	21%	0	0%	1	1%	3	2%	**3**	2%
34°C≤T<36°C	0	0%	0	0%	0	0%	0	0%	0	0%
T≥36°C	0	0%	0	0%	0	0%	0	0%	0	0%

ABC21 is funded by the EU's H2020 programme

3.4 Number of hours and frequency by relative humidity range


Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

Table 3 below lists the frequency by bins of 10% of RH for all the monitored rooms and for the outdoor conditions during the occupied hours.

Table 3 : Number of hours within a 10% range for all classrooms and for outdoor conditions

Hot period (26th Feb. to 12th March 2022) Occupation time: 8:00am to 4:00pm	GROUND LEVEL								OUTDOOR CONDITIONS			
	E1		E2		E4		E5		E3 - Covered and well-ventilated area		Pierrefonds weather station	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
[0,10%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[10,20%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[20,30%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[30,40%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[40,50%[	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
[50,60%[	3	2%	0	0%	0	0%	0	0%	3	2%	6	4%
[60,70%[	68	50%	65	48%	64	47%	41	30%	72	53%	62	46%
[70,80%[	61	45%	66	49%	68	50%	88	65%	54	40%	66	49%
[80,90%[	3	2%	4	3%	3	2%	6	4%	6	4%	1	1%
[90,100%]	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%

Hot period (26th Feb. to 12th March 2022) Occupation time: 8:00am to 4:00pm	FIRST LEVEL									
	P1		P2		P3		P4		P5	
Range	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
[0,10%[	0	0%	0	0%	0	0%	0	0%	0	0%
[10,20%[	0	0%	0	0%	0	0%	0	0%	0	0%
[20,30%[	0	0%	0	0%	0	0%	0	0%	0	0%
[30,40%[	0	0%	0	0%	0	0%	0	0%	0	0%
[40,50%[	1	1%	0	0%	0	0%	0	0%	0	0%
[50,60%[	32	24%	0	0%	0	0%	0	0%	19	14%
[60,70%[	87	64%	47	35%	74	55%	29	21%	93	69%
[70,80%[	15	11%	81	60%	53	39%	94	70%	23	17%
[80,90%[	0	0%	7	5%	8	6%	12	9%	0	0%
[90,100%]	0	0%	0	0%	0	0%	0	0%	0	0%

ABC21 is funded by the EU's H2020 programme

3.5 Analysis of a representative week

Short definition: a week with the **same successive days** in terms of **solar radiation (sunny days)** and **same diurnal variation of air temperature** and if possible without rainy days.
The representative week has been selected with a set of similar sunny days (see Figure 7). There is also a set of 3 windless days (from Monday to Wednesday). In terms of outdoor temperature the week is representative of the hot and humid season, with a temperature that varies from 31°C during the day to 24°C at night.

Solar radiation profile

Data are extracted from the closest weather station located at the nearest airport.

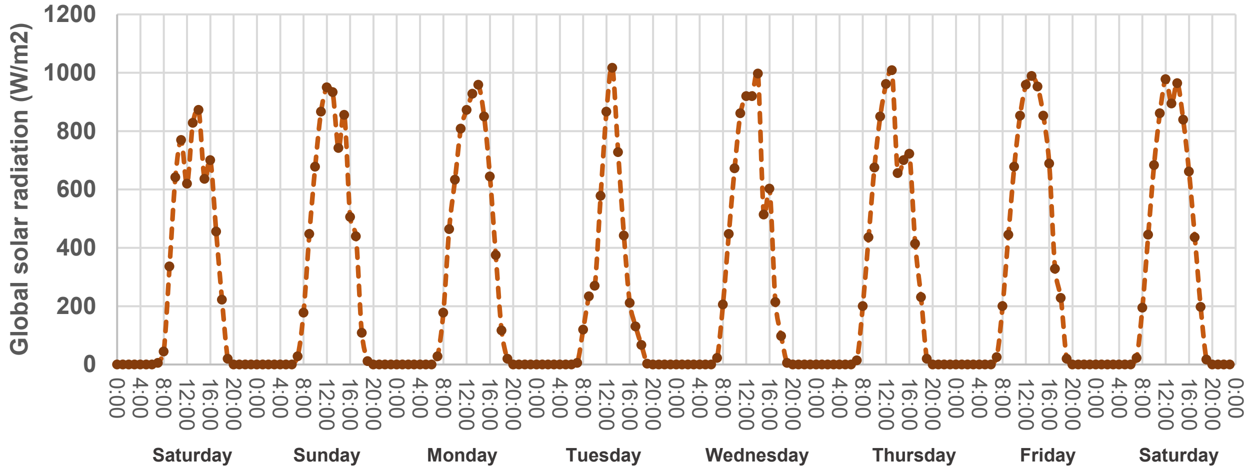


Figure 7 : Solar radiation profiles from the 5th to 12th March at the Pierrefonds site (closest airport).

3.5.1 Wind profile

Data are extracted from the closest weather station located at the nearest airport.

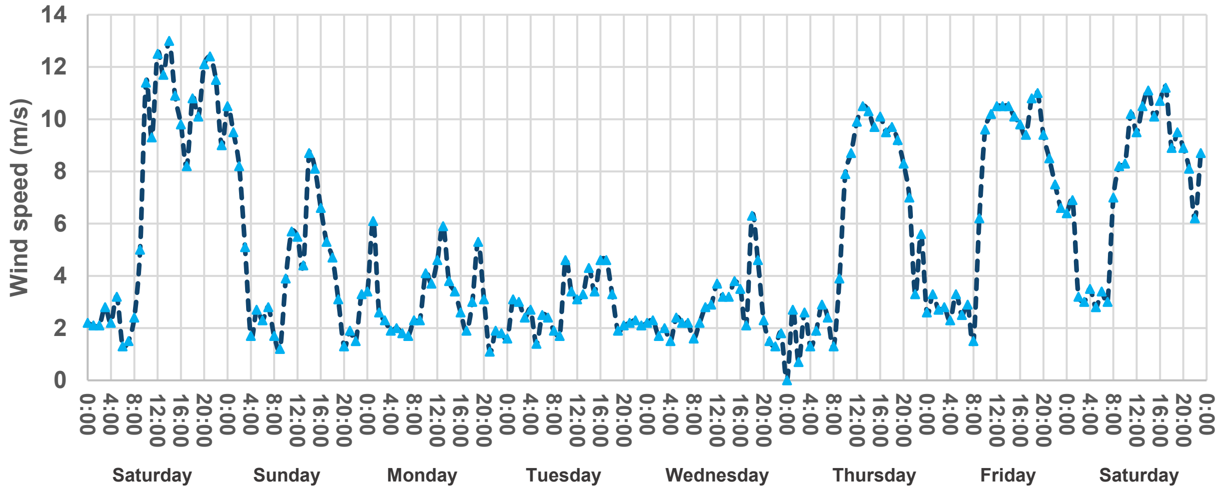


Figure 8 : Wind speed profiles from the 5th to 12th March at the Pierrefonds site.

ABC21 is funded by the
EU's H2020 programme

3.5.2 Air temperature profile

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

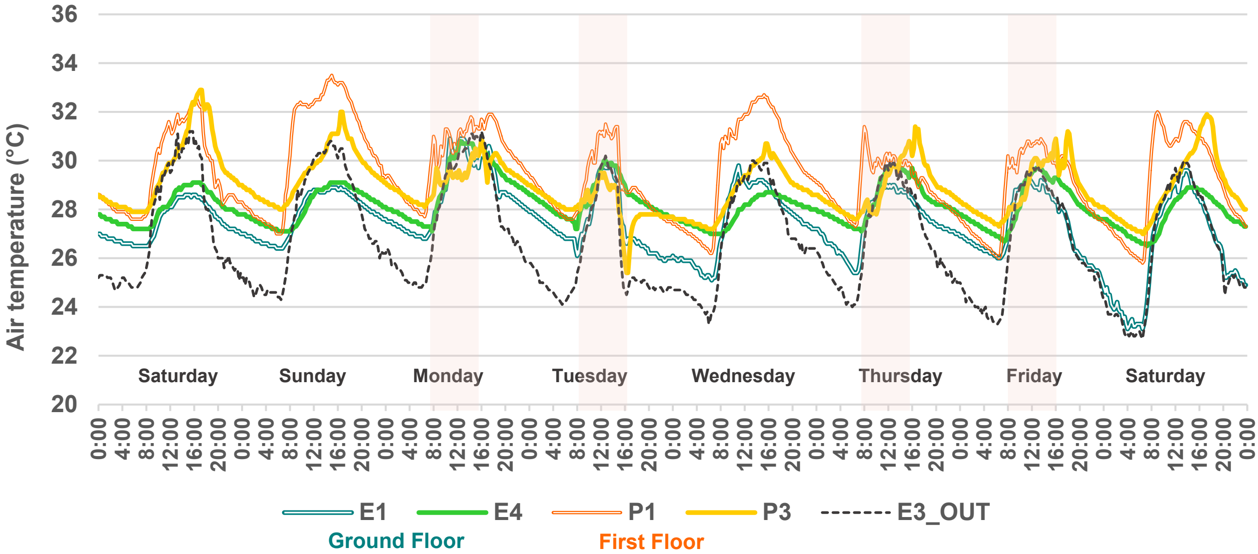


Figure 9 : Air temperature profiles for the selected rooms of the Aimé Césaire school from the 5th to 12th March

The analysis of the air temperature profiles confirms the previous comments :

- The air temperature in classrooms P1 and P3 is very hot. The temperature exceeds the outdoor temperature (around 2,5°C above the air temperature for P1, 1,5 °C for), which points out a bad design of the classrooms.
- The thermal behaviour of the classrooms located at the ground level is acceptable. The air temperature remains below the outdoor air temperature during day time.

4. Lessons learnt and recommendations

The analysis of the measured data coupled with the feedback of users allow to give some lessons learnt and recommendations for the Aimé Cézaire primary school.

Lessons learnt :

Overall, the classrooms at the ground level are comfortable with comfort conditions that are reached 90% of the time during the hot season

Despite the bioclimatic and passive design of the school, the measurement campaign has pointed out a bad thermal behaviour for all the classrooms at the first level that lead to higher air temperatures and dissatisfaction. Comfort conditions in those classrooms are reached only 25%-40% of the time only.

POE : no POE has been conducted for this school but we had some negative feedback from the teachers, specifically for the classrooms at the first floor.

The most uncomfortable ones are P1 and P5 due to the lack of solar shadings of the South-East facades coupled with a bad insulation of the roof.

Users complain about the hot conditions of work in summer. They complain as well about the too important air movements in the classrooms.

Recommendations :

It is recommended :

- to improve the insulation of the roof;
- to install fixed solar blades to shade the openings of classrooms P1 and P5.

Africa-Europe Bioclimatic Collaboration 21

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

MBAKADOU SCHOOL - SENEGAL

ABC21 is funded by the EU's H2020 programme

Authors

Name	Email	Institution
Virginie Grosdemouge	Virginie.grosdemouge@univ-reunion.fr	UR
François Garde	francois.garde@univ-reunion.fr	UR

Revision

Version	Date	Author	Description of changes
V0	19.05.2023	Virginie Grosdemouge and François GARDE	Draft of the document

CONTENTS

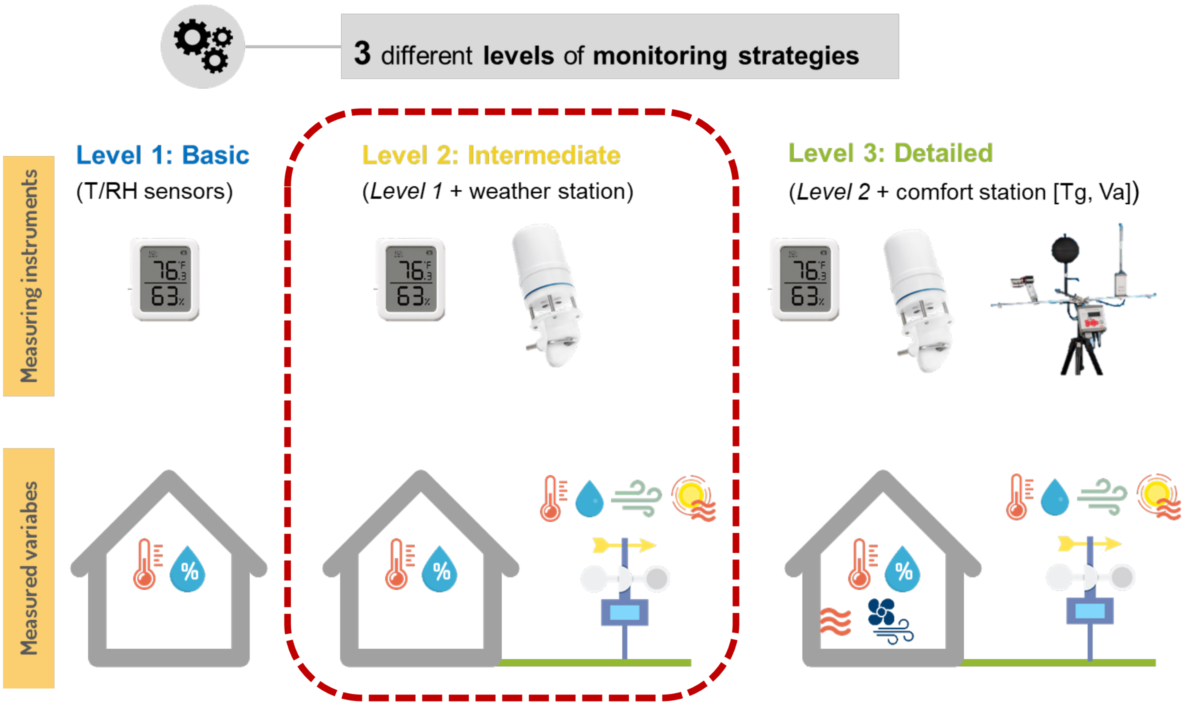
1. Presentation of the case study

Name	Mbakadou School
Architect / Designer	Architetti Senza Frontiere Italia
Location	15.291778, -15.936056
City	Mbakadou
Country	Senegal
Building type	Educational
Climate zone (Köppen–Geiger)	BSh: Hot semi-arid steppe
Description	The school consists of three independent classrooms, a fence with 14 tanks for collecting rainwater, a cassava orchard, a kitchen with a bread oven, a toilet block, and an ablution area. The school's newest classroom, built between 2018 and 2019, is characterised by a thatch roofing in typha that shapes a porch all around the building and shelters the earthen walls from the rain; clusters of windows on the East, South, and West sides that allow natural free cooling; an entrance protected from winds. The building combines low-tech technologies and local traditional knowledge: Foundations are made of on-site quarried sandbags, walls are of mudbricks and earth plaster, the thatched roof has a structure of wooden planks and bamboo.
Main bioclimatic strategies	Cross natural ventilation High thermal mass of the walls and roofs Use of local materials (mudbricks and typha) Large roof overhangs Cassava garden, shrubs and trees

ABC21 is funded by the EU's H2020 programme

2. Material and method

2.1 Monitoring campaign level



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: start date: 15/11/2022 End date: 10/03/2023

Occupied hours: 8:00am – 4:00pm

Collection of weather data:

- ☐ National weather station close to the site - distance from the site: …km
- ☒ TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield

Issues encountered:

- ☒ Missing data: Important missing data from 9th January to 29th January for all T/RH Sensors (22% of missing data for Meter 1 and 27% for Meter 2)
- ☒ Shortage
- ☒ Wifi connection
- ☐ Others:

2.2.1 Sensors and weather station location

This section gives information about the location of the T/RH sensors inside the building and the one of the weather station installed on site.

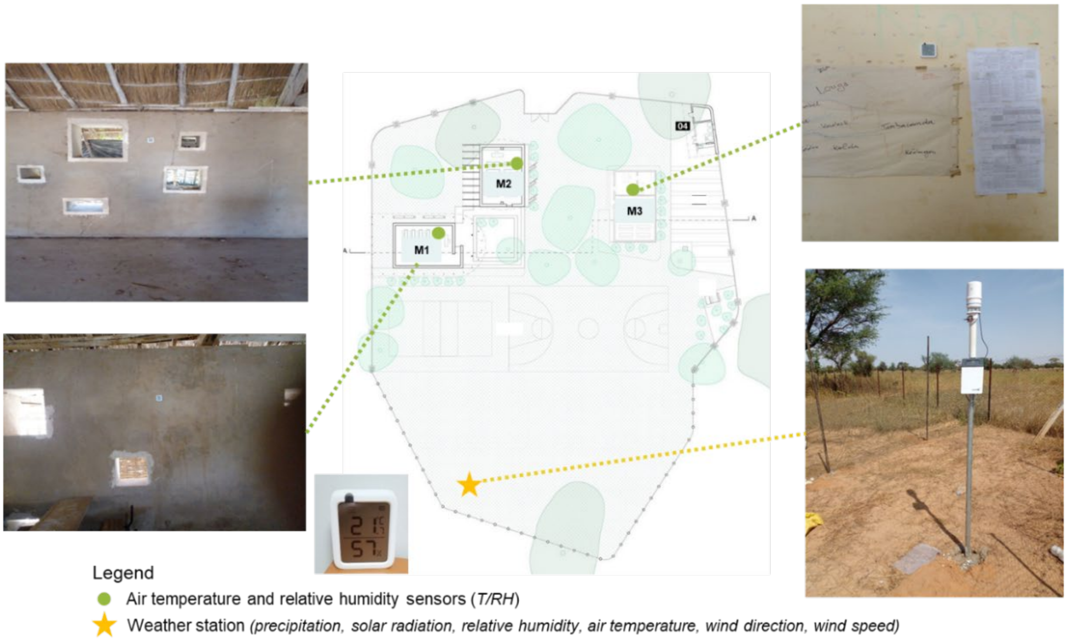


Figure 1: Localisation of the T/RH sensors (Meter 1- "M1" and Meter 2- "M2") and the weather station for the Mbakadou school.

2.2.2 Sensors specification

Details about the sensors are given in the table below

Instrument	Code in Fig. 1	Measured variables	Measuring range	Accuracy	Resolution
Switchbot Meter Plus	●	Air temperature (T)	-20 to 80°C	-20 to 0°C [±0.4°C] 0 to 65°C [±0.2°C] 65 to 80°C [±0.3°C]	0.1 °C
		Relative humidity (RH)	0 to 99%RH	0 to 10 %RH [±4%] 10 to 90%RH [±2%] 90 to 99%RH [±4%]	1 % RH
TAHMO weather station	★	Solar Radiation	0–1750 W/m²	±5% of measurement typical	1 W/m²
		Precipitation	0–400 mm/h	±5% of measurement from 0 to 50 mm/h	0.0017mm
		Vapour Pressure	0–47 kPa	Varies with temperature and humidity, ±0.2 kPa typical below 40 °C	0.01 kPa
		Relative Humidity	0–100% RH (0.00–1.00)	Varies with temperature and humidity, ±3% RH typical	0.1%RH
		Air Temperature	–50 to 60 °C	±0.6°C	0.1°C
		Barometric Pressure	50–110 kPa	±0.1 kPa from –10 to 50 °C ±0.5 kPa from –40 to 60 °C	0.01 kPa
		Horizontal Wind Speed	0–30 m/s	The greater of 0.3 m/s or 3% of measurement	0.01 m/s
		Wind Gust	0–30 m/s	The greater of 0.3 m/s or 3% of measurement	0.01 m/s
		Wind Direction	0° to 359°	±5°	1°
		Tilt	-90° to 90°	±1°	0.1°

2.3 Post Occupancy Evaluation Surveys

No questionnaire surveys were conducted for this case study.

3. Results and discussion

3.1 Boxplot

Figure 2 below presents the boxplot of air temperature for the two studied buildings over the total period of measurements as well as the one for the outdoor conditions extracted from the TAHMO weather station on site. The mean indoor temperature is equal to 27°C in building 1 while it is around 26.5°C for building 2 as well as for the outside temperature. The minimum temperature does not drop below 16°C compared to the outside temperature that can reach 11°C. The maximum of air temperature inside ranges between 36 to 38°C while it can exceed 40°C outside. Indoor conditions seem to be better in building 2 than in building one in terms of indoor temperature.

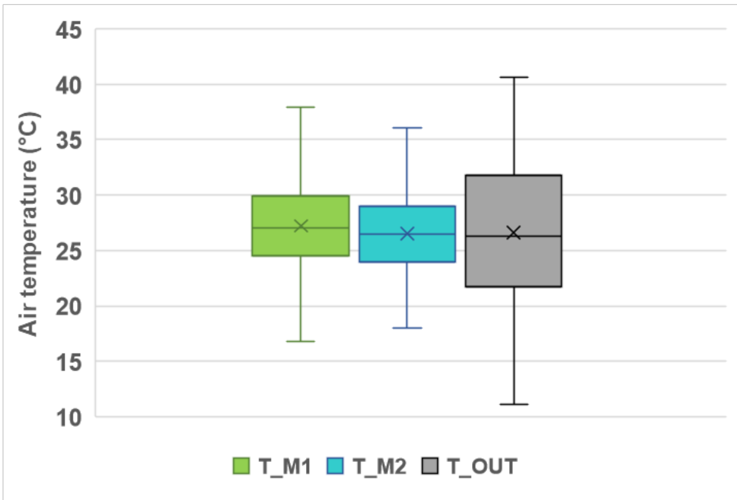
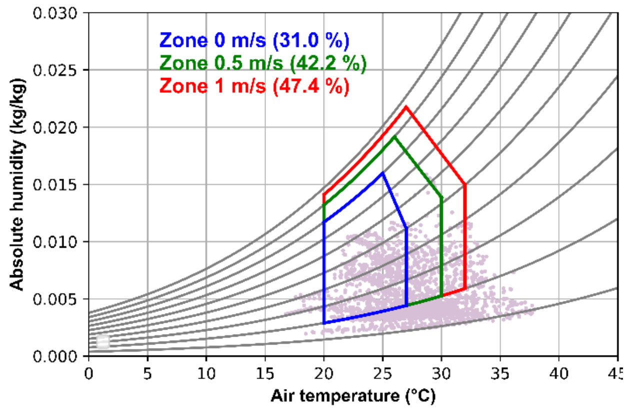


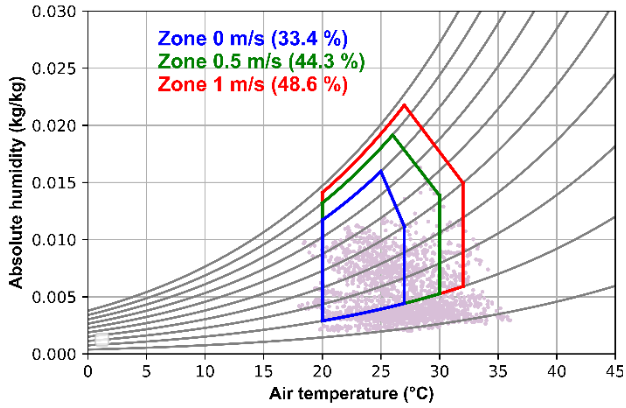
Figure 2: Boxplot of the air temperature for the indoor and outdoor conditions from the 15th of November to the 10th March for the Mbakadou school.

3.2 Givoni comfort zone

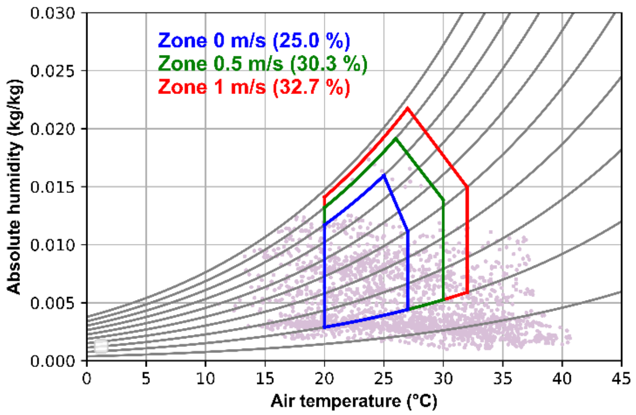
Figure 3 below shows the Givoni comfort zone for each room over the total period of measurements as well as the one for the outdoor conditions over the same period during the occupied hours. It can be observed that there is less dispersion of the air temperature/ relative humidity pairs inside the building compared to the outside. Less than 50% of the T/RH pairs are inside the Givoni comfort zone of 1m/s. Indoor thermal conditions inside could at least be comfortable half of the time if we can have an air velocity equals to 1m/s. Most of the pairs that are not inside the comfort zones presents very low level of humidity or air temperature higher than 32°C.



(a)



(b)



(c)

Figure 3: Givoni comfort zones for the conditions in (a) building 1 (Meter 1), (b) building 2 (Meter 2) and (c) for the outdoor conditions from the 15th of November to the 10th March for all hours.

3.3 Number of hours / frequency within a certain temperature range

This section presents the number of hours and the frequency of air temperature by bins of 2°c for the different monitored rooms during the occupied hours only and for the outdoor conditions.

Warm period: 15th Nov. 2022 to 10th March 2023 Occupation time: 8:00am to 4:00pm	METER 1 – M1		METER 2 – M2		OUTDOOR CONDITIONS	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<20°C	28	3,7%	24	3,1%	40	5,2%
20°C≤Ta<22°C	36	4,7%	64	8,3%	31	4,0%
22°C≤Ta<24°C	82	10,7%	89	11,6%	46	6,0%
24°C≤Ta<26°C	102	13,3%	122	15,9%	52	6,8%
26°C≤Ta<28°C	125	16,3%	142	18,5%	66	8,6%
28°C≤Ta<30°C	139	18,1%	139	18,1%	83	10,8%
30°C≤Ta<32°C	126	16,4%	114	14,9%	109	14,2%
32°C≤Ta<34°C	89	11,6%	61	8,0%	129	16,8%
34°C≤Ta<36°C	21	2,7%	12	1,6%	102	13,3%
Ta≥36°C	19	0,7%	0	0,0%	109	14,2%

The air temperature inside the buildings is mostly below 34°C and only exceeds 34°C a few time (1.6 to 3.4% of the occupied time) while it exceeds 34°C more than 27% of the time outside.

3.4 Number of hours / frequency by relative humidity range (all level of monitoring)

This section presents the number of hours and frequency of air relative humidity by bins of 10% RH for the different monitored rooms during the occupied hours only and for the outdoor conditions.

Warm period: 15th Nov. 2022 to 10th March 2023 Occupation time: 8:00am to 4:00pm	METER 1 – M1		METER 2 – M2		OUTDOOR CONDITIONS	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency	Nb of Hours	Frequency
[0,10%[	26	3,4%	34	4,4%	**279**	**36,4%**
[10,20%[	**383**	**49,9%**	**361**	**47,1%**	**238**	**31,0%**
[20,30%[	**170**	**22,2%**	**143**	**18,6%**	**118**	**15,4%**
[30,40%[	**113**	**14,7%**	**116**	**15,1%**	**56**	**7,3%**
[40,50%[	58	7,6%	67	8,7%	36	4,7%
[50,60%[	11	1,4%	29	3,8%	21	2,7%
[60,70%[	6	0,8%	17	2,2%	7	0,9%
[70,80%[	0	0,0%	0	0,0%	8	1,0%
[80,90%[	0	0,0%	0	0,0%	1	0,1%
[90,100%[	0	0,0%	0	0,0%	3	0,4%

The relative humidity inside the rooms ranges between 10 to 50 % for the majority of the occupied hours but can fall below 10% during some hours. The relative humidity outside is lower than inside and is below 10% more than 35% of the time.

3.5 Analysis of a representative week

3.5.1 Solar radiation profile

Global solar radiation measured by the weather station on site has been plotted for a typical hot week, from the 28th Nov. to the 3rd Dec. 2022, and is presented in Figure 4 below.

Almost all days were sunny days, except the third one, that was a cloudy day, with peaks of solar radiation that range between 800 to 900 W/m^2.

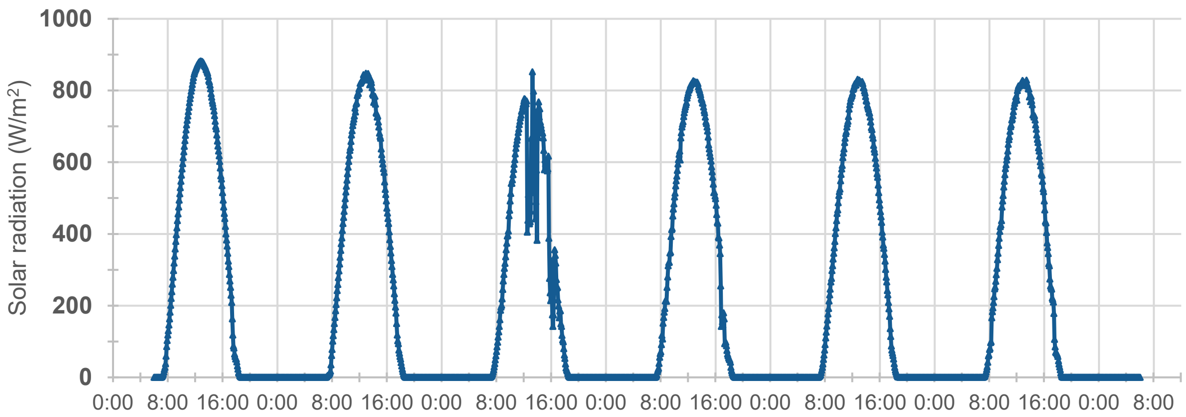


Figure 4 : Solar radiation profile from the 28th Nov. to 3rd Dec 2022 at Mbakadou school.

3.5.2 Wind profile

Wind speed measured by the weather station on site has been **plotted for the same typical hot week than section before** and is presented in Figure 5**.**
The highest values of the wind speed are observed between 8:00am and 4:00pm, i.e., during the occupied hours. The mean wind speed outside between 8:00am and 4:00pm is approximately **2,3 m/s.**

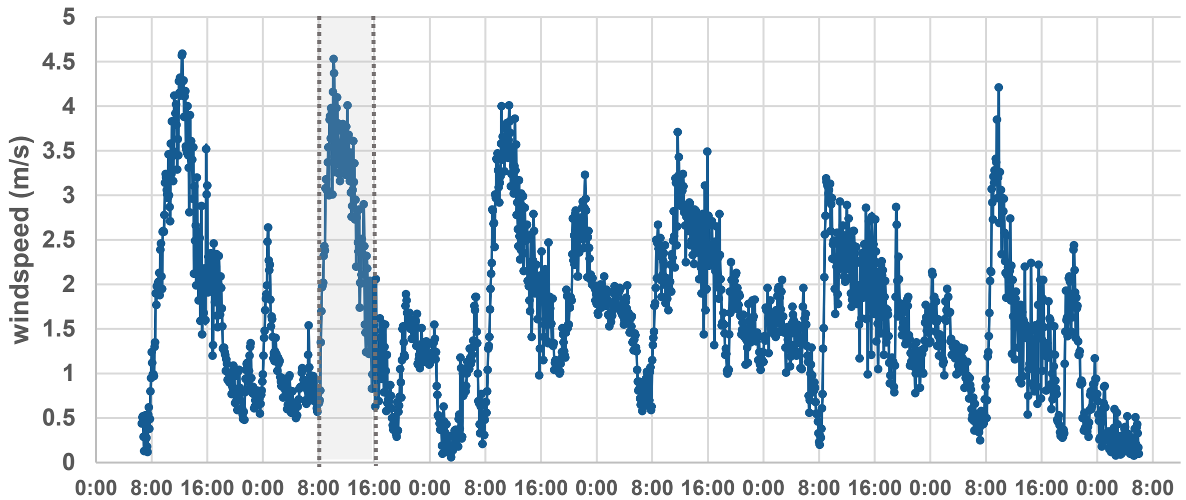


Figure 5 : Wind speed profile from the 28th Nov. to 3rd Dec 2022 at Mbakadou school

3.5.3 Air temperature profile

Air temperature profiles inside the two buildings have been plotted for the same typical hot week along with the outdoor air temperature (obtained from the weather station on site) and is presented in Figure 6 below.

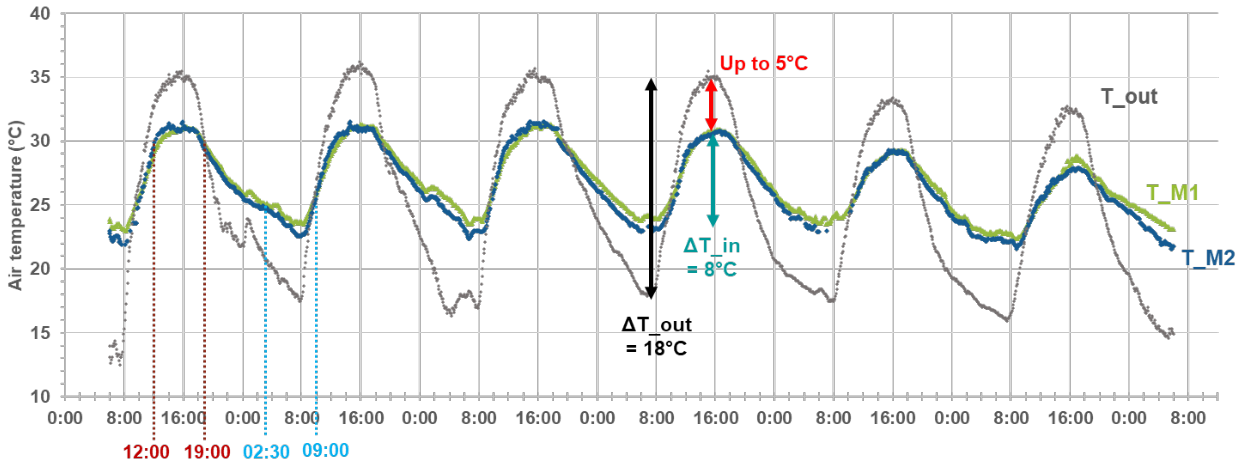


Figure 6: Air temperature profiles for the Mbakadou school from the 28th Nov. to 3rd Dec 2022.

It can be observed that the maximum of air temperature inside the buildings is 5°C below the maximum value of air temperature outside (Tmax_in = Tmax_out – 5°C).
In addition, the diurnal air temperature variation inside is equal to 8°C whereas the diurnal variation is much higher for the outside air temperature with 18°C (ΔT_in = 8°C while ΔT_out = 18°C).

4. Lessons learnt and recommendations

Lessons learnt :

1. The different results obtained highlight the impact of the high thermal inertia of the materials used, with the mud brick walls of 40 cm and the typha roof of 35cm.
2. Another important point to emphasise is that no thermal lag is observed in this case study while this phenomenon is generally observed in buildings with high thermal inertia. One of the assumptions made is that since the buildings are made of small openings with no glass (only simple holes in the walls), the air is continuously entering the buildings both during the day and at night and is counterbalancing the effect of thermal mass.
3. Finally, the use of natural ventilation alone is possible from 8:00am to 12:00 am since the air temperature outside is below 32°C until 12:00 am and mean wind speed outside is around 2.3m/s. Then, since the temperature is above 32°C, natural ventilation alone should not be used.

Recommendations:

1. Natural ventilation alone should be used only when the air temperature outside is below 32°C
2. When the air temperature outside is above 32°C, it is recommended to:
   - To **minimize** the use of **openings** (only for hygienic purpose) and to combine the use of **ceiling fans** and **evaporative cooling** (vegetation / water features)
   - Or to combine comfort ventilation principle with **evaporative cooling solutions**

Direct or indirect evaporative cooling solutions can be used since the relative humidity is very low and these solutions will help decrease the air temperature.

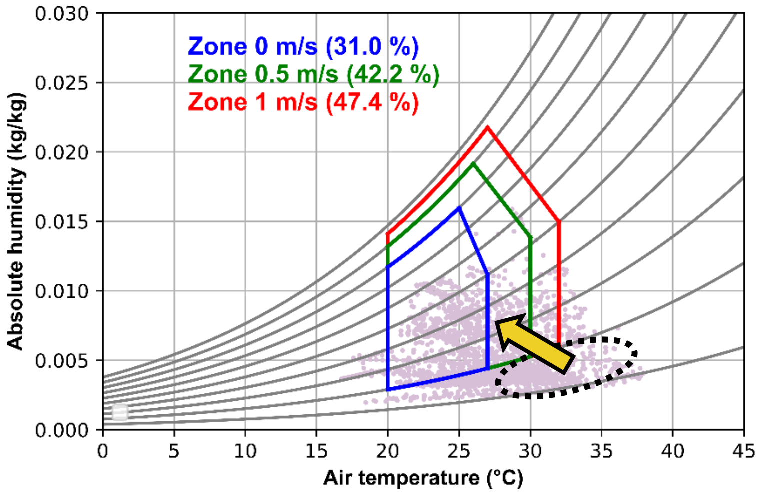


Figure 7: Givoni diagram for the conditions inside the building 1 (Meter 1) and direct evaporative principle.

<u>**Solutions to be considered for:**</u>

Step 1: Harvesting water:

- from air during the night from condensation on corrugated iron sheets;
- or thanks to fog collectors;
- or by digging a well.

Step 2: To use **water mist spray systems** during the day.

Africa-Europe Bioclimatic Collaboration 21

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

CFP NIORO - SENEGAL

ABC21 is funded by the EU's H2020 programme

Authors

Name	Email	Institution
François GARDE	garde@univ-reunion.fr	UR
Ernest DIONE	ernes.dione@gmail.com	DEEc

Revision

Version	Date	Author	Description of changes
V0	26.07.2023	François Garde &Ernest Dione	Final version

CONTENTS

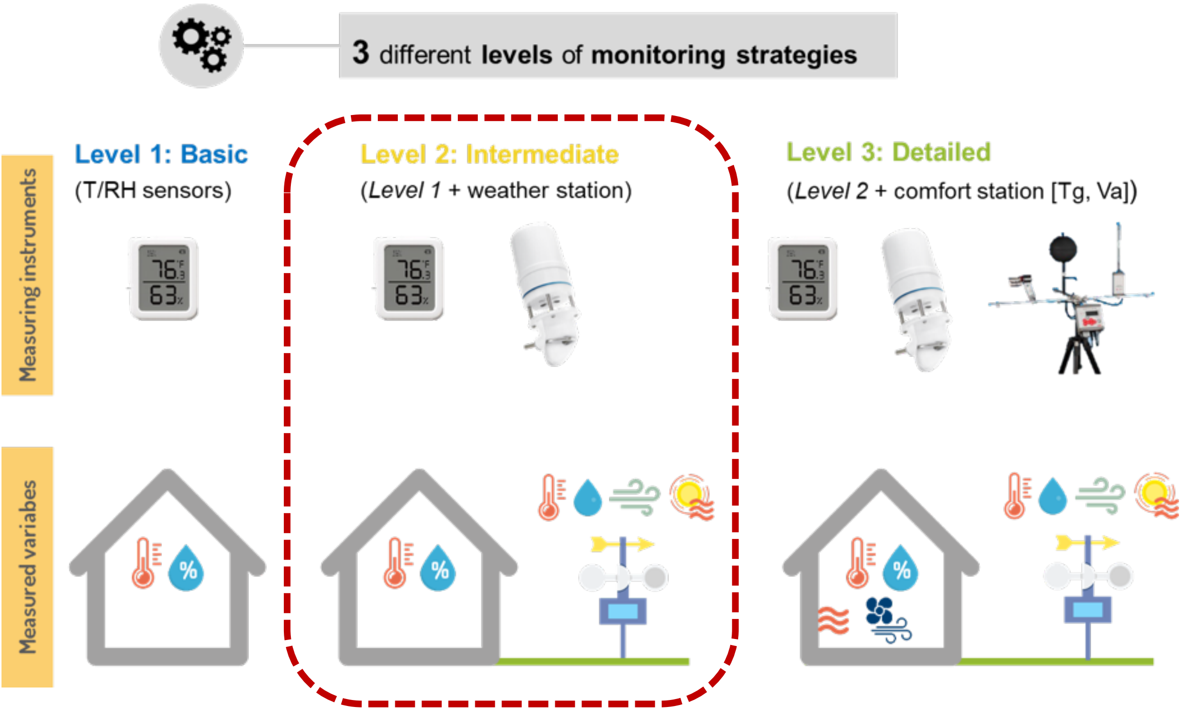
1. Presentation of the CFP NIORO/SENEGAL

The professional training Center of Nioro (CFP of Nioro) combines several uses into one place, such as food production, hairdressing trade as well as dyeing, cutting and sewing activities; catering area; accommodation area; classrooms and conference rooms; technical rooms and lavatories. Based on a pavilion type architecture; the different elements are linked by exterior walkways, forming a compact unit, with a shape close to that of the square. This allows it to be easily adapted to any plot of similar size which could be the subject of a similar program in the future, as requested by the project owner. The project relies on a bioclimatic concept and a sustainable approach in terms of energy and comfort based on the optimization of the physical characteristics of the building.

Name	Centre de Formation Professionnelle de NIORO (CFP Nioro)
Architect / Designer	KHôZé architecture
Location	13.744376437735298, 15.76656745830613
City	Nioro
Country	Senegal
Building type	Educational
Climate zone (Köppen–Geiger)	BWh: Arid, desert, hot
Description  *Figure 1 : Exterior view of the CFP Nioro buildings.*  *Figure 2: Site plan of the CFP Nioro buildings.*	CFP Nioro is a complex composed of several buildings with several uses (administration H , classroom K L, sewing training workshops K, conference room G, housing A). It has fourteen buildings constructed with beam posts with infill with compressed earth bricks. The different buildings are cooled by split-system units and/or adiabatic cooling system. In some spaces, air conditioning is combined with the adiabatic cooling system or with ceiling fans. The center is built on an area of 2100 square meters. In the conference room, bedrooms, AC systems, adiabatic system and ceiling fans. Users have the control on the AC system and ceiling fans. They don't have the control on the adiabatic cooling system.
Main bioclimatic strategies	Vegetation of spaces between buildings. Natural cross ventilation. Detached overhanging roofs protect the interiors from excessive heat Vertical large openings (natural light) High inertia : Walls made of 30 cm compressed earth blocks. Production of domestic hot water by thermal solar panels.

2. Material and method

2.1 Monitoring campaign level



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: start date: 28/10/2022 End date: 10/03/2023

Collection of weather data:

- ☐ National weather station close to the site :
- ☒ TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield

Issues encountered:

- ☒ Missing data
- ☒ Shortage
- ☒ Wifi connection
- ☐ Others

2.2.1 Sensors and weather station location

This section gives information about the location of the sensors inside the building and outside for the TAMO weather station. T°/RH sensors are fixed on walls generally at a heigh of 2 m.

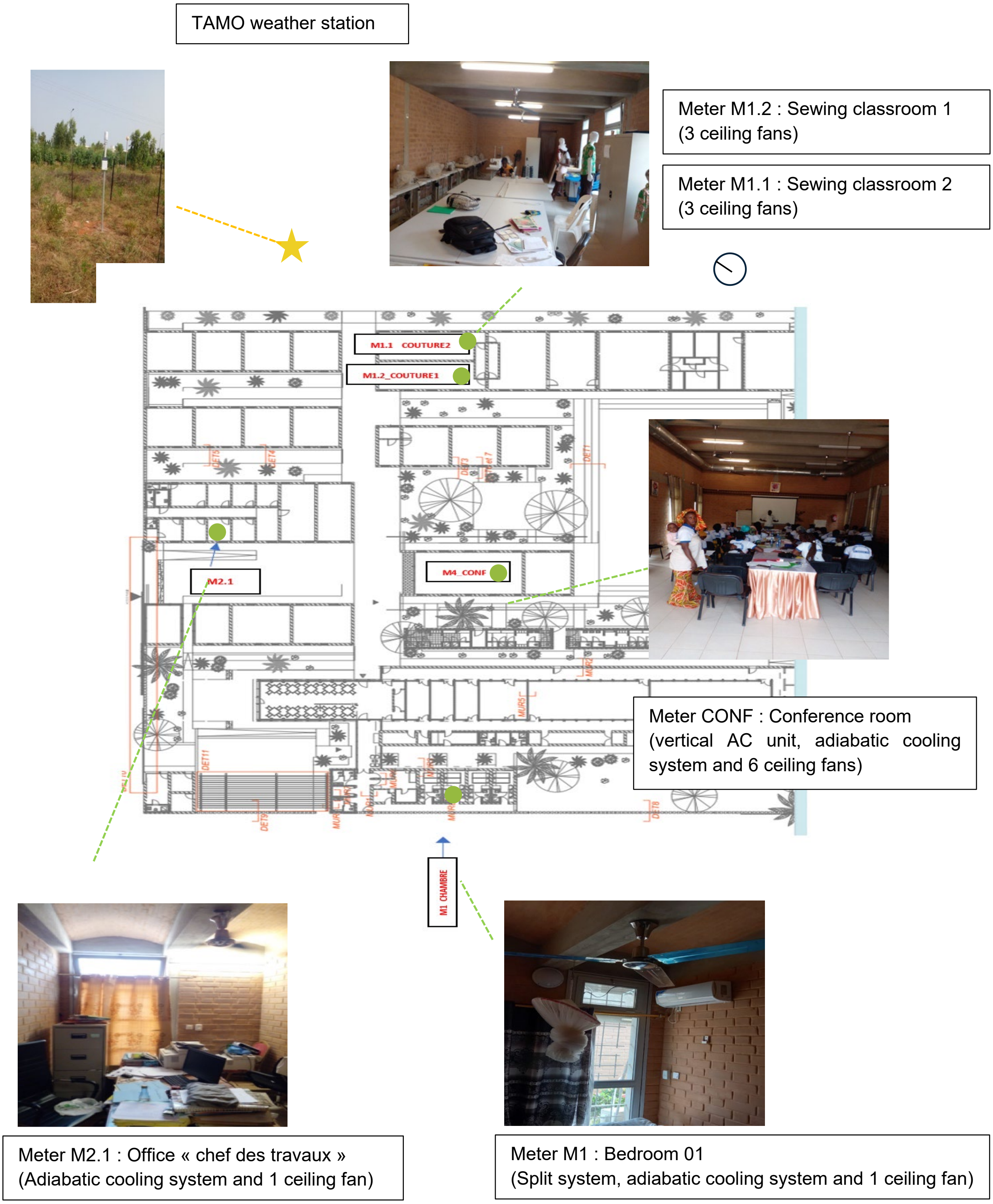


Figure 3: Sensors and Tahmo location for the CFP NIORO

2.2.2 Sensors specification (All sensors)

Details about the sensors are given in the table below

Instrument	Code in Fig. 1	Measured variables	Measuring range	Accuracy	Resolution
Switchbot Meter Plus	●	Air temperature (T)	-20 to 80°C	-20 to 0°C [±0.4°C] 0 to 65°C [±0.2°C] 65 to 80°C [±0.3°C]	0.1 °C
		Relative humidity (RH)	0 to 99%RH	0 to 10 %RH [±4%] 10 to 90%RH [±2%] 90 to 99%RH [±4%]	1 % RH
TAHMO weather station	★	Solar Radiation	0–1750 W/m^2	±5% of measurement typical	1 W/m^2
		Precipitation	0–400 mm/h	±5% of measurement from 0 to 50 mm/h	0.0017mm
		Vapour Pressure	0–47 kPa	Varies with temperature and humidity, ±0.2 kPa typical below 40 °C	0.01 kPa
		Relative Humidity	0–100% RH (0.00–1.00)	Varies with temperature and humidity, ±3% RH typical	0.1%RH
		Air Temperature	–50 to 60 °C	±0.6°C	0.1°C
		Barometric Pressure	50–110 kPa	±0.1 kPa from –10 to 50 °C ±0.5 kPa from –40 to 60 °C	0.01 kPa
		Horizontal Wind Speed	0–30 m/s	The greater of 0.3 m/s or 3% of measurement	0.01 m/s
		Wind Gust	0–30 m/s	The greater of 0.3 m/s or 3% of measurement	0.01 m/s
		Wind Direction	0° to 359°	±5°	1°
		Tilt	-90° to 90°	±1°	0.1°

2.3 Post Occupancy Evaluation Surveys

No POE has been conducted.

ABC21 is funded by the EU's H2020 programme

3. Results and discussion

3.1 Boxplot

Figure 2 below presents the boxplot of air temperature over the total period of measurements as well as the one for the outdoor conditions extracted from the TAHMO weather station on site.

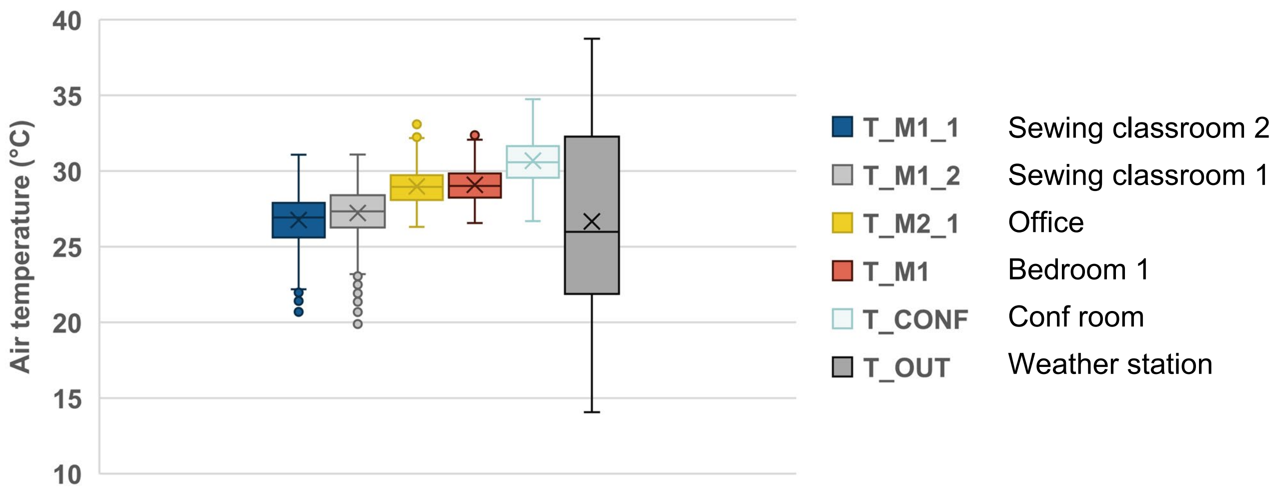


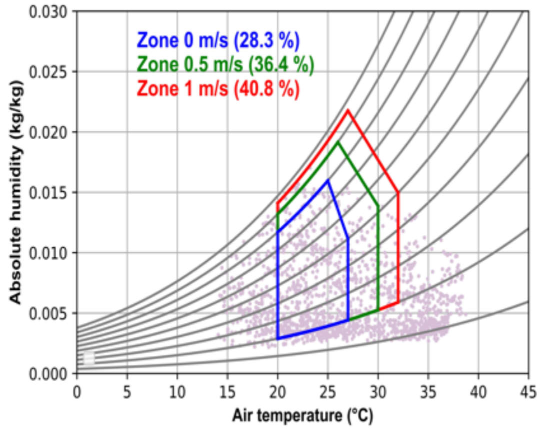
Figure 4 Boxplot of the air temperature for the indoor and outdoor conditions for the CFP of NIORO Givoni comfort zone (Level 1, 2 & 3)

Figure 4 shows that the hotter room is the conference room, followed by the office and bedroom 1.
One hypothesis for the hot conditions of the conference room is this room is not often used and the AC systems are off.
The seewing classrooms are used all the time. The indoor temperature is acceptable and never exceed 31 °C. With the use of ceiling fans, the comfort conditions are acceptable.
The boxplot of the weather station shows that the mean temperature is around 27°C. The IQR (interquartile range) is large for the outdoor temperature whereas all the other IQRs are narrow. This show the effect of high inertia materials (walls made of compressed earth bricks are 30 cm thick).

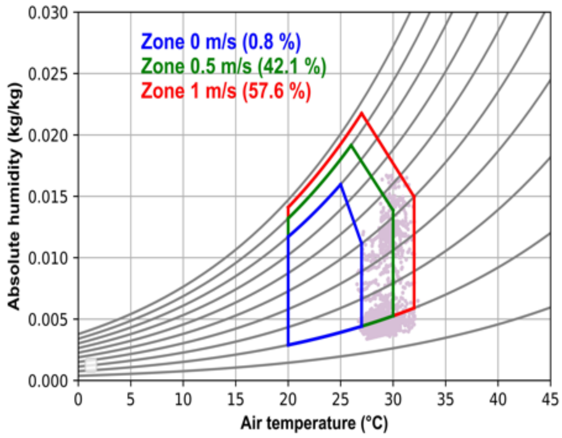
Figure 5 display the Givoni comfort zones for the outdoor conditions and for the different monitored spaces. The outdoor conditions are typical of the BWh climate (Arid, desert, hot). The outdoor air is dry and hot.
One can notice that the comfort conditions are acceptable in the seewing classrooms, despite the lack of AC and adiabatic systems. As the wind speed is low (see Figure 7), one can assume that natural cross ventilation does not work well and that the ceiling fans are efficient and sufficient in terms of number installed. They must generate an air movement of 1 m/s at least. If all these conditions are reached, one can assume that the people feel comfortable.
For all the other spaces (conference room, bedroom, office), the indoor conditions remain dry and hot, despite the active systems (AC and adiabatic systems). As the users can not control the adiabatic system, it is possible that this solution does not work properly.

3.2 Givoni comfort zones

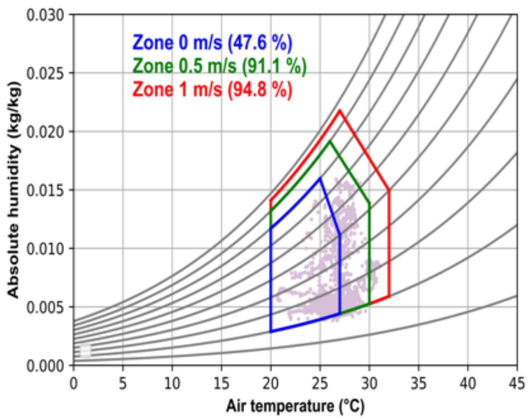
The measurement period has spanned 5 months from : Oct 22 to Feb 2023.



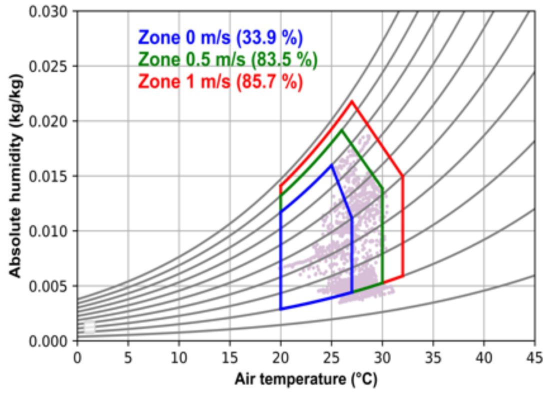
(a) Givoni Nioro OUT_ Weather _station



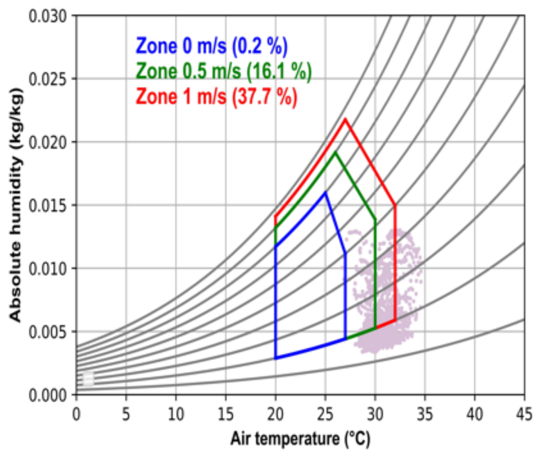
(b) Givoni_meter3 chambre1



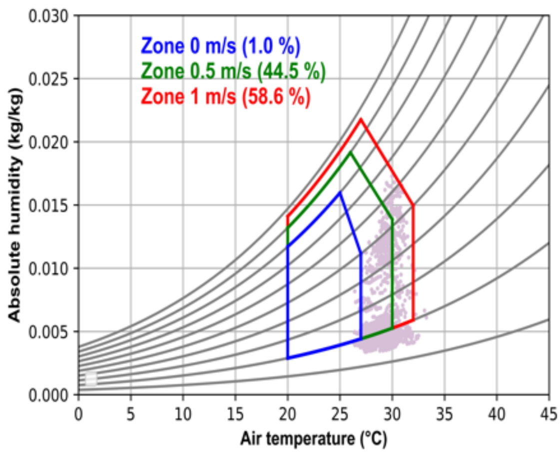
(**c) Givoni_Meter.1.1 : Seewing classroom 2**



(d) Givoni_nioro_meter 1.2 : Seewing classroom 1



(e) **Givoni weather_meter 4 : Conférence room**



(f) Givoni_Weather_meter2.1 : Office chef des travaux

Figure 5: Givoni comfort zones for (a) Weather station TAHMO, (b) Bedroom 1, (c) Sewing classroom 2, (d) Sewing classroom 1, (e) Conference room, (f) Office chef des travaux

3.3 Number of hours / frequency within a certain temperature range

This section presents the number of hours and the frequency of air temperature by bins of 2°c for the different monitored rooms during the occupied hours only and for the outdoor conditions.

Oct 22 to Feb 2023	Seewing classroom 2		Seewing classroom 1		Office		Bedroom 1		Conf room		Weather Station	
	Nb of Hours	Fq.	Nb of Hours	Fq.	Nb of Hours	Fq..	Nb of Hours	Fq..	Nb of Hours	Fq..	Nb of Hours	Fq.
Ta<16°C	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%
16°C≤Ta<18°C	0	0%	0	0%	0	0%	0	0%	0	0%	8	2%
18°C≤Ta<20°C	0	0%	1	0%	0	0%	0	0%	0	0%	10	2%
20°C≤Ta<22°C	13	3%	2	0%	0	0%	0	0%	0	0%	20	5%
22°C≤Ta<24°C	17	4%	19	4%	0	0%	0	0%	0	0%	20	5%
24°C≤Ta<26°C	114	26%	88	20%	0	0%	0	0%	0	0%	26	6%
26°C≤Ta<28°C	194	44%	209	48%	114	26%	114	26%	9	2%	32	7%
28°C≤Ta<30°C	85	19%	110	25%	**224**	51%	**223**	51%	**214**	49%	27	6%
30°C≤Ta<32°C	14	3%	8	2%	**92**	21%	**97**	22%	**152**	35%	42	10%
32°C≤Ta<34°C	0	0%	0	0%	7	2%	3	1%	54	12%	75	17%

3.4 Number of hours / frequency by relative humidity range

This section presents the number of hours and frequency of air relative humidity by bins of 10% RH for the different monitored rooms during the occupied hours only and for the outdoor conditions.

Oct 22 to Feb 2023	Seewing classroom 2		Seewing classroom 1		Office		Bedroom 1		Conf room		Weather Station	
	Nb of Hours	Freq.	Nb of Hours	Freq.	Nb of Hours	Freq.	Nb of Hours	Freq.	Nb of Hours	Freq.	Nb of Hours	Freq.
[0,10%[	0	0,00%	0	0,00%	0	0,00%	0	0,00%	0	0,00%	50	0,23%
[10,20%[	20	4,58%	**79**	18,08%	**164**	37,53%	**170**	38,90%	**233**	53,32%	209	1,83%
[20,30%[	203	46,45%	150	34,32%	140	32,04%	128	29,29%	126	28,83%	89	2,29%
[30,40%[	84	19,22%	37	8,47%	44	10,07%	55	12,59%	59	13,50%	45	4,58%
[40,50%[	80	18,31%	80	18,31%	73	16,70%	68	15,56%	18	4,12%	19	4,58%
[50,60%[	43	9,84%	55	12,59%	15	3,43%	15	3,43%	1	0,23%	11	5,95%
[60,70%[	6	1,37%	32	7,32%	1	0,23%	1	0,23%	0	0,00%	6	7,32%
[70,80%[	1	0,23%	4	0,92%	0	0,00%	0	0,00%	0	0,00%	2	6,18%
[80,90%[	0	0,00%	0	0,00%	0	0,00%	0	0,00%	0	0,00%	3	9,61%

One can clearly see that the hottest and driest spaces are the conference room, bedroom 1 and the office, with around 200 hours of hot and dry conditions (less than 20% of relative humidity).

ABC21 is funded by the EU's H2020 programme

3.5 Analysis of a representative week

3.5.1 Solar radiation profile

Global solar radiation measured by the weather station on site has been plotted for a typical hot week, from Feb 1st to the Feb. 7th 2023, and is presented in Figure 6 below.
Almost all days were sunny days, with peaks of solar radiation that range around 800 W/m².

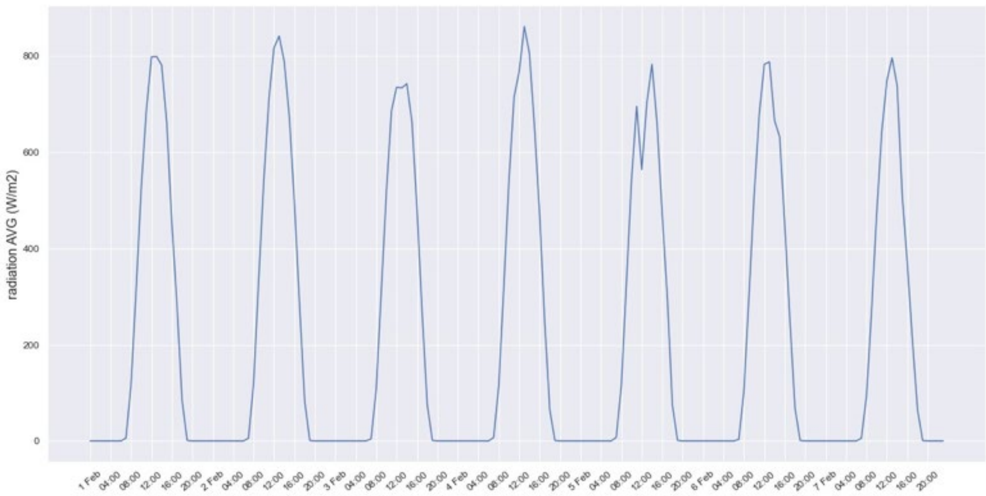


Figure 6 : Solar radiation profile from Feb. 1st to Feb 7th 2023

3.5.2 Wind profile

Wind speed measured by the weather station on site has been plotted for the same typical hot week than section before and is presented in Figure 7. The wind speed ranges from 2-3 m/s during day time to almost zero at night. Most of the time, there is no wind at night.

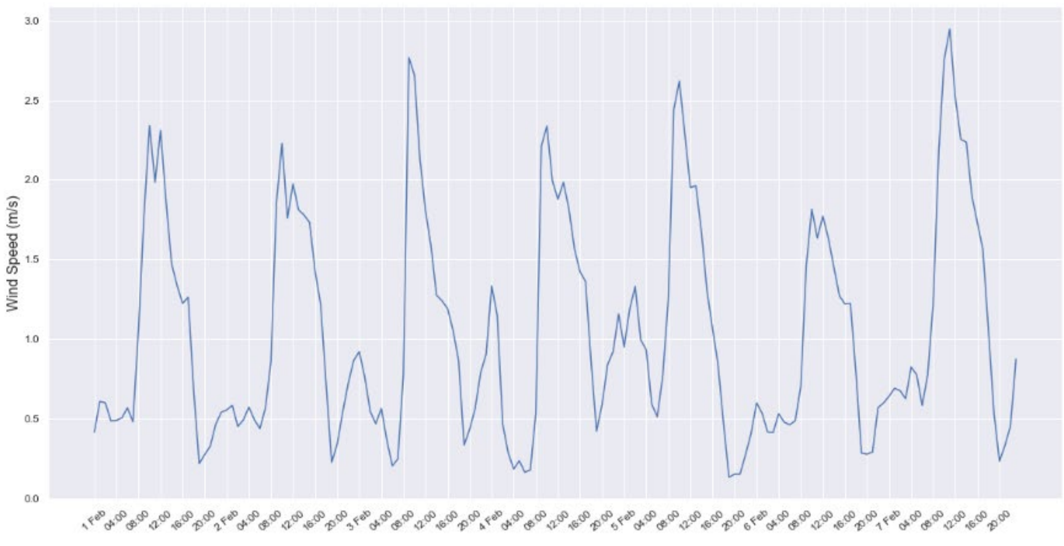


Figure 7: Wind speed profile from Feb. 1st to Feb 7th 2023

3.5.3 Air temperature profile (all level of monitoring)

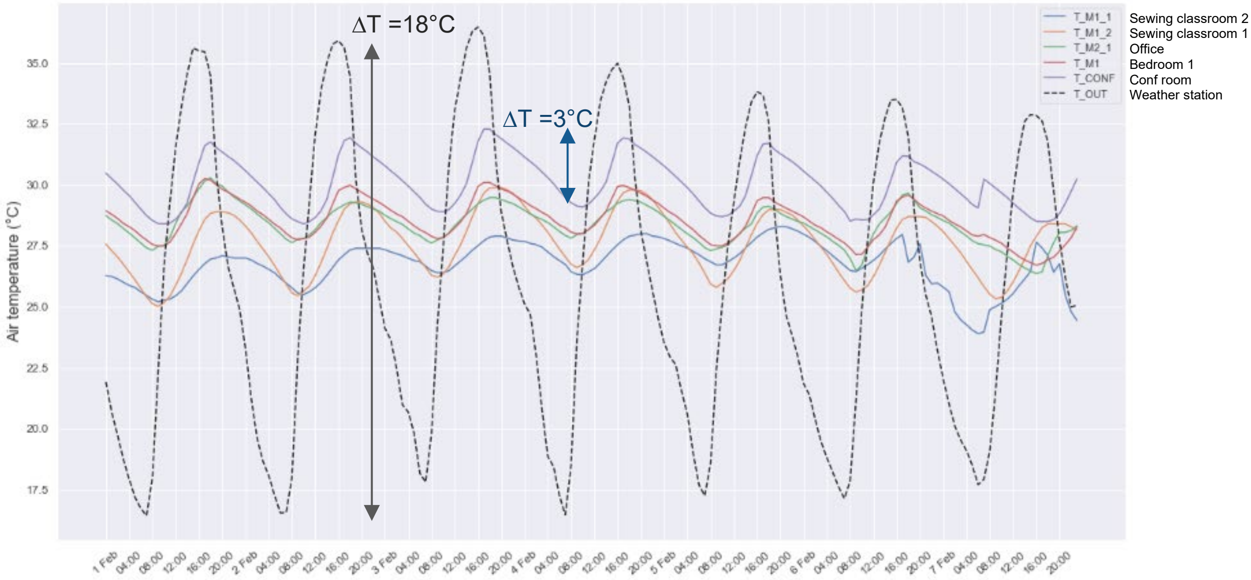


Figure 8 : Air temperature profiles for the CFP Nioro from Feb 1st to Feb 7th

Figure 8 shows that during this representative week, the difference of outdoor temperature during day and night is around 18°C, whereas it is around 3°C maximum for the indoor spaces. One can notice that there is a gap between the maximum of the outdoor temperature and the indoor spaces. This gap is around 4 hours for the seewing classrooms and approximately 2 hours for the other spaces. This shows clearly the effect of the high inertia materials which works well. Surprisingly, the thermal behaviour of the seewing classrooms (only equipped with ceiling fans) is the same as the other spaces (equipped with AC and adiabatic systems). An explanation could be that those systems are not used properly.

The potential of the low outdoor temperature at night is not used properly. It is almost sure that nocturnal convective cooling is not used to cool the buildings at night.

4. Lessons learnt and recommendations

Lessons learnt :

The feedback from users is reserved about the comfort conditions of the building.

The users are happy with their working environment and appreciate the architectural design (based on a pavilion type architecture) and the presence of vegetation in the outdoor spaces.

Nevertheless, some spaces remain hot, dry and uncomfortable and must be improved in terms of thermal comfort.

Recommendations :

- Teach the occupants and the staff how to use properly the building (nocturnal convective cooling, adiabatic system);

- Check if the adiabatic system works well ;
- Improve the management of passing cooling strategies (nocturnal convective cooling, evaporative cooling, natural cross ventilation);
- Check if the ratio ceiling fans
- Extend the adiabatic system to the seewing classrooms and classrooms.

Africa-Europe Bioclimatic Collaboration 21

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

LYCEE MERMOZ - SENEGAL

ABC21 is funded by the EU's H2020 programme

Authors

Name	Email	Institution
François GARDE	garde@univ-reunion.fr	UR
Ernest DIONE	ernes.dione@gmail.com	DEEc

Revision

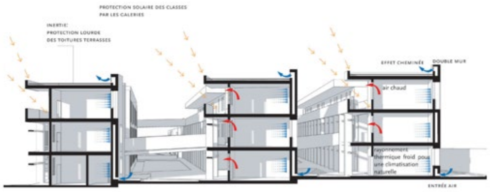
Version	Date	Author	Description of changes
V0	26.07.2023	François Garde &Ernest Dione	Final version

CONTENTS

1. Presentation of the Lycée Jean Mermoz of Dakar

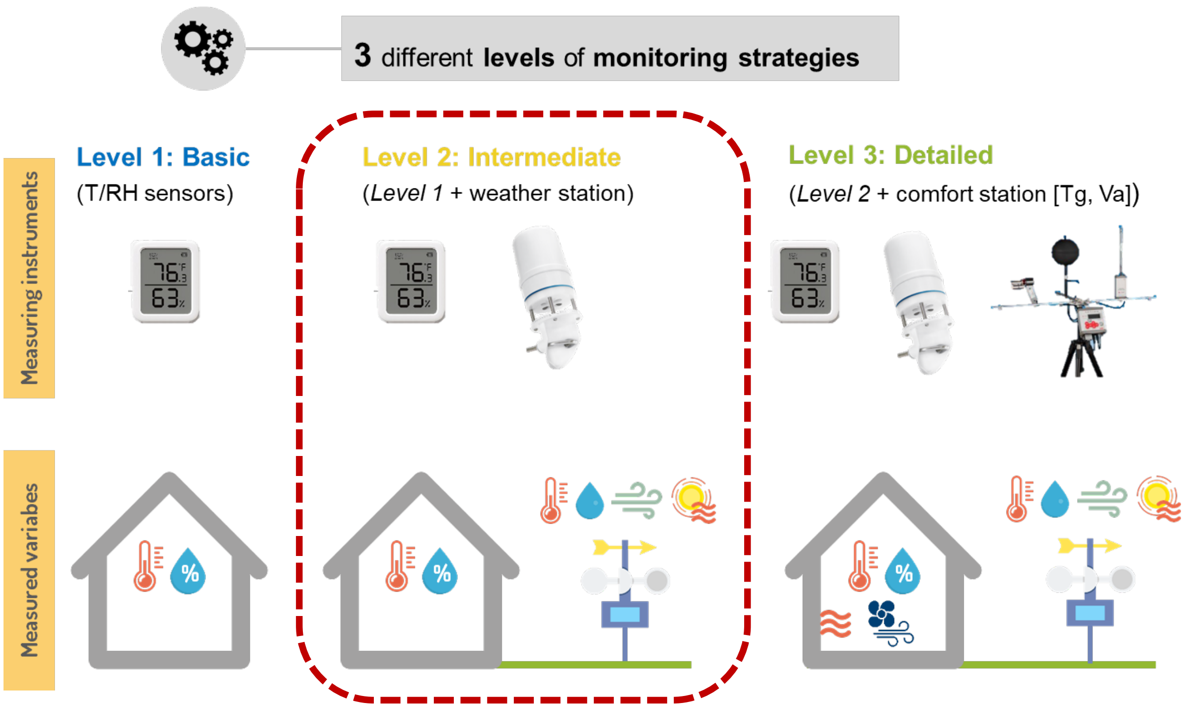
The "Lycée Lycée Mermoz is a completely modern and state-of-the-art building, using innovative passive solutions so as to ensure thermal comfort. This project is based on the local knowledge, enhancing a great economy of technical means and limiting the importation of manufactured products. The layout of the buildings in narrow strips, whose in-betweens form shaded tree-lined interior islands, optimizes natural cross ventilation. The building typology of each entity offers several "passive" solutions for cooling and solar protection: exterior corridors, ventilated double walls, solar shading devices and high inertia of the roofs. All of these features ensure thermal comfort during most of the school year and reduce the period of air conditioning use to one or two months per year. The facility includes a school complex that welcomes students from kindergarten to high school. It also includes an administrative centre and common facilities such as a school restaurant, a multi-purpose room and sports' infrastructures.

Name	LYCEE JEAN MERMOZ | SENEGAL
Architect / Designer	TERRENEUVE architects (lead architect), Adam Yedid Architect (associate architect), Architecture and Climate (Architects and Construction Economics
Location	13.744376437735298, -15.76656745830613
City	Dakar
Country	SENEGAL
Building type	Educational (Kindergarten, primary, high school, CDI, administrative centre and sports platform)
Climate zone (Köppen–Geiger)	BSh: Hot semi-arid steppe
Description	The Mermoz high school is located in the densely built-up Ouakam district, along the western coastline of the Dakar peninsula. The new buildings replace the old high school built temporarily in 1994 and made up of prefabricated modular constructions but benefiting from a very appreciated vegetal environment. The French high school has a special relationship with the surrounding neighbourhood, since the configuration of the site offers only two points of contact with the city. Almost totally enclosed, the lycée is hardly visible from the urban space. The project tends to minimize its impact on the immediate environment, and in particular on the existing urban networks. The traffic and parking of school buses and private vehicles has been taken care of within the plot, as well as all water treatment. The total floor area is estimated at 17 000m^2

<table>
<tr>
<td>Main bioclimatic strategies

</td>
<td>Comfort ventilation (natural cross ventilation)
The arrangement of the buildings in relation to each other generates micro-climates in the patios that enhance the natural cooling of the interior spaces.
The trade winds, which benefit the oceanic climate of Dakar, justify the linear and tight organization of the buildings which amplifies the effect of the air movements and increases the impression of freshness.
The rooms are equipped with French windows in the double-walled facades and louvers on the corridor side, which can be used for night-time cooling and also act as an anti-intrusion strategy.
High thermal mass of the roofs
On the front facade of the teaching spaces, galleries and awnings prevent the sun from impacting the facades during the hottest hours. On the rear facade, ventilated double walls prevent the interior walls from heating up, and form thick walls and window panels that limit direct sunlight.
All exterior corridors and common pathways are at the same time places of life, architectural walks, and solar protection.
Pergolas planted with Bougainvillea and other tropical species also provide shaded spaces.</td>
</tr>
</table>

2. Material and method

2.1 Monitoring campaign level



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: start date: 29 09 2022 End date: 14 04 2023

Collection of weather data: X

- ☐ X National weather station close to the site: from the site 8 km
- ☐ X TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield

Issues encountered:

X Missing data:
X Shortage
X Wifi connection
☐ Others:

<u>IMPORTANT NOTE :</u> we are not sure about the quality of data. Lots of issues have been encountered (shortage, missing data etc.). The following sections will present a first draft but does not reflect the actual behaviour of the monitored spaces. They give general trends that need to be confirmed by a new measurement campaign.

ABC21 is funded by the EU's H2020 programme

2.2.1 Sensors and weather station location

This section gives information about the location of the sensors inside the building and outside for the TAMO weather station. T°/RH sensors are fixed on walls generally at a heigh of 2 m.

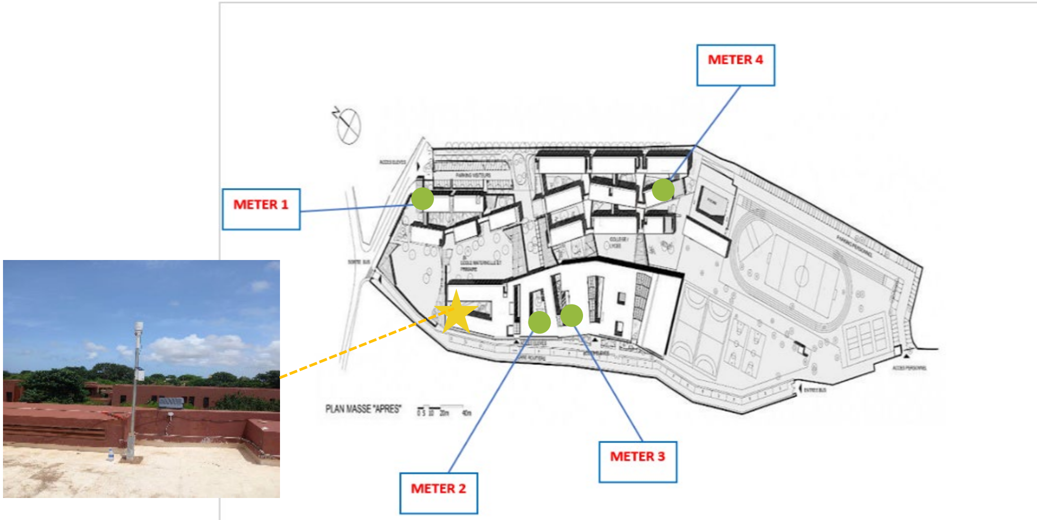


Figure 1: Sensor location for the Lycée Mermoz Meter1 (Bureau Abdallah), Meter 2 (Bureau Proviseur) Meter 3 (Learning centre -CDI) Meter 4 (Classe E24)

2.2.2 Sensors specification

Details about the sensors are given in the table below

Instrument	Code in Fig. 1	Measured variables	Measuring range	Accuracy	Resolution
Switchbot Meter Plus	●	Air temperature (T)	-20 to 80°C	-20 to 0°C [±0.4°C] 0 to 65°C [±0.2°C] 65 to 80°C [±0.3°C]	0.1 °C
		Relative humidity (RH)	0 to 99%RH	0 to 10 %RH [±4%] 10 to 90%RH [±2%] 90 to 99%RH [±4%]	1 % RH
TAHMO weather station	★	Solar Radiation	0–1750 W/m^2	±5% of measurement typical	1 W/m^2
		Precipitation	0–400 mm/h	±5% of measurement from 0 to 50 mm/h	0.0017mm
		Vapour Pressure	0–47 kPa	Varies with temperature and humidity, ±0.2 kPa typical below 40 °C	0.01 kPa
		Relative Humidity	0–100% RH (0.00–1.00)	Varies with temperature and humidity, ±3% RH typical	0.1%RH
		Air Temperature	–50 to 60 °C	±0.6°C	0.1°C
		Barometric Pressure	50–110 kPa	±0.1 kPa from –10 to 50 °C ±0.5 kPa from –40 to 60 °C	0.01 kPa
		Horizontal Wind Speed	0–30 m/s	The greater of 0.3 m/s or 3% of measurement	0.01 m/s
		Wind Gust	0–30 m/s	The greater of 0.3 m/s or 3% of measurement	0.01 m/s
		Wind Direction	0° to 359°	±5°	1°
		Tilt	-90° to 90°	±1°	0.1°

ABC21 is funded by the EU's H2020 programme

3. Results and discussion

3.1 Boxplot

Figure 2 below presents the boxplot of air temperature over the total period of measurements as well as the one for the outdoor conditions extracted from the TAHMO weather station on site.

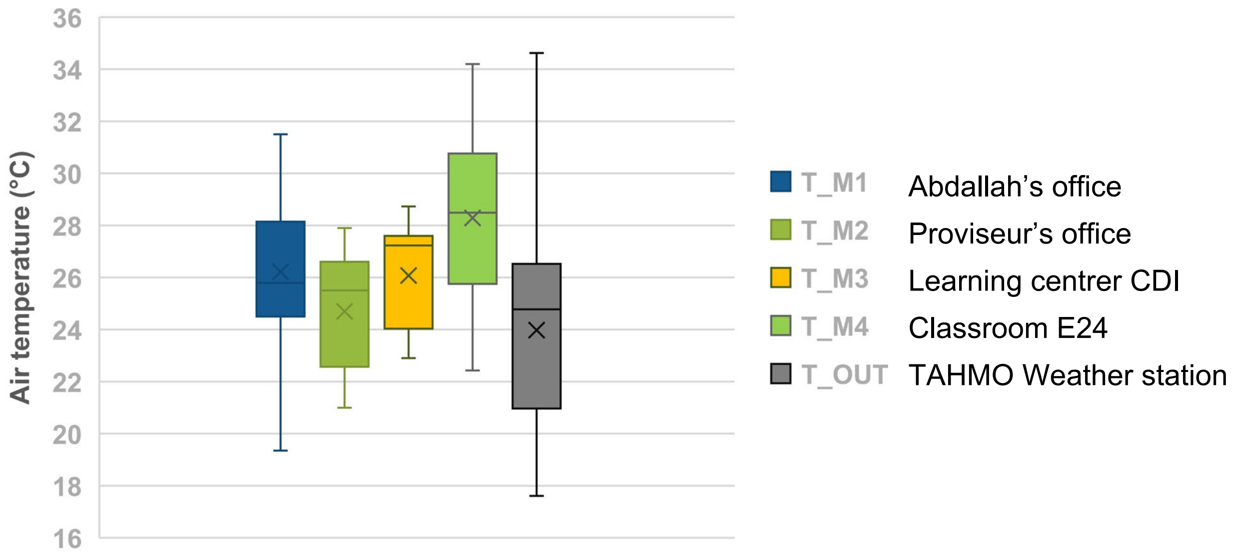


Figure 2: Boxplot of the air temperature for the indoor and outdoor conditions Lycee Jean Mermoez Dakar

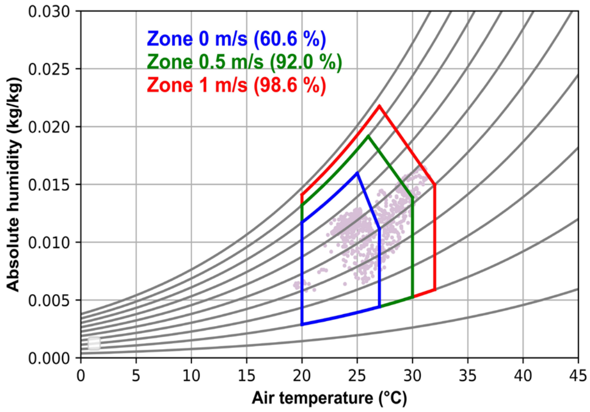
The boxplot of the weather station shows that the outdoor condition are acceptable with c during the monitored period.
In parallel, the hottest space is classroom E24 with 28°c as a mean indoor air temperature. The other spaces

Those comments are confirmed by the Givoni comfort zones. Classroom E24 is really uncomfortable with more that 20% of temperature and humidity pairs outside the Givoni comfort zone of 1m/s.

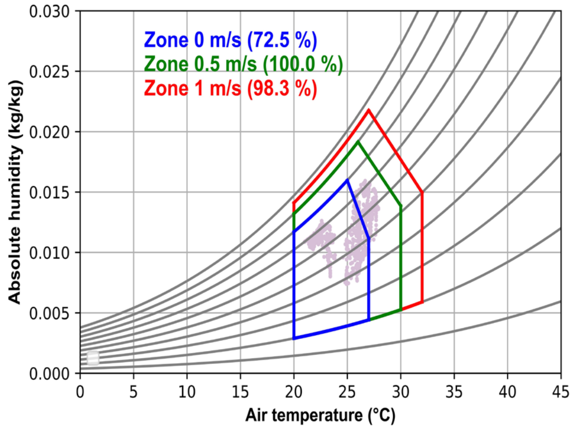
Section 3.3 points out the same conclusions.

ABC21 is funded by the EU's H2020 programme

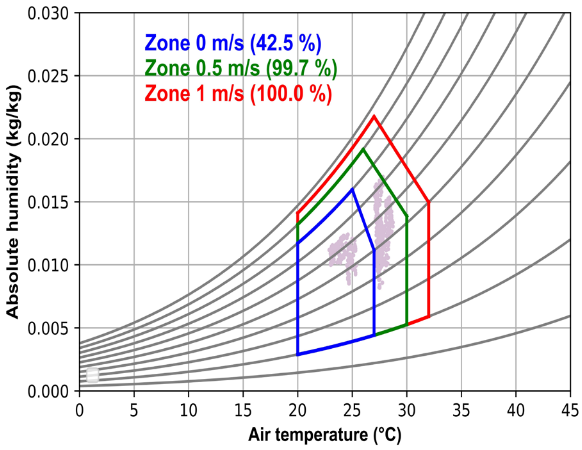
3.2 Givoni comfort zone



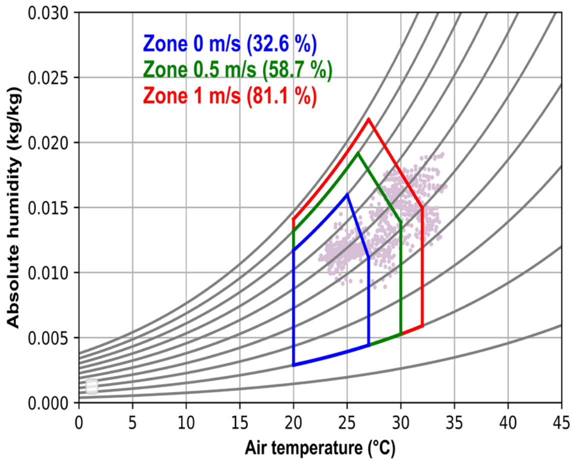
(a) Givoni_mermoz_meter1 (Abdallah)



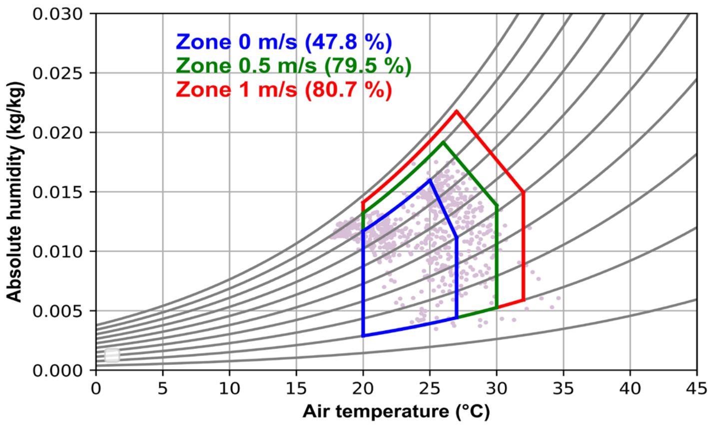
b) Givoni_mermoz_meter2 (Proviseur)



(c) Givoni_mermoz_meter3 (CDI)



d) Givoni_weather_meter4 (Classroom E24)



(e) Givoni_Mermoz_ weather_OUT

Figure 3: Givoni comfort zones for the conditions in (a) Abdallah's office Meter 1 , (b) Proviseur Meter 2 (c) CDI meter 3, (d) Classe E24 Meter 4, (e) for the outdoor conditions from the TAHMO weather station

3.3 Number of hours / frequencies within a certain temperature range

	ABDALLAH' OFFICE meter 1		PROVISEUR meter 2		CDI meter 3		Classroom E24		WEATHER STATION	
	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
Ta<18°C	0	0,00%	0	0,00%	0	0,00%	0	0,00%	3	1,52%
18°C≤Ta<20°C	6	3,03%	0	0,00%	0	0,00%	0	0,00%	12	6,06%
20°C≤Ta<22°C	6	3,03%	14	7,07%	0	0,00%	0	0,00%	41	20,71%
22°C≤Ta<24°C	42	21,21%	67	33,84%	25	12,63%	18	9,09%	13	6,57%
24°C≤Ta<26°C	78	39,39%	64	32,32%	56	28,28%	41	20,71%	36	18,18%
26°C≤Ta<28°C	57	28,79%	52	26,26%	108	54,55%	37	18,69%	52	26,26%
28°C≤Ta<30°C	8	4,04%	0	0,00%	8	4,04%	**59**	29,80%	28	14,14%
30°C≤Ta<32°C	0	0,00%	0	0,00%	0	0,00%	**24**	12,12%	4	2,02%
32°C≤Ta<34°C	0	0,00%	0	0,00%	0	0,00%	**18**	9,09%	6	3,03%
Ta≥34°C	0	0,00%	0	0,00%	0	0,00%	0	0,00%	2	1,01%

3.4 Number of hours / frequency by relative humidity range

	ABDALLAH' OFFICE meter 1		PROVISEUR meter 2		CDI meter 3		Classroom E24		WEATHER STATION	
	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq	Nb of Hours	Fq
[0,10%[	0	0,00%	0	0,00%	0	0,00%	0	0,00%	0	0,00%
[10,20%[	0	0,00%	0	0,00%	0	0,00%	0	0,00%	8	4,04%
[20,30%[	0	0,00%	0	0,00%	0	0,00%	0	0,00%	14	7,07%
[30,40%[	35	17,77%	12	6,06%	9	4,55%	5	2,53%	31	15,66%
[40,50%[	67	34,01%	55	27,78%	65	32,83%	64	32,32%	34	17,17%
[50,60%[	55	27,92%	33	16,67%	63	31,82%	52	26,26%	33	16,67%
[60,70%[	40	20,30%	75	37,88%	42	21,21%	70	35,35%	20	10,10%
[70,80%[	0	0,00%	22	11,11%	18	9,09%	6	3,03%	31	15,66%
[80,90%[	0	0,00%	0	0,00%	0	0,00%	0	0,00%	19	9,60%
[90,100%[	0	0,00%	0	0,00%	0	0,00%	0	0,00%	7	3,54%

4 Lessons learnt and recommendations

Lessons learnt :

Green spaces are appreciated a lot by the users.

This first monitoring campaign points out that the building does not work well in terms of thermal and energy performance. Despite favourable outdoor conditions, the indoor air temperature remains above the outdoor conditions is all the monitored spaces.

All the spaces are air conditioned.
The lack of ceiling fans does not allow to use them to balance the hot conditions or to reduce the period of air-conditioning.

The electric density in terms of consumption is equal to 64 kWh/m^2/year, which is surprisingly high for a building that is supposed to be bioclimatic.
The electric density is 3 times higher compare to a conventional high school.

It is reported that there is not an energy management strategy. Users and staff are not concerned and trained to demand side management.
Air conditioning and artificial lighting are used all day long with sometimes the doors opened to the outside.

We are doubtful about the efficiency of the double wall used for nighttime cooling. Due to the weather conditions that are closed to a tropical climate, this passive solution may not work properly. Also, the position of the different buildings parallel to each other does not facilitate natural cross ventilation.

Recommendations :

- Information and training of the staff and the users to demand side management;
- Install ceiling fans in all the working spaces (1 CF/10 m^2);
- Carry out an in-depth analysis of the electric consumption;
- Launch a new measurement campaign and a POE;
- Hire an energy manager.

ABC21 is funded by the EU's H2020 programme

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

UNITED NATIONS BUILDING IN NAIROBI, KENYA

ABC21 is funded by the EU's H2020 programme

Authors

Name	Email	Institution
Gian Luca Brunetti	gianluca.brunetti@polimi.it	PoliMi
Virginie Grosdemouge	virginie.grosdemouge@univ-reunion.fr	UR
François Garde	francois.garde@univ-reunion.fr	UR
Silvia Erba	silvia.erba@polimi.it	PoliMi
Andrea Sangalli	andrea.sangalli@polimi.it	Polimi

Revision

Version	Date	Author	Description of changes
V0	08.03.2023	Silvia Erba	Draft of the document
V1	13.03.2023	Virginie Grosdemouge	Revision and new propositions
V2	23.03.2023	Virginie Grosdemouge	Revision of the document after partners meeting
V3	07.07.2023	Gian Luca Brunetti	Input of information and text about the monitoring of the building in question and the deriving analysis
V4	22.07.2023	Gian Luca Brunetti	Insertion of new graphic analyses and of the results of inquiries to the occupants

ABC21 is funded by the
EU's H2020 programme

CONTENTS

1 Presentation of the UN Building

This section includes a short description of the project.

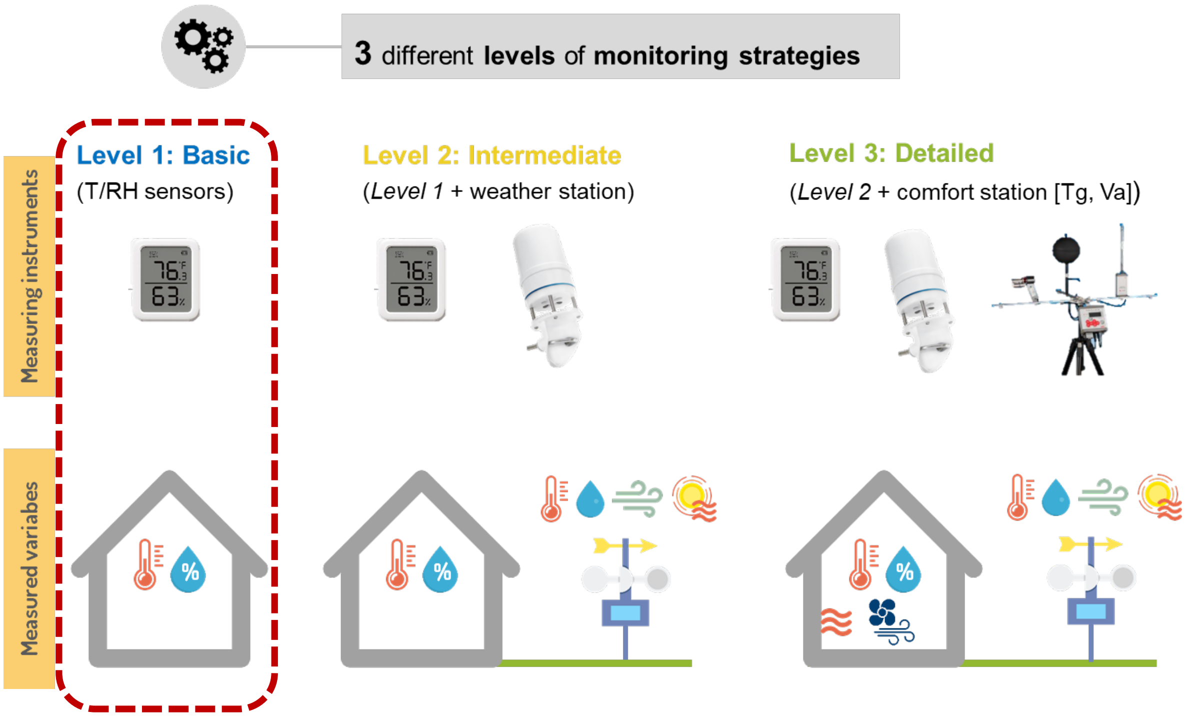
Name	UNON Building, Nairobi
Architect / Designer	Beglin Woods Architects
Location	Parklands/Highridge, United Nations Ave
City	Nairobi,
Country	Kenya
Building type	Offices
Climate zone (Köppen–Geiger)	Cwb: subtropical highland climate. Temperate, dry winter, warm summer
Description	The building is composed of four blocks linked by walkways and enclosing a long atrium/courtyard hosting plants. The central atrium, full-length and top-shaded, runs the length of the building, allowing natural light to flood into offices while encouraging airflow by stack effect.
Main bioclimatic strategies	The top-shaded, "green", full-height, building-long enclosed atrium, in combination with the rooms' openings and the wide overhangs, constitutes the core system driving all the kinds of environmental control involved, from stack effect, to cross-ventilation, to solar shading, lighting control, moisture regulation, and water preservation. In this framework, a substantial role is also played by the top canopy, constituted by a wooden superstructure. Windows remain generally closed. The users have the manual control of opening or not the windows.

ABC21 is funded by the
EU's H2020 programme

2 Material and method

2.1 Monitoring campaign level

The level of monitoring for the case in question is basic, constituted by sensors of dry bulb temperature and relative humidity.



2.2 Data acquisition and equipment

Monitoring campaign: start date: 11/07/2022 End date: 05/30/2023.

Collection of weather data:

- ☐ National weather station near site. Distance from the site: 5 km
- ☒ TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield

The data from the following TAHMO weather stations have been available:

Station id	Location name	Country	Latitude	Longitude
TA00025	Kenya Meteorological Department	Kenya	-1.3018389	36.7602
TA00057	St. Scholastica Catholic School	Kenya	-1.253029763	36.85648709
TA00066	Alliance Girls High School	Kenya	-1.2654376	36.6623375
TA00182	RCMRD	Kenya	-1.22151	36.89292
TA00779	CEMASTEA	Kenya	-1.3554754	36.711964

Table 1. The available weather data sources.

ABC21 is funded by the
EU's H2020 programme

Of these data sources, the ones of the Kenya Meteorological Department have been chosen as the most suited. This has been done considering that the data series of the Alliance Girls High School for the period in question are less complete, and because the wind speeds in the data of the St. Scholastica Catholic School and of RCMRD are less exhaustive than the alternative ones.

Issues encountered: NONE

- ☐ Missing data
- ☐ Shortage
- ☐ Wifi connection
- ☐ Others: …………………….

2.2.1 Sensors location

This section gives information about the location of the sensors inside and outside the building.
The plan of the building is the following.

Figure 1: Above: the building in its surroundings (from Google Maps) Below: typical floor of the building.

10 sensors have been installed, with the following layout.

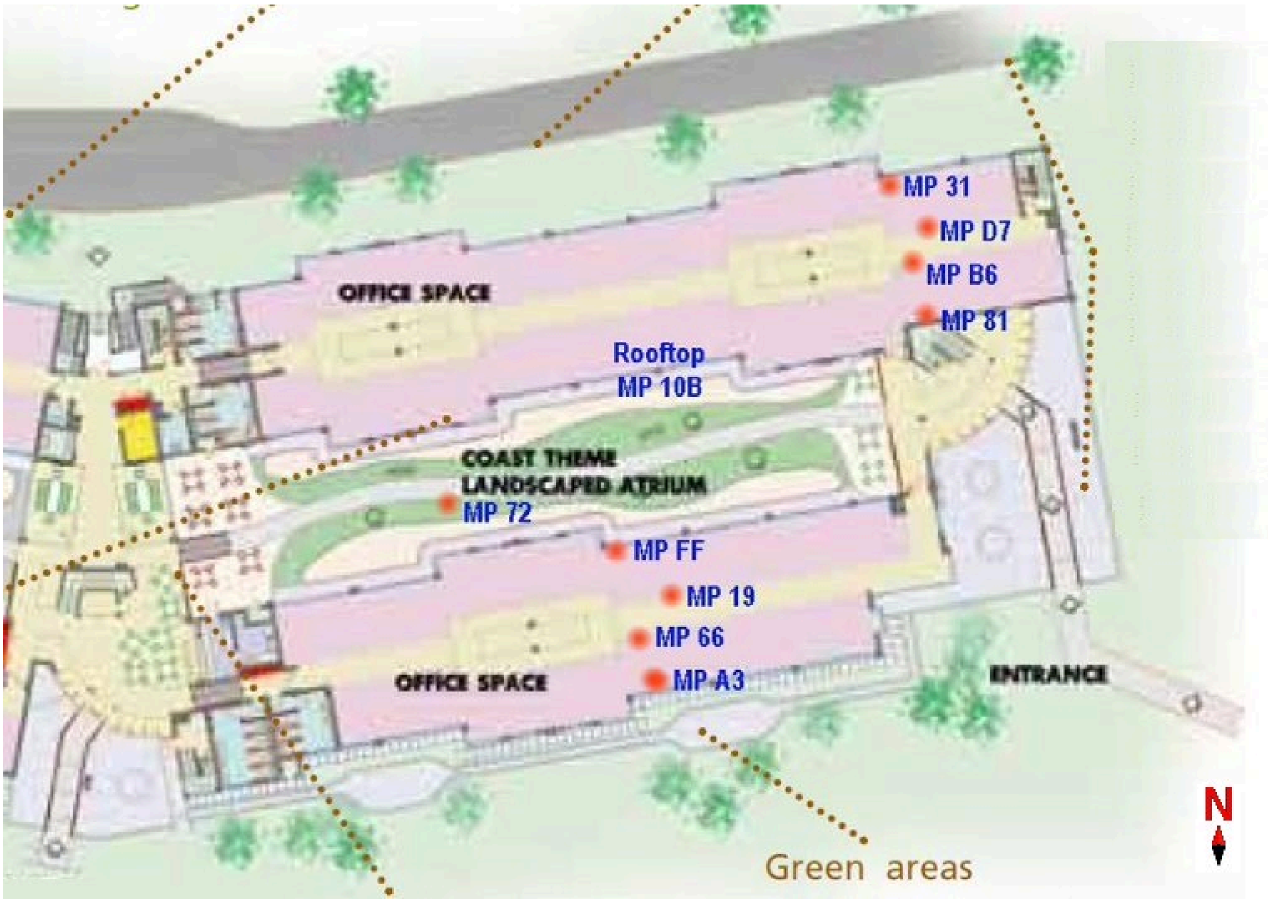


Figure 2: The sensors' location.

The list of the sensors' names is the following:
1. Meter 72 Garden;
2. Meter Plus 10B Roof;
3. Meter Plus 19 Cecilia Office C;
4. Meter Plus 31 Raf Window;
5. Meter Plus 66 Vincent office C;
6. Meter Plus 81 Paola Window;
7. Meter Plus A3 Vincent Office Window;
8. Meter Plus B6 Paola Corridor;
9. Meter Plus D7 Raf Corridor;
10. Meter Plus FF Cecilia Window.

2.2.2. Sensors specification

Details about the sensors are given below.

Datasheet SHTC3
Humidity and Temperature Sensor IC

- Ultra-low power consumption
- Full battery supply voltage range (1.62 - 3.6 V)
- Small DFN package: 2 × 2 × 0.75 mm3
- Typical accuracy: ±2 %RH and ±0.2 °C
- Fully calibrated and reflow solderable
- Power-up and measurement within 1 ms
- NIST traceability

2.3. Post Occupancy Evaluation Surveys

No questionnaire surveys were conducted for this case study. However, some specifically aimed interviews have been conducted. These highlighted that the comfort levels in the offices are considered satisfactory by the occupants, except :

- (a) for the heat and glare near the solstices in some room (see following Figure), deriving by the lack of shading devices
- (b) some temperature conditions during the cool season (June-July-August), deemed to be somewhat too low.

The lack of shading devices is addressed by the occupants by applying provisionally paper sheets on the glasses. The coolth during the cool season is instead addressed by some occupants via electric heaters. The manual control of the windows is here allowed by design to the users, which seldom use it, however, keeping the windows mostly shut. the control of lighting appliances is instead entirely automated, both as regards its on/off switching and is dimming, which takes place according to the daylight intensity.

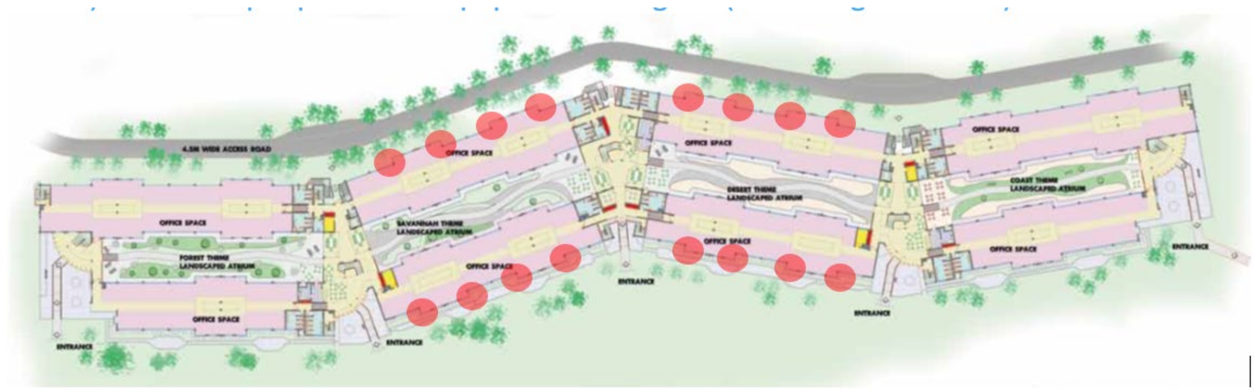


Figure 3. With red dots, the office locations liable to glare for lack of shading devices are here shown.

3. Results and discussion

The period whose data have been plotted spans between the 7th of November 2022 and the 30th of May 2023.

3.1. Boxplots

The air temperatures excursions for the studied spaces over the considered period of are shown below.

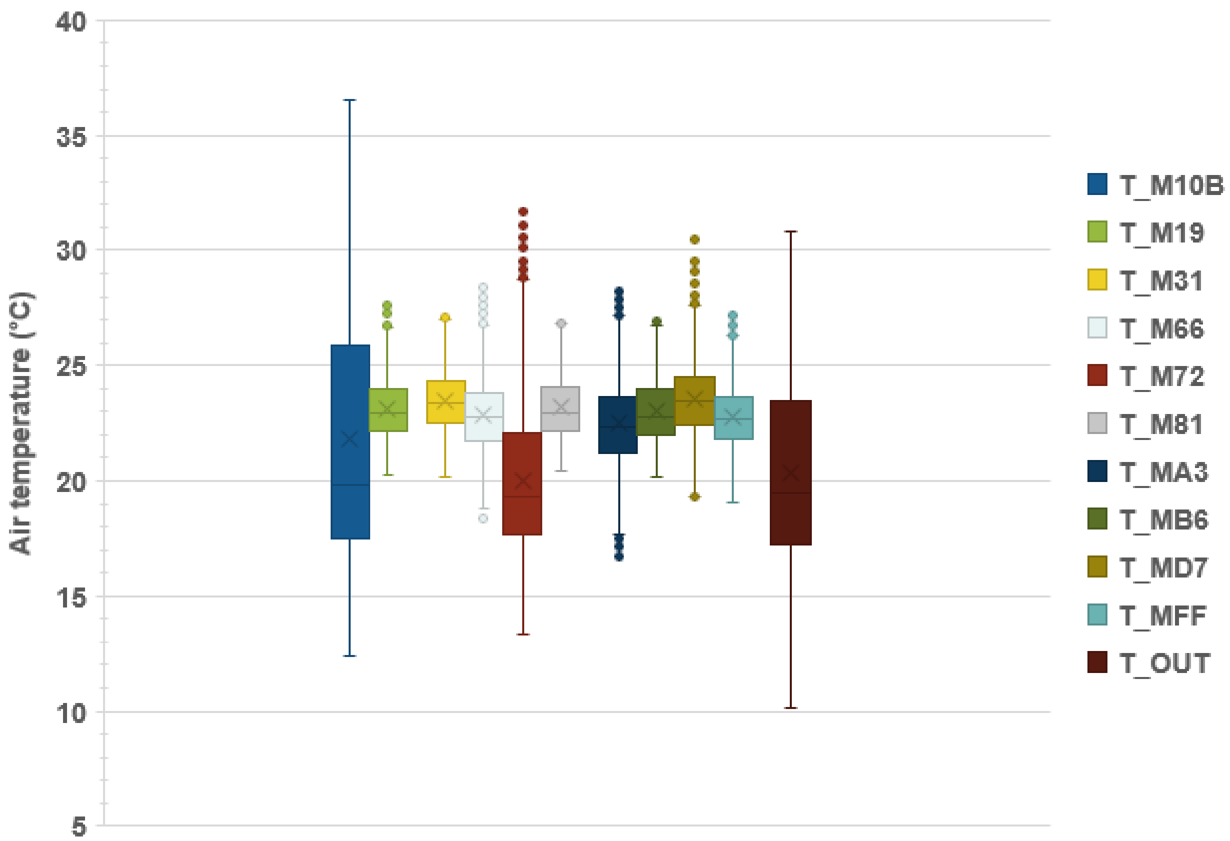


Figure 4. Boxplot of the dry bulb air temperatures in the monitored spaces between November 7th 2022 and May 30th 2023.

This boxplot prompts the following remarks:

- The indoor temperatures in the offices are fairly stable, and fairly homogeneous;
- The cooler space of the building is the garden included in the atrium (sensor M72). This is likely to be due both to the fact that its hight level with respect to the monitored rooms is lower, and to the fact that the long atrium is widely open at the top, and permeable to air at the sides.
- The atrium that has been monitored is one, but its environmental conditions are likely to be similar to those of the other atria with garden of the complex.
- The air temperatures at the level of the roof remain slightly above the environmental temperatures. This might suggest that the potential for radiative heat loss towards the sky in the site in question is not particularly great (at least, in the considered period), despite the fair altitude of the site (above 1000 meters). (This would be consistent with the fair amount of cloud dover (around 50% on

average), and also with the fact that the air temperature minima on the roof are higher than the environmental temperature. However, the most likely reason of the just described recorded situations is most likely to be found in the position of the sensor set on the roof, which, as can be seen in the following Figure, is located in a position which is intermediate between indoors and outdoors, at one side of the atrium top level.

In general terms, the hygro-thermal data that have been obtained highlight the existence of mild climate conditions well-suited to the pursuit of a mechanical-plant-free approach to environmental control.

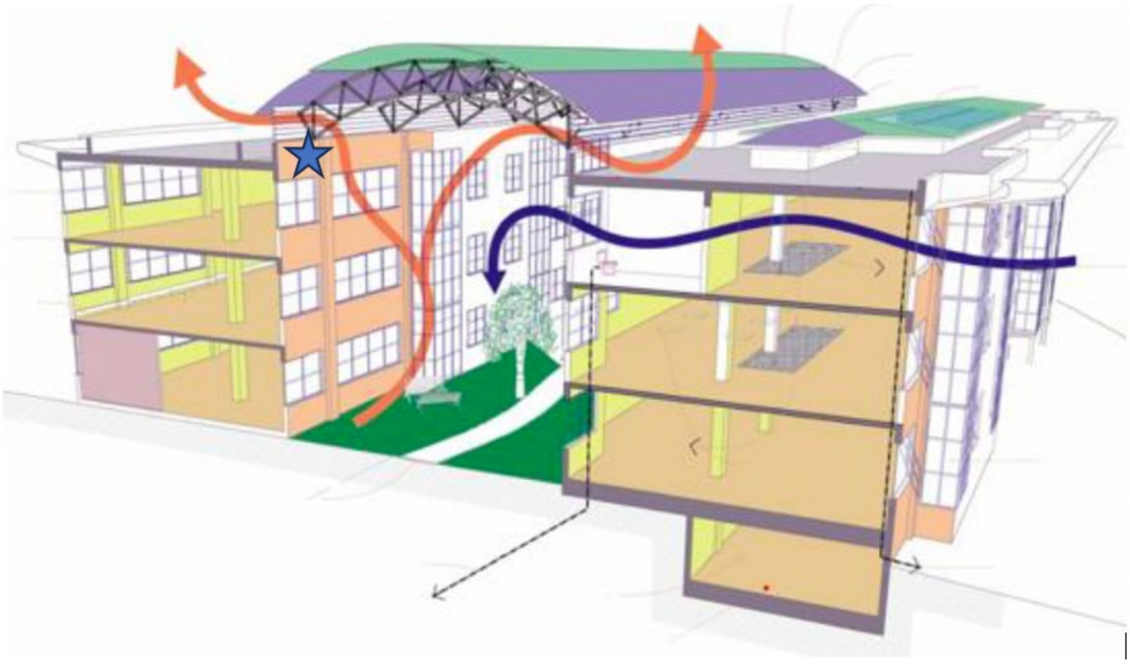


Figure 5. Position of the roof sensor (signalled by the star symbol).

3.2 Givoni comfort zones

The figures below show the Givoni comfort zone for each monitored space over the total period of measurements, as well as of those the garden space, and the roof, during the occupied hours, plus the outdoors.

The main comment is that the temperature and humidity pairs in all the spaces remain inside the comfort zone, which reflects the good thermal design of the building. Vincent's office is slightly colder and warmer because Vincent opens regularly his window whereas the other users don't.

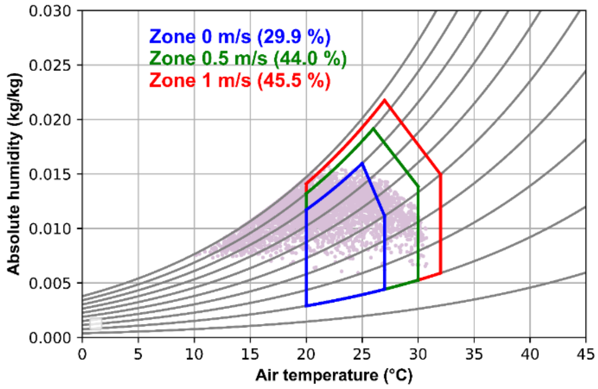


Figure 6.1: Givoni comfort zone regarding the outdoor conditions (from the weather data station).

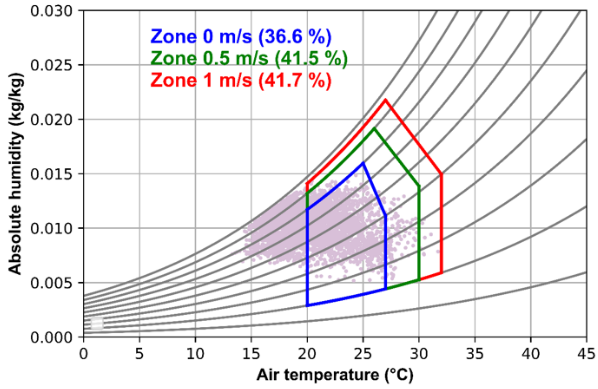


Figure 6.2. Givoni comfort zone measured at the sensor 72 - garden.

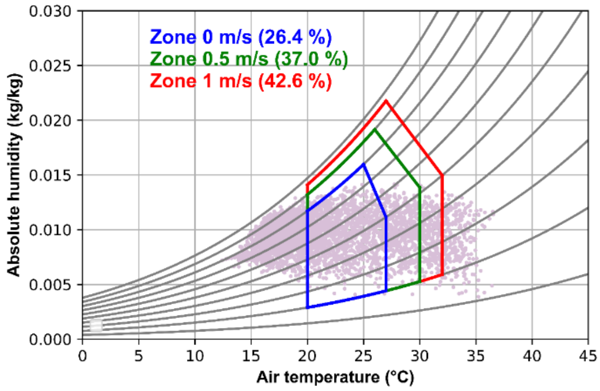


Figure 6.3: Givoni comfort zone measured at the sensor 10B (roof).

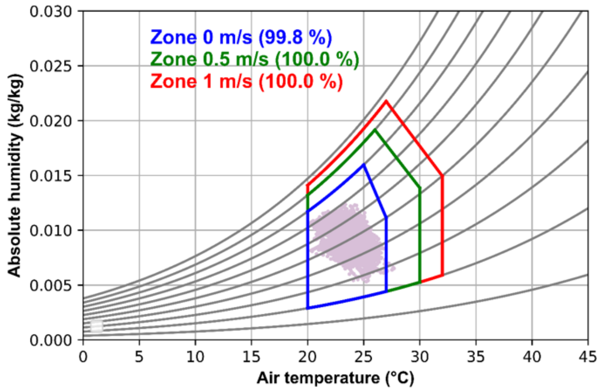


Figure 6.4: Givoni comfort zone measured at the sensor 19 - Cecilia Office C.

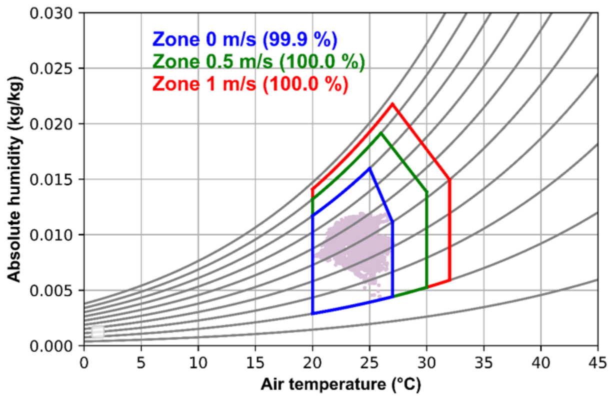


Figure 6.5: Givoni comfort zone measured at the sensor 31 - Raf Window.

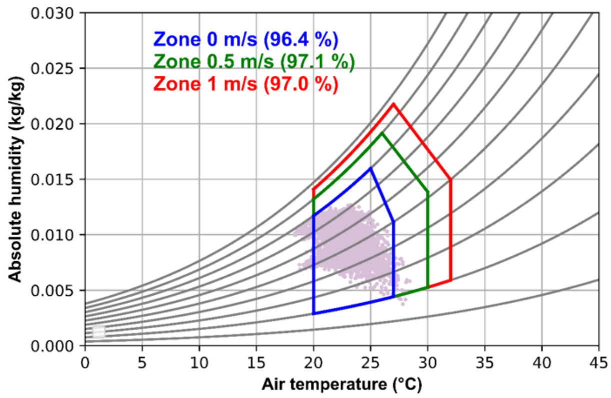


Figure 6.6: Givoni comfort zone measured at the sensor 66 - Vincent office C.

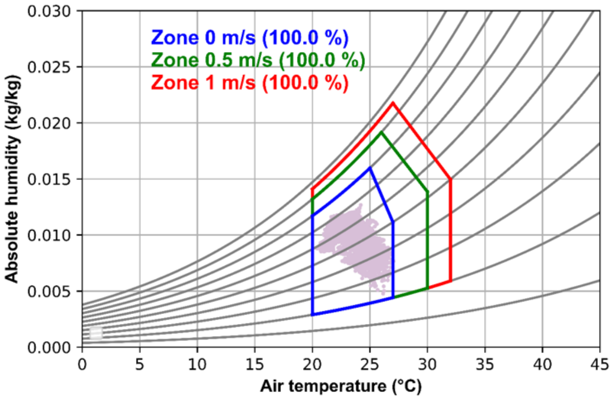


Figure 6.7: Givoni comfort zone measured at the sensor 81 - Paola Window.

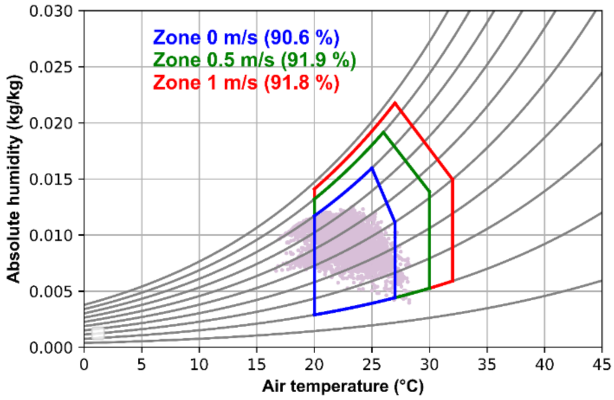


Figure 6.8: Givoni comfort zone measured at the sensor A3 - Vincent Office Window.

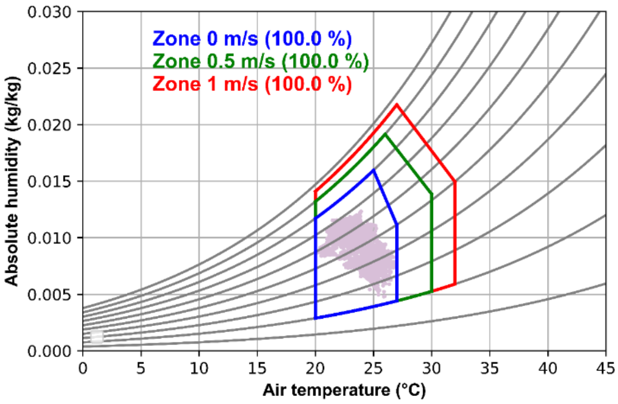


Figure 6.9: Givoni comfort zone measured at the sensor B6 - Paola Corridor.

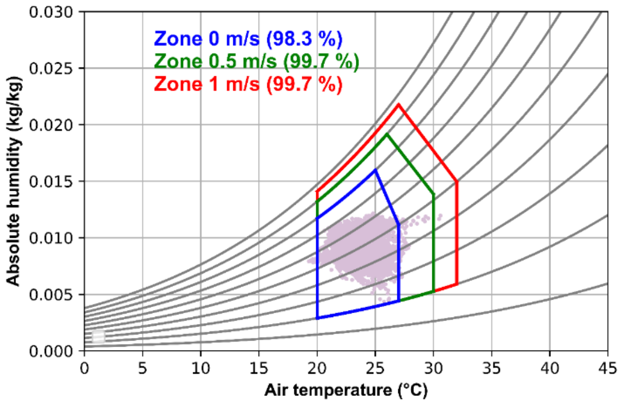


Figure 6.10: Givoni comfort zone measured at the sensor D7 - Raf Corridor.

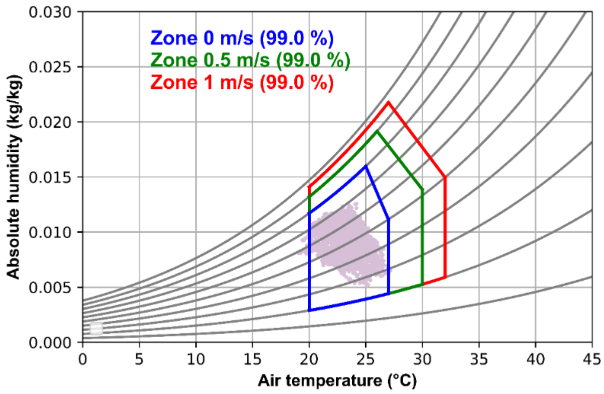


Figure 6.11: Givoni comfort zone measured at the sensor FF - Cecilia Window.

ABC21 is funded by the
EU's H2020 programme

3.3 Temperature ranges within the adaptive comfort boundaries

In the following graphs, the dry bulb temperatures of Cecilia's office spaces are plotted withing the bounds of the adaptive comfort range calculated according the norm EN 15251:2007 ("Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics").

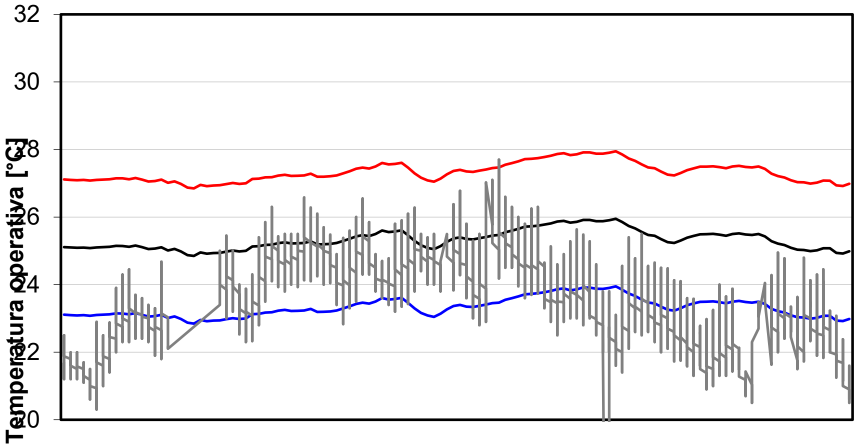


Figure 7.1: The temperature of the sensor 19 - Cecilia Office C within the adaptive comfort range according to the norm EN 15251, from 1st January 2023 to 31st May 2023.

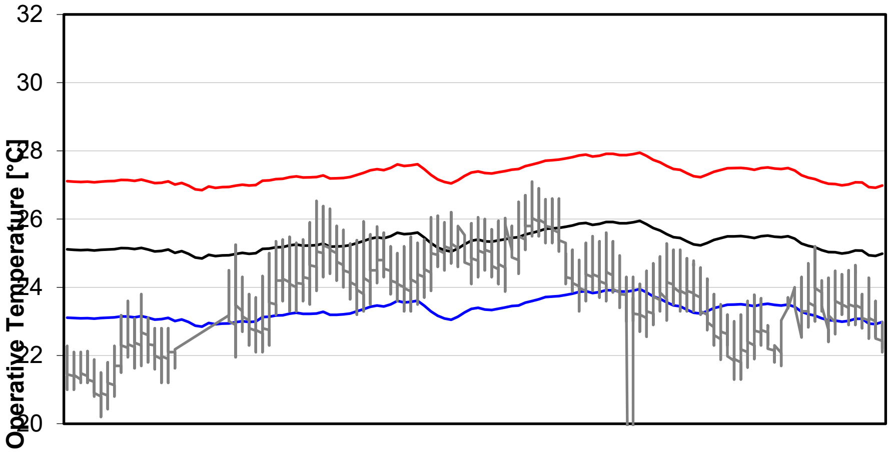


Figure 7.2: The temperature of the sensor 31 – Raf Window within the adaptive comfort range according to the norm EN 15251, from 1st January 2023 to 31st May 2023.

ABC21 is funded by the
EU's H2020 programme

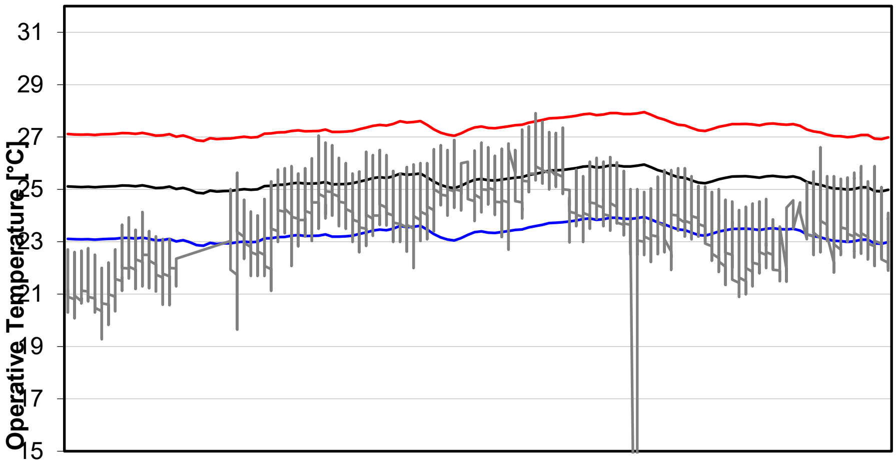


Figure 7.3: The temperature of the sensor D7 – Raf Corridor within the adaptive comfort range according to the norm EN 15251, from 1st January 2023 to 31st May 2023.

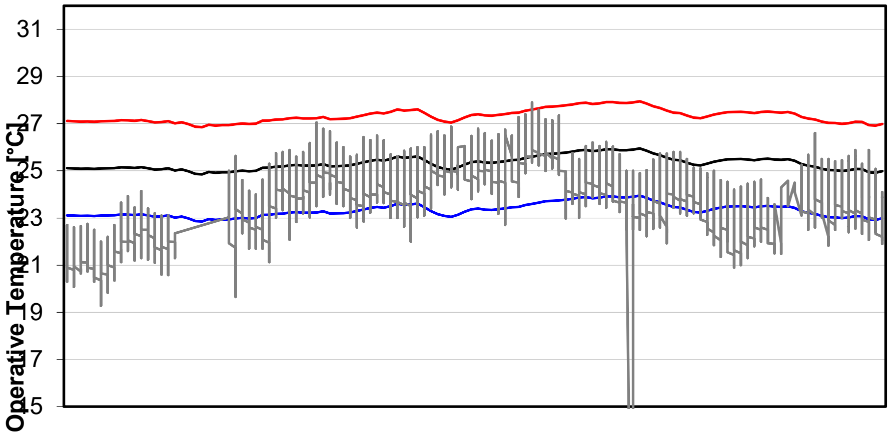


Figure 7.4: The temperature of the sensor 66 – Vincent Office C within the adaptive comfort range according to the norm EN 15251, from 1st January 2023 to 31st May 2023.

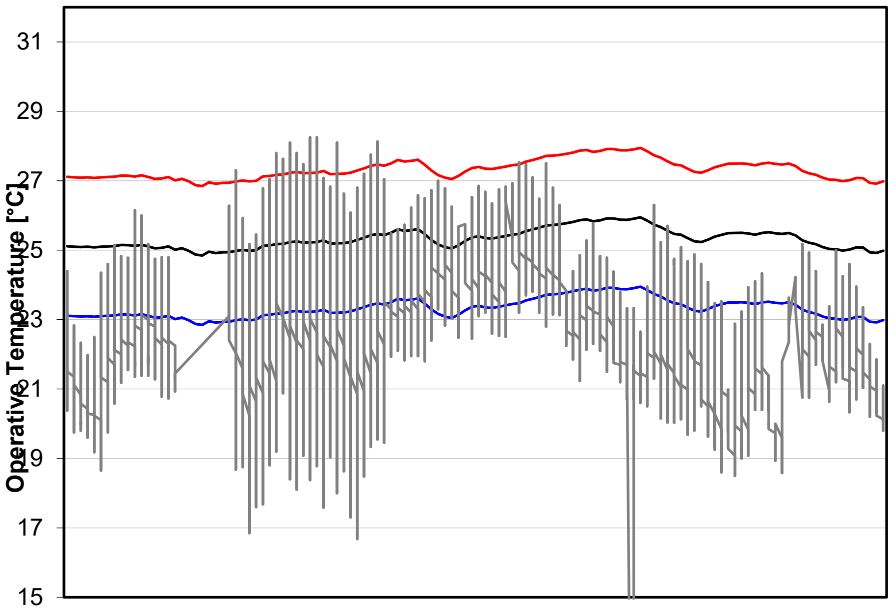


Figure 7.5: The temperature of the sensor A3 – Vincent Office Window within the adaptive comfort range according to the norm EN 15251, from 1st January 2023 to 31st May 2023.

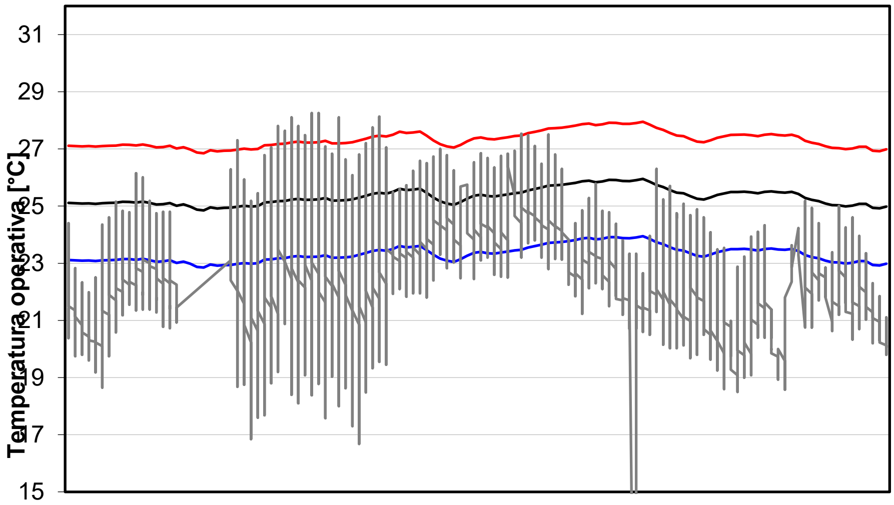


Figure 7.6: The temperature of the sensor 81 Paula Window within the adaptive comfort range according to the norm EN 15251, from 1st January 2023 to 31st May 2023.

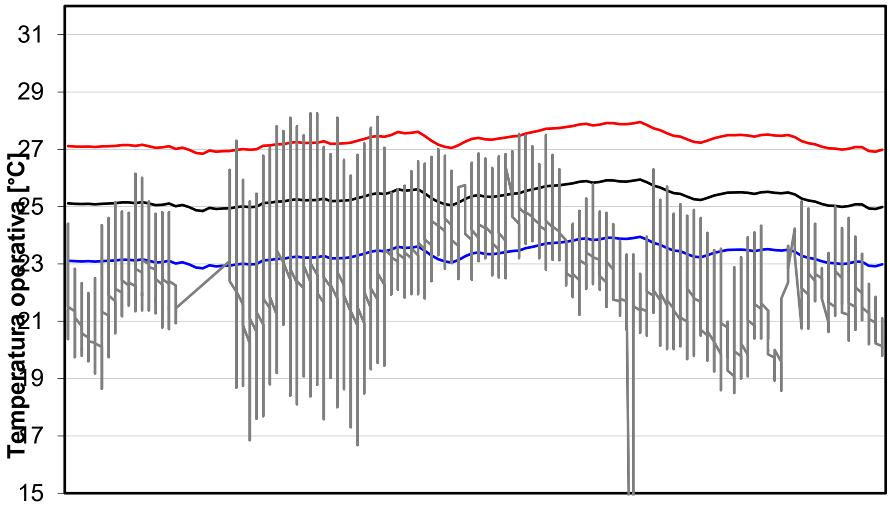


Figure 7.7: The temperature of the sensor B6 Paula Corridor within the adaptive comfort range according to the norm EN 15251, from 1st January 2023 to 31st May 2023.

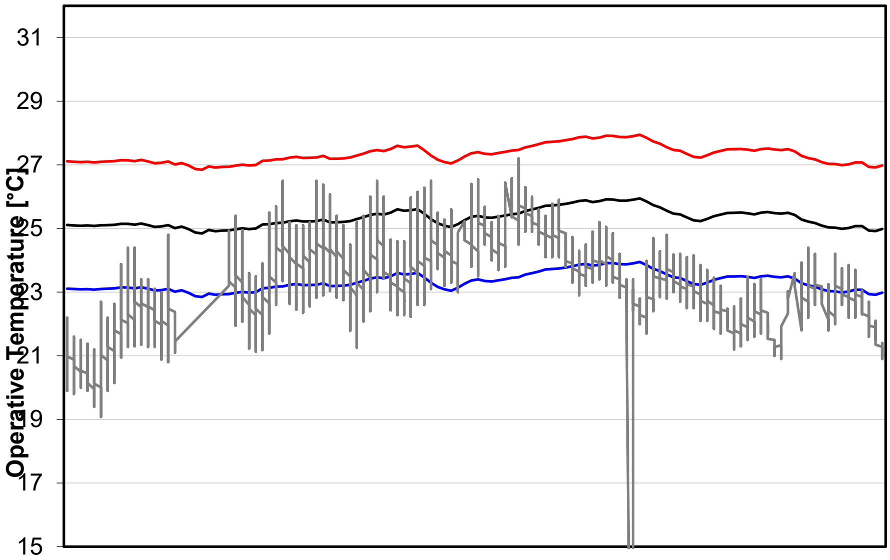


Figure 7.8: The temperature of the sensor FF - Cecilia Window within the adaptive comfort range according to the norm EN 15251, from 1st January 2023 to 31st May 2023.

Considerations

The conditions of temperatures and relative humidities in the offices appear to be fairly stable and almost always within the comfort zone. Slightly larger excursions, sometimes outside (above and below) the comfort zone (but always within the range addressable by passive means) have been found only in Vincent's office (sensors A3 and 66). But it has been verified (see section 2.3) that the reason for this is the fact that Vincent's preference is keeping the windows open and the door shut – for the sake of air purity -, differently from his colleagues, who do the opposite, keeping the window close and obtaining more stable thermal conditions.
The outdoor conditions (see Figure 4.1) are centered around the comfort zone, but have greater excursions, which extend outside of the comfort zone, but never of a great amount.
The hygro-thermal excursions are somewhat larger on the roof, and the temperatures overall slightly hotter. But as said in section 2.3, about the temperatures monitored there, the fact that the sensor position was partially indoors has to be taken into account.
Last but not least, the garden space at the bottom of the atrium (see Figure 4.2) shows an interesting situation of slightly lower temperatures than the outdoor ones, as well as somewhat smaller thermal excursions.

ABC21 is funded by the
EU's H2020 programme

3.4 Number of hours / frequency within a certain temperature range

The tables below list the frequencies (Fq) within a certain temperature range calculated for all the monitored rooms and for the outdoor conditions during the occupied hours.

Tables 1A, 2B and 2C: Number of hours within a 2°C temperature range for all the classrooms, and the outdoor conditions. One can note that in the indoor spaces the values are fairly concentrated in the central intervals

Table 2A: Temperature frequencies, part 1.

	METER 10B roof		METER 19 Cecilia Office C		METER 31 Raf Window		METER 66 Vincent office C		OUTSIDE	
	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.
Ta<16°C	2	0,%	0	0%	0	0%	0	0%	7	1%
16°C≤Ta<18°C	42	3%	0	0%	0	0%	0	0%	90	7%
18°C≤Ta<20°C	122	9%	0	0%	0	0%	17	1%	206	15%
20°C≤Ta<22°C	120	9%	215	16%	91	7%	325	24%	182	13%
22°C≤Ta<24°C	130	10%	727	53%	737	54%	635	46%	234	17,%
24°C≤Ta<26°C	168	12%	376	27%	486	36%	298	22%	297	22%
26°C≤Ta<28°C	**202**	15%	50	4%	54	4%	89	7%	**205**	15%
28°C≤Ta<30°C	**209**	15%	0	0%	0	0%	4	0%	**124**	9%
30°C≤Ta<32°C	**186**	14%	0	0%	0	0%	0	0%	**23**	2%
32°C≤Ta<34°C	**143**	10%	0	0%	0	0%	0	0%	0	0%
Ta≥34°C	**44**	3%	0	0%	0	0%	0	0%	0	0%

Table 3B: Temperature frequencies, part 2.

	METER 72 garden		METER 81 Paola Window		METER A3 Vincent Office Window		OUTSIDE	
	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.
Ta<16°C	11	0,80%	0	0,00%	0	0,00%	7	0,51%
16°C≤Ta<18°C	157	11,48%	0	0,00%	4	0,29%	90	6,58%
18°C≤Ta<20°C	256	18,71%	0	0,00%	57	4,17%	206	15,06%
20°C≤Ta<22°C	243	17,76%	207	15,13%	332	24,27%	182	13,30%
22°C≤Ta<24°C	329	24,05%	743	54,31%	505	36,92%	234	17,11%
24°C≤Ta<26°C	210	15,35%	360	26,32%	324	23,68%	297	21,71%
26°C≤Ta<28°C	**128**	9,36%	58	4,24%	**137**	10,01%	**205**	14,99%
28°C≤Ta<30°C	**26**	1,90%	0	0,00%	**9**	0,66%	**124**	9,06%
30°C≤Ta<32°C	8	0,58%	0	0,00%	0	0,00%	**23**	1,68%
32°C≤Ta<34°C	0	0,00%	0	0,00%	0	0,00%	0	0,00%
Ta≥34°C	0	0,00%	0	0,00%	0	0,00%	0	0,00%

ABC21 is funded by the
EU's H2020 programme

Table 4C : Temperature frequencies, part 3.

	Temp°C	METER B6 Paola Corridor		METER D7 Raf Corridor		METER FF Cecilia Window		OUTSIDE	
	bins	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.
Ta<16°C	16	0	0,00%	0	0,00%	0	0,00%	7	0,51%
16°C≤Ta<18°C	18	0	0,00%	0	0,00%	0	0,00%	90	6,58%
18°C≤Ta<20°C	20	0	0,00%	2	0,15%	6	0,44%	206	15,06%
20°C≤Ta<22°C	22	301	22,00%	105	7,68%	320	23,39%	182	13,30%
22°C≤Ta<24°C	24	687	50,22%	537	39,25%	703	51,39%	234	17,11%
24°C≤Ta<26°C	26	337	24,63%	566	41,37%	294	21,49%	297	21,71%
26°C≤Ta<28°C	28	43	3,14%	**153**	11,18%	45	3,29%	**205**	14,99%
28°C≤Ta<30°C	30	0	0,00%	**4**	0,29%	0	0,00%	**124**	9,06%
30°C≤Ta<32°C	32	0	0,00%	1	0,07%	0	0,00%	**23**	1,68%
32°C≤Ta<34°C	34	0	0,00%	0	0,00%	0	0,00%	0	0,00%
Ta≥34°C		0	0,00%	0	0,00%	0	0,00%	0	0,00%

3.5 Number of hours / frequency by relative humidity range

The tables below list the frequencies (Fq) within a certain Relative Humidity range calculated for all the monitored rooms and the outdoor conditions during the occupied hours.

Tables 3A, 3B and 3C: Number of hours within a Relative Humidity range of 10% for all the classrooms and the outdoor conditions. Here too, one can note that in the indoor spaces the values are fairly concentrated in the central intervals.

Table 3A: UR frequencies, part 1.

	RH	METER 10B roof		METER 19 Cecilia Office C		METER 31 Raf Window		METER 66 Vincent office C		OUTSIDE	
	bins	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.
[0,10%[	10	0	0,00%	0	0,00%	0	0,00%	0	0,00%	0	0,00%
[10,20%[	20	31	2,27%	0	0,00%	0	0,00%	7	0,51%	0	0,00%
[20,30%[	30	159	11,62%	27	1,97%	18	1,32%	37	2,70%	9	0,66%
[30,40%[	40	297	21,71%	126	9,21%	129	9,43%	120	8,77%	51	3,73%
[40,50%[	50	298	21,78%	237	17,32%	264	19,30%	209	15,28%	126	9,21%
[50,60%[	60	183	13,38%	471	34,43%	686	50,15%	375	27,41%	193	14,11%
[60,70%[	70	148	10,82%	498	36,40%	271	19,81%	464	33,92%	288	21,05%
[70,80%[	80	140	10,23%	9	0,66%	0	0,00%	**156**	11,40%	**235**	17,18%
[80,90%[	90	101	7,38%	0	0,00%	0	0,00%	0	0,00%	**189**	13,82%
[90,100%[		11	0,80%	0	0,00%	0	0,00%	0	0,00%	**277**	20,25%

ABC21 is funded by the
EU's H2020 programme

Table 3B: UR frequencies, part 2.

	RH	METER 72 garden		METER 81 Paola Window		METER A3 Vincent Office Window		OUTSIDE	
	bins	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.
[0,10%[	10	0	0,00%	0	0,00%	0	0,00%	0	0,00%
[10,20%[	20	0	0,00%	0	0,00%	7	0,51%	0	0,00%
[20,30%[	30	20	1,46%	18	1,32%	37	2,70%	9	0,66%
[30,40%[	40	108	7,89%	118	8,63%	132	9,65%	51	3,73%
[40,50%[	50	114	8,33%	230	16,81%	215	15,72%	126	9,21%
[50,60%[	60	235	17,18%	485	35,45%	399	29,17%	193	14,11%
[60,70%[	70	227	16,59%	514	37,57%	435	31,80%	288	21,05%
[70,80%[	80	**255**	18,64%	3	0,22%	**136**	9,94%	**235**	17,18%
[80,90%[	90	**250**	18,27%	0	0,00%	**7**	0,51%	**189**	13,82%
[90,100%[		**159**	11,62%	0	0,00%	0	0,00%	**277**	20,25%

Table 3C: UR frequencies, part 3.

	RH	METER B6 Paola Corridor		METER D7 Raf Corridor		METER FF Cecilia Window		OUTSIDE	
	bins	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.	n.Hours	Freq.
[0,10%[	10	0	0,00%	0	0,00%	0	0,00%	0	0,00%
[10,20%[	20	0	0,00%	0	0,00%	0	0,00%	0	0,00%
[20,30%[	30	21	1,54%	24	1,75%	18	1,32%	9	0,66%
[30,40%[	40	120	8,77%	141	10,31%	125	9,14%	51	3,73%
[40,50%[	50	230	16,81%	293	21,42%	215	15,72%	126	9,21%
[50,60%[	60	485	35,45%	697	50,95%	383	28,00%	193	14,11%
[60,70%[	70	509	37,21%	213	15,57%	599	43,79%	288	21,05%
[70,80%[	80	3	0,22%	0	0,00%	28	2,05%	**235**	17,18%
[80,90%[	90	0	0,00%	0	0,00%	0	0,00%	**189**	13,82%
[90,100%[		0	0,00%	0	0,00%	0	0,00%	**277**	20,25%

3.6. Analysis of a representative week

The representative week has here been selected looking for a set of similar days on the basis of considerations including temperatures, wind speeds and radiation. The chosen period is between February 3rd and February 9th.

The data, shown in the sub-sections below, highlight the existence of mild temperatures conditions, with small excursions, rather high radiation profiles, and rather low, but very regular, wind speeds.

3.6.1 Solar radiation profile

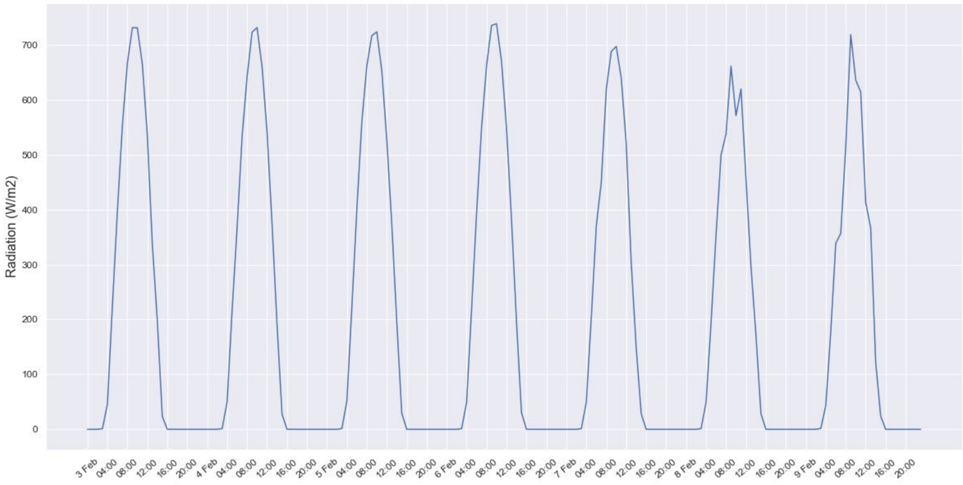


Figure 8: Solar radiation profiles from the 3rd to 9th February in Nairobi (closest airport). The representative week is very stable in terms of consecutive sunny days.

3.6.2 Wind profile

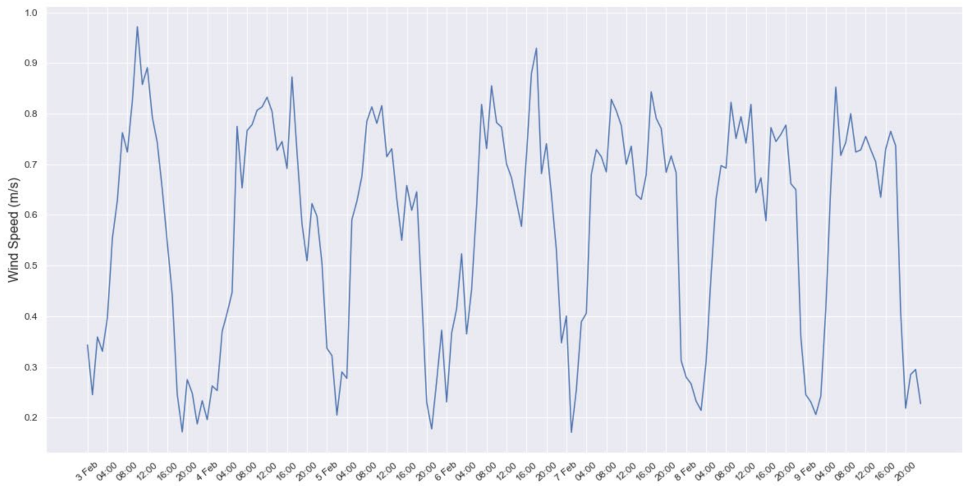


Figure 9: Wind speed profiles from the 3rd to 9th February in Nairobi (closest airport). One can note that the wind speed is very low, but regular.

3.6.3 Air temperature profile

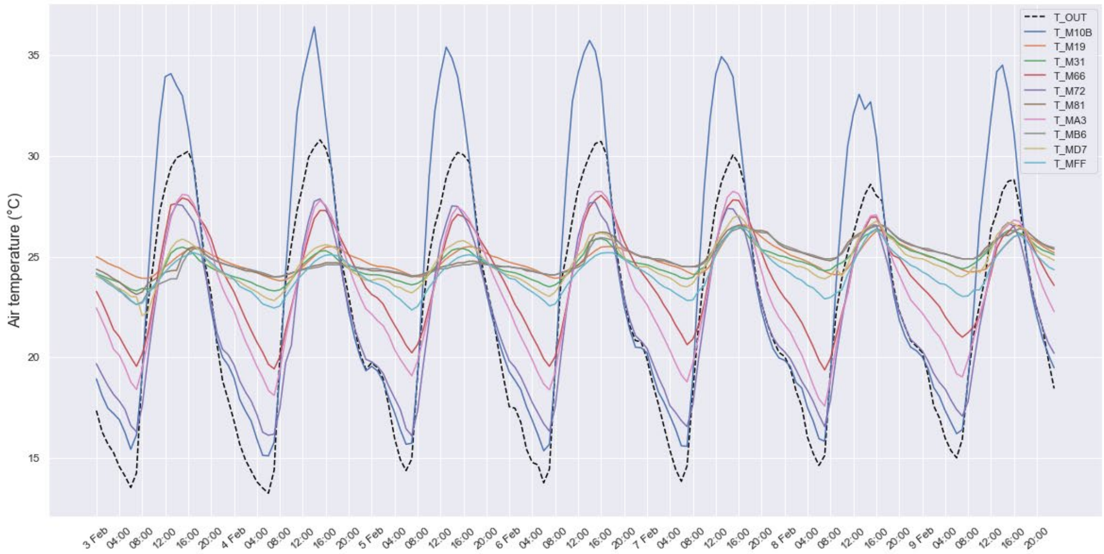


Figure 10 : Air temperature profiles from the 3rd to 9th February in the UN-Building in Nairobi (closest airport).

It can be noticed that the diurnal temperature difference is very small in all the offices (around 3°C between 22,5° and 25,5°C) whereas the difference of the outdoor temperature is around 13°C (17°C at night and 30°C during the day).

With respect to the M72 sensor (garden): the data show that the air temperature is very close to the outdoor temperature at night, but remains at 25°C during the day, even at the peak of the outdoor conditions, as an effect of the fixed louvres.

With respect to Vincent's office (MA3 and M66): the amplitude is higher compare to the other offices 8°C (19°C-27°C), and the office is 2°C hotter during the day and 4°C colder at night.

4 Lessons learnt and recommendations

Preliminary considerations

The data regarding the roof temperatures show thermal swings which are smaller than those recorded in the courtyard, and even more in the rooms, as totally expected, and somewhat warmer than the fully outdoor ones, but not wide in absolute terms, due to the remarkable mildness of the climate in question.

The temperatures in the rooms seem markedly comfortable, and those at the bottom of the atrium, at the level of the vegetation, even more so. This is what allowed the designers to avoid integrating any mechanical plant in the building for heating and for cooling in the first place. The hygro-thermal conditions that have been monitored demonstrate the soundness of this decision.

Lessons learnt:

The main lesson learnt is that air conditioning is not necessary in Nairobi. It is possible to design a comfortable bioclimatic office building in Nairobi with no active air conditioning systems. Thermal comfort conditions can be easily reached with a well ventilated building, an appropriate orientation and insulation in walls and roofs in subsequent projects, using local materials, such as bio-sourced fibers.

Ceiling fans are not necessary as well. The overall advantageous conditions at the bottom of the atria show the effectiveness of the main environmental control strategy of the buildings in question: that of exploiting the climatic control potential of widely open-top atria allowing the stack effect and not impermeable to cross-ventilation, combined with the effect of the planted gardens at the bottom of them (both thanks to the effect of the vegetation and to the presence of the somewhat moist ground mass).

The mild climatic conditions of the site raise the expectations cast on the building, but this specific building solution seems to have met those expectations, and confirmed the suitability of the considered design strategies.

Recommendations:

Two only recommendations should be made.

One recommendation derives from the lack of shading devices in the offices, which, as said, produce glare and localized radiant thermal discomfort near the solstices. This could be avoided by integrating adjustable external shading devices, or fixed external shading devices devised in such a manner to reduce insolation at the solstices without penalizing substantially daylighting near the equinoxes, or – somewhat less effectively - by adopting inner shading devices of clear color. (Due the mildness of the required shading task, even the benefit of the latter solution could indeed be substantial.)

The other recommendation is more geared towards new constructions than towards improving the present building, and regards the goal of passive solar heating. Indeed, as it has been seen, the temperature conditions indoors can become somewhat cool during the cool season, despite the mildness of the climate. In a new project, this potential issue could be addressed by giving a larger size to the windows exposed towards the equator (here, north), considering that the coolest month are around July.

In the considered buildings, however, due to their massing (shape and mutual position), this would have beneficial consequences on the cool season temperatures mainly for the northern facade of the northern « row » + of buildings, which is the only one exposed to direct radiation during June, July and August. A more generalized solar access however would be difficult to attain for the building typology in question, characterized by large building widths and two building volumes set in parallel around an elongated atrium. Indeed, such a result would be possible only with slimmer building shapes and with a roof of the atrium open enough to allow abundant direct solar access to the façades facing he atrium. In the present situation, alternative solution for obtaining a greater amount of solar gains in theory would be the adoption of reflective window sills, which in practice however could also increase the risk of glare, and would be presently mostly effective in the north side of the northern building « row ». Another solution (also suited to retrofit) in theory could be that of increasing the thermal resistance of the opaque envelope by integrating a layer of insulation on its indoor side; but in practice this would decrease the effective thermal mass of the building and increase the likelihood of overheating in the warm season as a side effect.

ABC21 is funded by the
EU's H2020 programme

Africa-Europe Bioclimatic Collaboration 21

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS OF BURKINA INSTITUTE OF TECHNOLOGY (BIT) – BURKINA FASO

ABC21 is funded by the
EU's H2020 programme

Authors

Name	Institution
Humera Mughal (data curation and draft text)	eERG-PoliMi
Andrea Sangalli (selection of measurement equipment, measurement setup, remote training of African teams)	eERG-PoliMi
Imbga B Kossi and Ratousiri Arnaud A.A Valea, (performing on site measurement and subjective surveys)	Norbert ZONGO University (NZU)
Lorenzo Pagliano (oversight and revision)	eERG-PoliMi
Silvia Erba (definition of the measurement campaign, POEs scheduling, organization of the stored data, oversight and revision)	eERG-PoliMi

Revision

Version	Date	Author	Description of changes
V0	06/2023	Silvia Erba, Lorenzo Pagliano	Draft version
V1	09/2023	Humera Mughal	Updated version
V2	09/2023	Lorenzo Pagliano	Updated version
V3	10/2023	Silvia Erba	Updated version
V4	11/2023	Lorenzo Pagliano	Updated version
V5	10/2023	Silvia Erba	Updated version
V6	12/2023	Lorenzo Pagliano	Updated version

TABLE OF CONTENTS

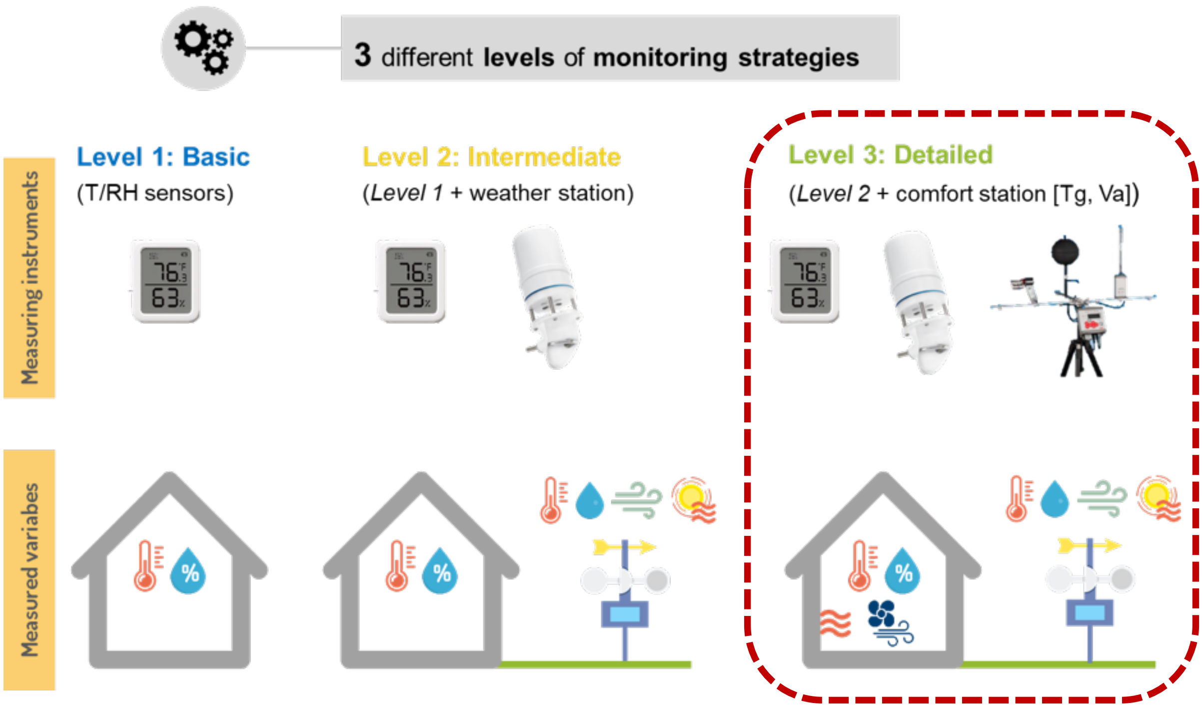
1. Presentation of the Burkina Institute of Technology (BIT)

Name	Burkina Institute of Technology (BIT)
Architect / Designer	Kéré Architecture
Location	12.2167° N, 2.3781° W
City	Koudougou
Country	Burkina Faso
Building type	Educational
Climate zone (Köppen–Geiger)	BSh
Description	BIT is an educational institute that was planned by the architect Francis Kéré. It is an extended project in the same campus as that of Lycée Schorge Secondary School, since there was a need for a new building that would allow high school graduates to continue their study after they had completed their secondary education. Situated within a flood plain, the project encompassed a comprehensive undertaking of landscaping measures aimed at safeguarding the structures. In the period of increased precipitation, water is directed into a substantial subterranean reservoir, subsequently utilized for the purpose of irrigating the mango plantations situated on the premises. The campus is designed in a way that the wind-cooled classes made from local Burkinabé building materials and equipped up-to-date IT equipment are set in a tree-filled area with lots of sports facilities for the students. To establish a cohesive connection with the surrounding campus, the architectural design of the buildings incorporates a “perforated” facade made of eucalyptus wood, harmonizing with the aesthetic of the Lycée Schorge. The BIT building is built with a system of repetitive modules that can house classrooms as well as auxiliary functions. These modules are positioned orthogonally to define a rectangular courtyard. The campus can expand gradually in response to changing requirements thanks to the orthogonal configuration of its building modules. Because the modules are offset from one another, air can flow freely through the middle void, to generate a comfortable environment in which students can socialize and unwind. The recurring roof profiles generate a dynamic rhythm and establish a chimney structure at the rear of each module, facilitating the release of accumulated warm air. The interior spaces are enhanced by the installation of hung ceilings, which are constructed using locally sourced eucalyptus wood. These ceilings serve to

	illuminate the area and harmonize with the sleek clay walls.
Main bioclimatic strategies	**A rectangular courtyard** is defined by an orthogonally structured system of repeated modules that houses classrooms and auxiliary functions. The staggered modules allow air to circulate through the middle gap, creating a cool area where students can unwind and socialize. **Clay walls** are poured i**n-situ (rammed earth)**. Large formworks allowed a whole module to be poured in one session, speeding up construction. **The repeating roof profiles** form a chimney at the back of each module, allowing built-up warm air to be discharged.  *Figure 1 Openings for ventilation on facades and roof* **Hung ceilings made of local eucalyptus** wood brighten and complement the smooth clay walls. Since the building is in a flood plain, a lot of **landscaping work** was done to protect it. Moreover, during the rainy season **water is being harvested**. The excessive water is sent to a big underground tank, which is then used to water the campus's many mangos' fields.

2. Material and method

2.1 Monitoring campaign level



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: Start date: 29/03/2023- End date: 31/05/2023.

Collection of weather data:

- ☐ National weather station close to the site - distance from the site: …km.
- ☐ Outdoor temperature and relative humidity in a solar radiation shield
- ☐ Other: University weather station on site
- ☒ TAHMO weather station on site

Issues encountered:

- ☐ Missing data: Please specify period of missing data or percentage of missing data.
- ☐ Shortage
- ☐ Wi-Fi connection
- ☒ Others: Database,

ABC21 is funded by the
EU's H2020 programme

2.2.1 Sensors and weather station location

This section provides details regarding the placement of sensors within the building as well as outside for the weather station. Three distinct rooms were monitored using temperature and relative humidity (T/RH) sensors over a period of three months. The sensors were strategically positioned in the centre of the room, shielded from direct exposure to solar radiation, and placed at a vertical distance of 2 meters from the floor. Measurements coupled to right-here right-now surveys were conducted within the classroom settings at various times and days utilizing the Comfort Kit. Please refer to the subsequent section for detailed specifications of the sensors.

The weather data were obtained from an on-site weather station, installed by ABC 21 in the network of TAHMO weather stations.

Figure 2 : Location of the weather station near BIT

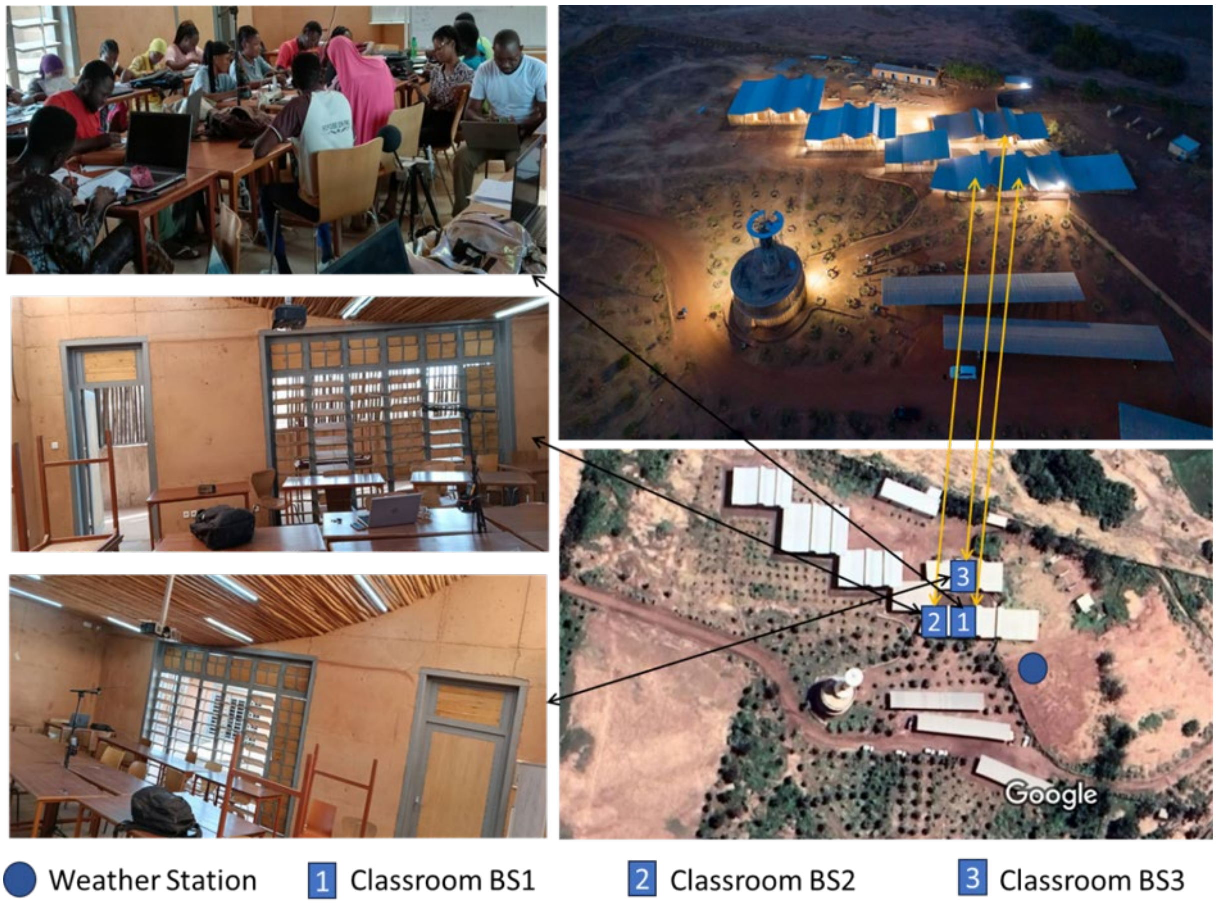


Figure 3 Location of the three classrooms under study and of the weather station near BIT

2.2.2 Sensor's specification

Figure 4 shows the plan of the building with the indication of the three classrooms under investigation (named BS1, BS2 and BS3). Details about the sensors are given in Table 1.

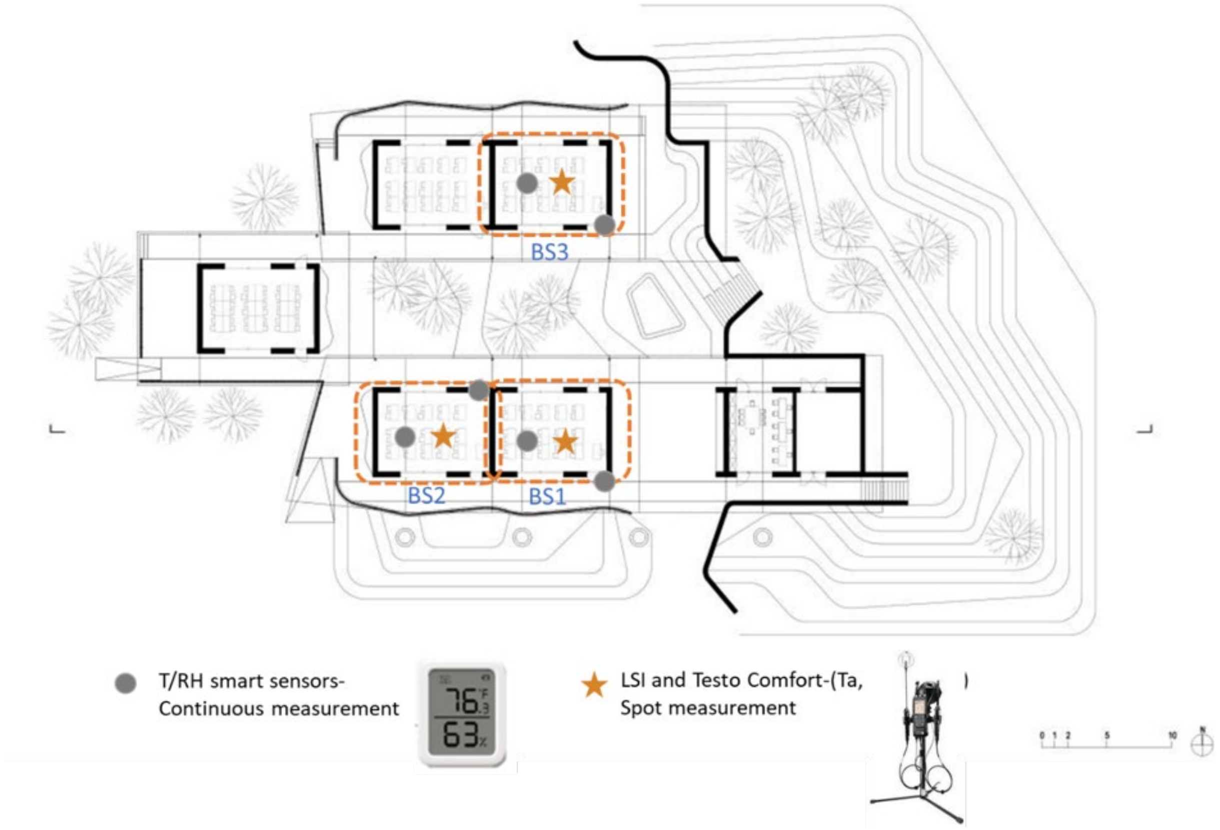
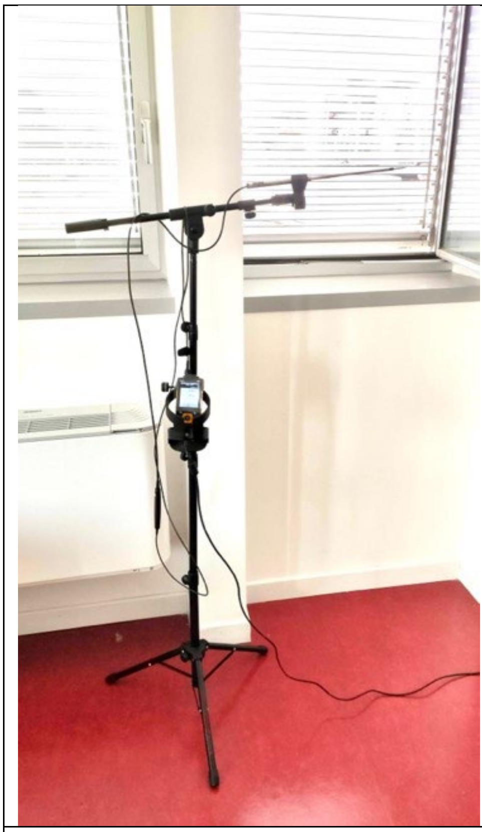
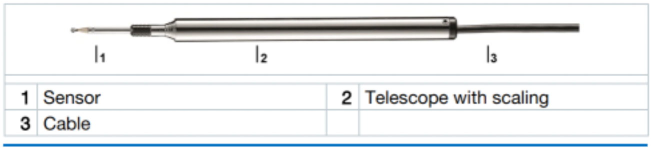


Figure 4: Location of the sensors at BIT



LSI Lastem black globe sensor + thermo-hygrometer + datalogger M-log



Testo hot sphere for air velocity measurement + M440 data logger

Table 1 Details about the sensors installed in BIT.

Sensor name	Code in Fig. 1	Measured variables	Accuracy	Resolution	Operating/ measuring range
SwitchBot sensors	●	Air temperature (T)	± 0.3 °C	0.01 °C	-40 to +125 °C
		Relative humidity (RH)	± 3 %RH	0.04 %RH	0 to 100%
LSI Globe temperature sensor. LSI thermo-hygrometer, LSI M-log; Testo hot ball probe and M440 data logger	★	Air temperature (T)	± 0.1 °C @ 0 °C	0.01 °C	-50℃ to 100 ℃
		Relative humidity (RH)	±1 %RH (@ 5 to 95 %RH)	0.1 %RH	5 to 100 %RH
		Air velocity (Va) , Testo hot ball probe	± (0.03 m/s + 5 % of m.v.)	0.01 m/s	0 to 10 m/s
		Black globe temperature (Tg)	±0,15°C (0 °C)	0.1 °C	-30 to +70 °C

2.3 Statistical (past) weather data

In the following graphs we present a statistical weather data file for the city Ouagadougou, 100 km from Koudougou, the location of the building under analysis. This is the closest location available in the database climate.onebuilding.org. The statistical weather file is based on data collected between 1949 and 2021. The graphical representation is performed using the online tool https://clima.cbe.berkeley.edu/. The measurements performed at the building site in Koudougou with the weather station we installed confirm, for the months under analysis, the trend expected based on the climate.onebuilding file for Ouagadougou.

The analysis presented in this chapter (measurement of physical variables and occupants' surveys) has been performed during the months (March to June) which present high maximum daily temperatures and medium humidity, hence challenging conditions. This should be kept in mind while considering the results of the Post Occupancy Survey.

There is a distinct humid/rainy period (July - September), when cloud coverage limits solar irradiance and hence maximum temperatures.

The very dry period (December-February) presents low minimum temperatures at night and hence it is favorable to both Nocturnal Ventilative Cooling and evaporative cooling during the day.

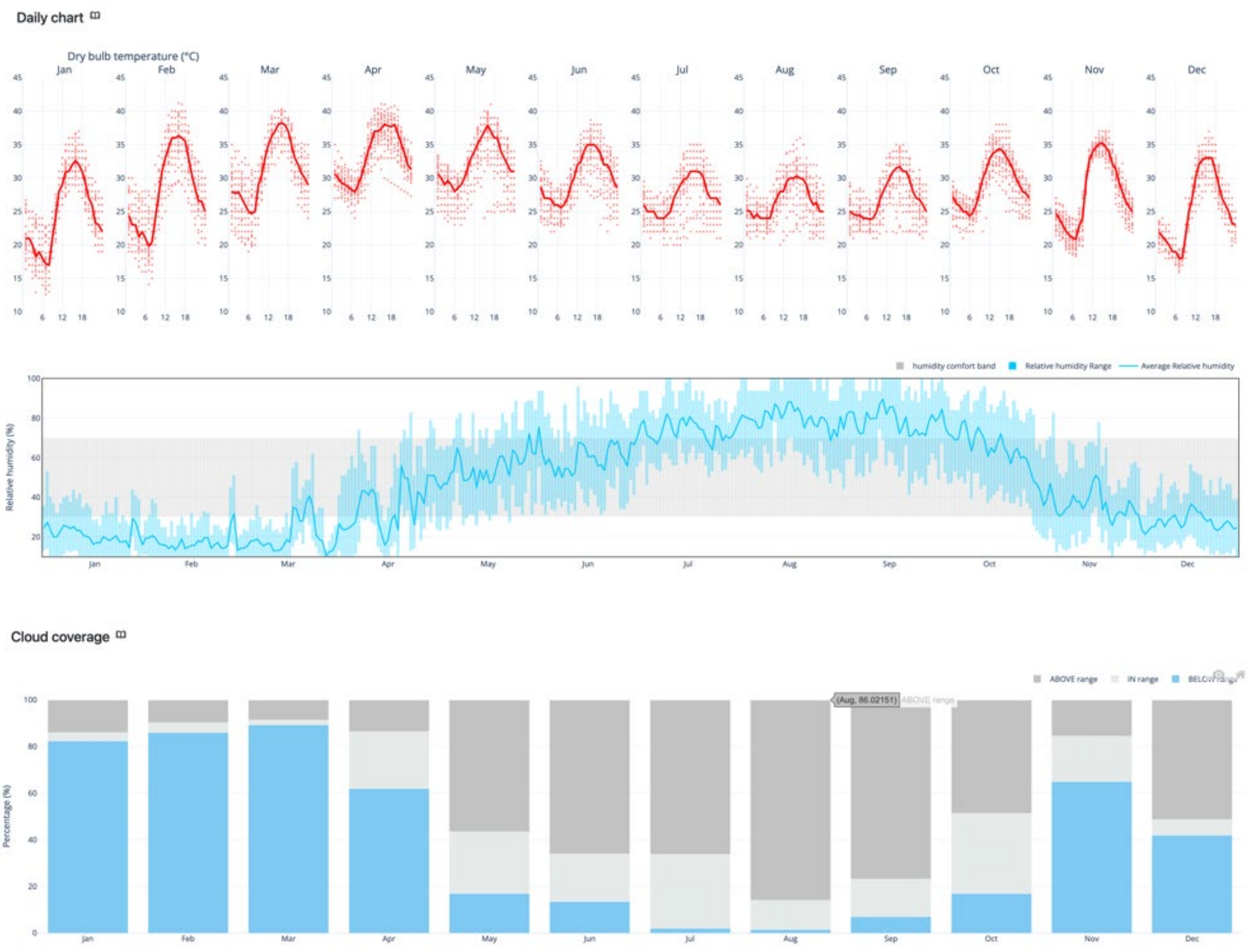


Figure 5: Weather features in Ouagadougou, 100 km from the building site in Koudougou

2.4 Post Occupancy Evaluation Surveys

This section includes general information concerning the POE surveys, i.e. surveys of sensations and preferences, structured according to International Standards, of users of a space. Measurements and questionnaires were done in the 3 different classrooms (BS1, BS2 and BS3) over different days in the hot period and for different times of the day, i.e., morning and afternoon. Table 2 reports details about the dates, time, room, number of responses and respondent information (category, clothing and metabolic activity). The respondents were mainly students from the Burkina Institute of Technology (BIT).

Table 2 Schedule of POE Surveys

Date	Time	Room	Number of responses	Respondents information			
				category	Mean CLO value of participants during the survey	Mean metabolic activity before conducting the survey	Mean metabolic activity during the survey
29/03/2023	11:20–11:30am	BS1	18	Students and professor	0.55	1.3	1
	3:57-4:10 pm		25		0.53	1.14	1
30/3/2023	9:37–9:45 am		24		0.6	1.2	1
31/3/2023	11:38-11:42am		20		0.52	1.15	1
12/04/2023	10:06 am		29		0.51	1.06	1
	03:08am		31		0.49	1.74	1
13/04/2023	02:50pm		32		0.55	1.1	1.01
14/04/2023	11:35-11:36am		33		0.56	1.13	1
17/04/2023	11:36 am		33		0.54	1.12	1
	04:00 pm		20		0.52	1.14	1
18/04/2023	10:45-11:29am		58		0.48	1.12	1
19/04/2023	12:11pm		30		0.47	1.12	1
19/04/2023	03:45pm		11		0.5	1.04	1
14/04/2023	10:13am	BS2	24		0.43	1.4	1
11/05/2023	10:35-10:36am		20		0.42	1.38	1
	03:35am		24		0.54	1.35	1
15/05/2023	10:16am		28		0.6	1.4	1
	04:05pm		29		0.55	1.21	1
16/05/2023	10:15am		27		0.47	1.31	1
	05:15pm		22		0.44	1.2	1
17/05/2023	08:30am		32		0.42	1.3	1
	03:15pm		27		0.44	1.31	1
23/05/2023	9:48am		36		0.52	1.27	1
	05:20pm		22		0.43	1.4	1
25/05/2023	10:25am		24		0.47	1.35	1
	03:48pm		23		0.51	1.3	1
31/05/2023	11:15am		20		0.46	1.2	1
	04:09pm		23		0.4	1.2	1
19/04/2023	10:15am	BS3	25		0.45	1.37	1
	04:35pm		23		0.48	1.38	1

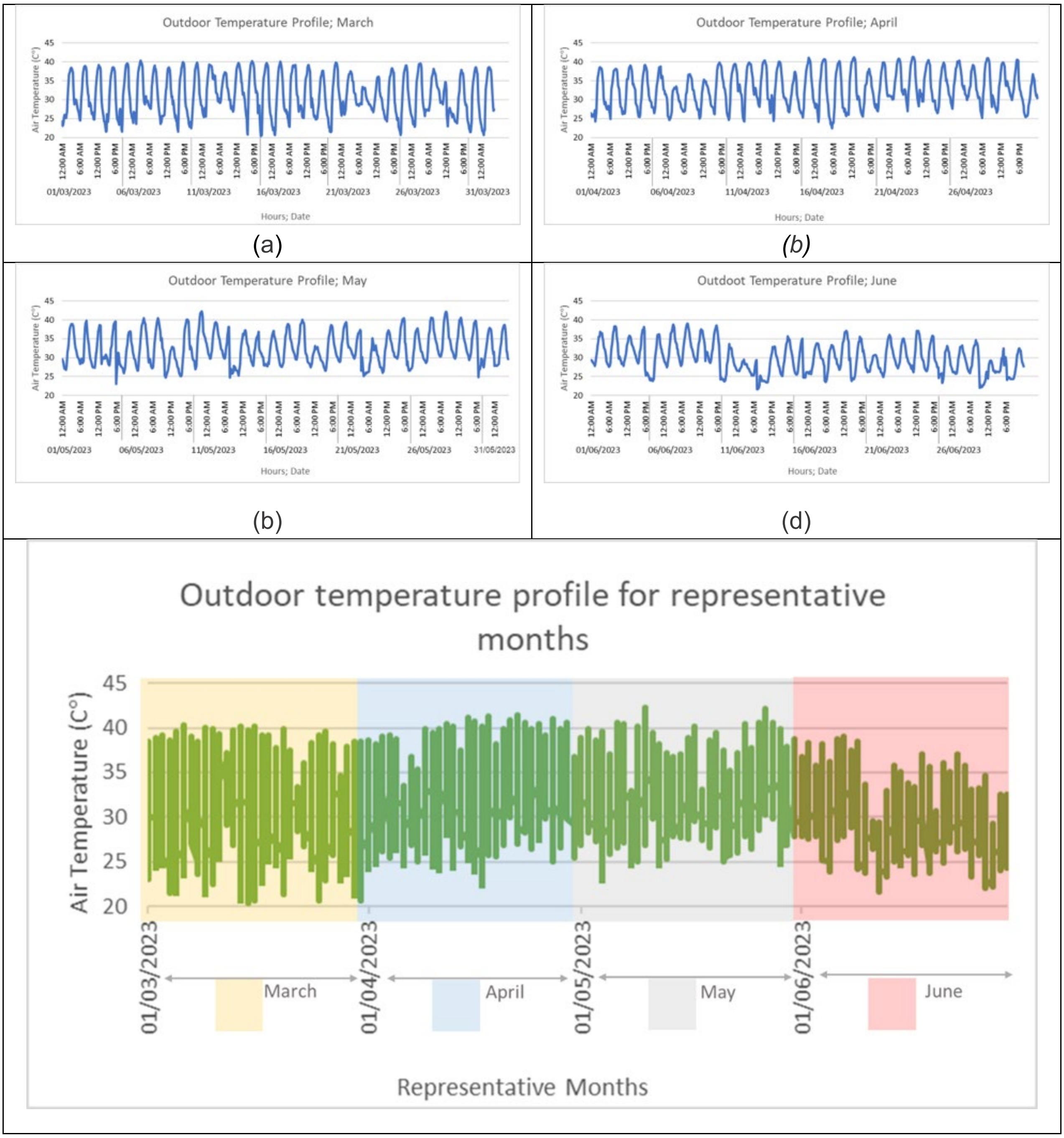
24/04/2023	03:52pm		27		0.50	1.36	1
25/04/2023	11:02am		22		0.42	1.16	1
	05:35am		18		0.49	1.02	1
26/04/2023	10:48am		28		0.45	1.4	1
	02:28pm		28		0.46	1.38	1
27/04/2023	10:25am		25		0.54	1.38	1
	03:05pm		29		0.49	1.39	1
28/04/2023	09:31am		27		0.46	1.38	1
	03:35pm		27		0.45	1.39	1
05/05/2023	09:54am		28		0.55	1.36	1
	03:01pm		15		0.51	1.4	1
26/05/2023	01:01-3:55pm		50		0.48	1.3	1
Total			**1117**				

3. Results and discussion

3.1 Analysis of Weather Data

3.1.1 Outdoor Air Temperature

Measured data show, in the considered months, there is a large variation in temperature from day to night. The maximum temperature recorded at the TAHMO weather station in the month March is 40.5°C while minimum recorded is 20.2°C. Similarly, maximum temperature recorded in the months of April, May and June is 41.5°C, 42.7°C and 39.5°C respectively, while the minimum recorded for these months is 22.2°C, 21.6°C, and 20.8°C.

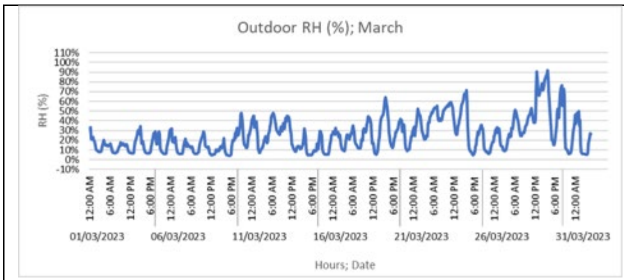


(e)

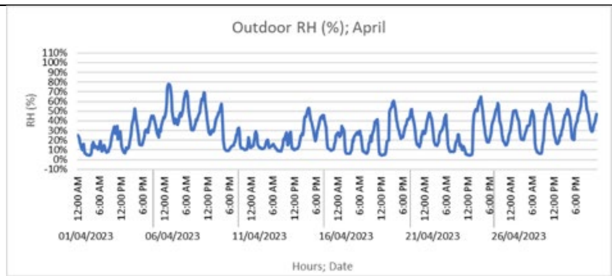
Figure 6 (a) Temperature profile of March 2023 (b) Temperature profile of April 2023 (c) Temperature profile of May 2023 (d) Temperature profile of June 2023 (c) Temperature profile from March to June 2023. (Data obtained from the weather station on site)

3.1.2 Relative Humidity

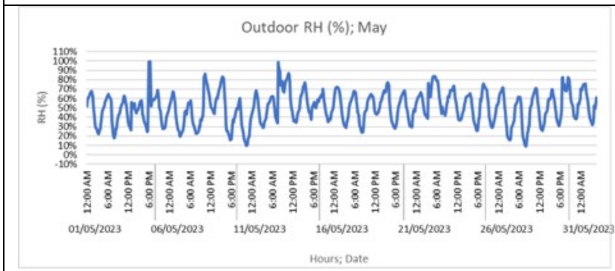
Figure 7 shows that the relative humidity level is gradually increasing from March to June, in accordance with the approaching rainy season.



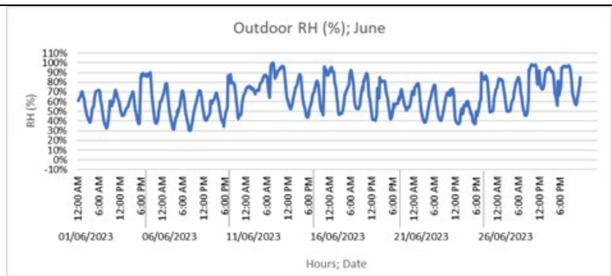
(a)



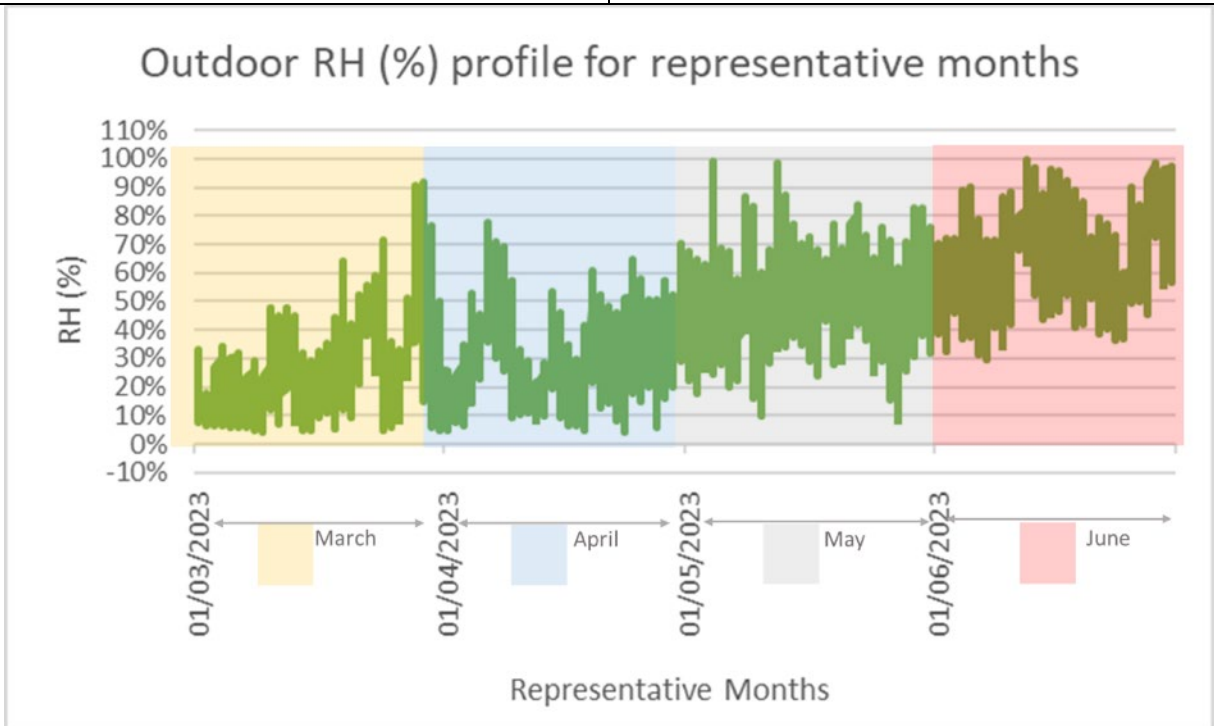
(b)



(b)



(d)

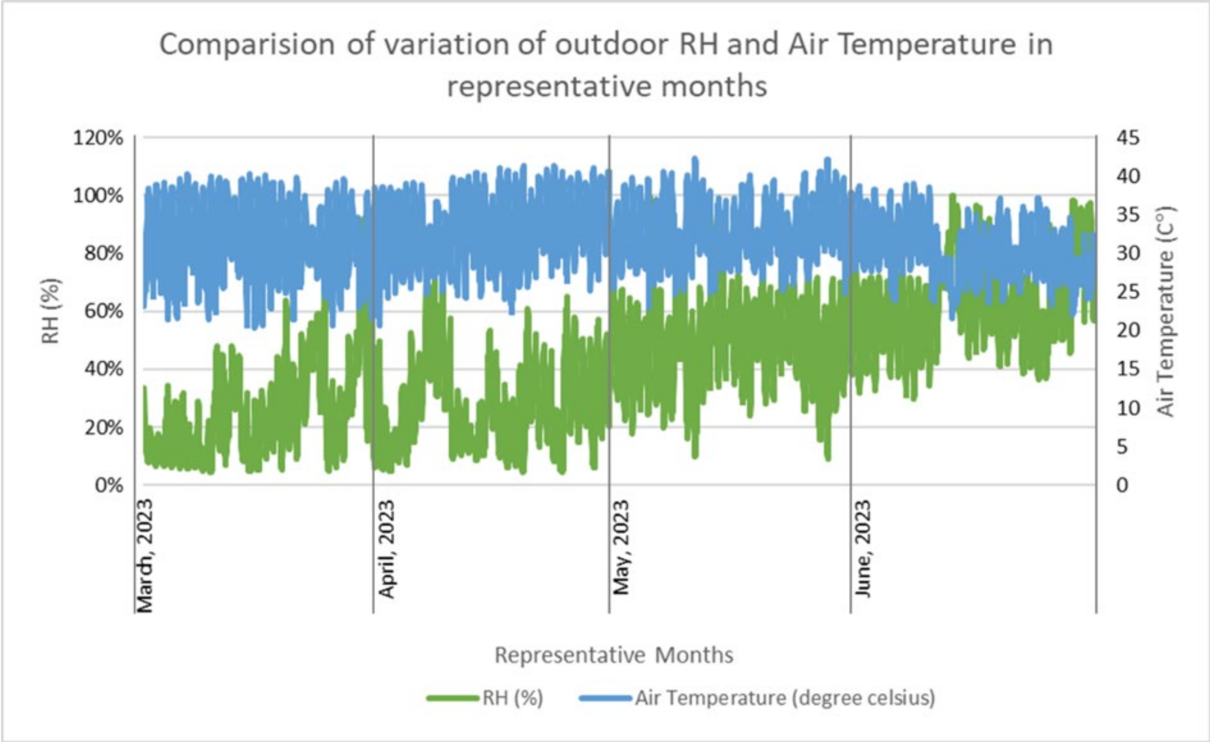


(e)

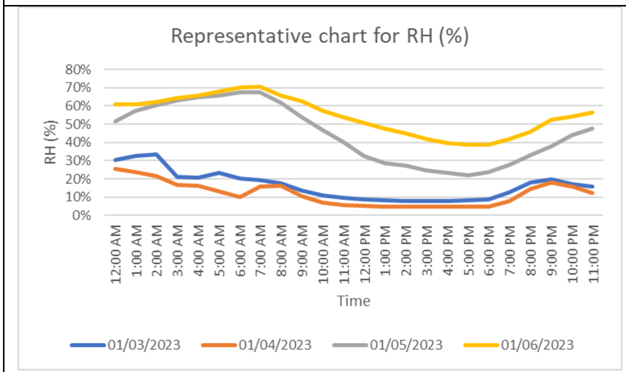
Figure 7 (a) RH (%) levels of March, (b) RH (%) levels of April, (c) RH (%) levels of May (d) RH (%) levels of June, (c) Comparison of RH (%) for the months of March, April, May and June 2023. (Data was collected via the weather station on site)

3.1.3 Comparison of air temperature and relative humidity data of Koudougou, Burkina Faso

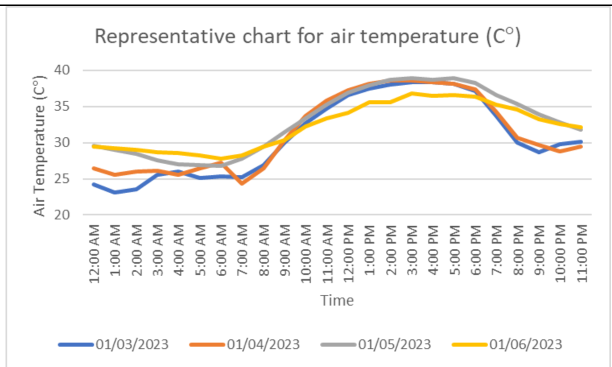
There is not much of a difference between the average daily temperatures of the months, but the relative humidity chart reveals that March and April are less humid than May and June (and in fact quite dry). Here, we'll look at April and May as a whole and compare their relative humidity readings.



(a)



(b)



(c)

Figure 8 (a) Comparison of RH (%) and Air Temperature (C°) values of outdoors during the representative month (March to June 2023). Comparison of RH (b) and Air Temperature (c) on 1st March, 1st April, 1st May and 1st June 2023, showing a similar temperature trend in all the four cases while a significant difference in RH between March/April and May/June. (a) Representative chart of Air Temperature on 3rd March 3rd April 3rd May and 3rd June. Data was obtained from the weather station on site.

3.1.4 Wind Profile

The average monthly wind speeds measured by the TAHMO weather station are as follows: 1.3 m/s in March, 1.4 m/s in April, 1.9 m/s in May, and 1.8 m/s in June. From Figure 9 (e), that the months of May and June appear slightly more windy than the months of March and April.

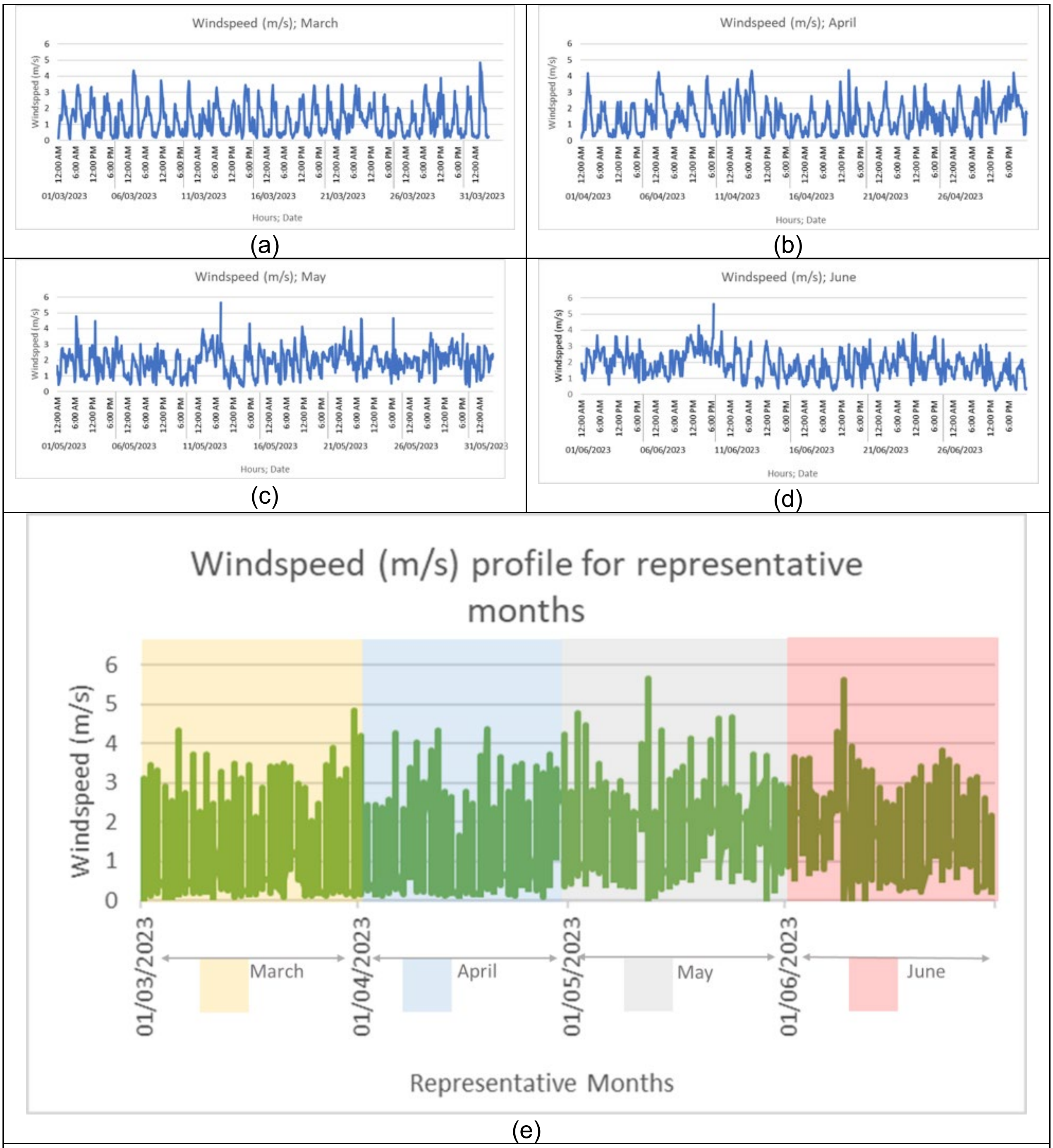


Figure 9 (a) Windspeed (m/s) levels of March 2023, (b) Windspeed (m/s) levels of April 2023, (c) Windspeed (m/s) levels of May 2023, (d) Windspeed (m/s) levels of June 2023, (e)Comparison of wind speed data for the months of March, April, May and June 2023. (Data was obtained from the weather station on site)

3.1.5 Solar Radiation Profile

Daily global solar irradiance measured at an interval of 15 minutes by the weather station on site in Koudougou, Burkina Faso has been **plotted for the months of March, April, May and June**,

showing an average value of 482 W/m² and a peak value of 1052 W/m², registered in the respective months of 2023.

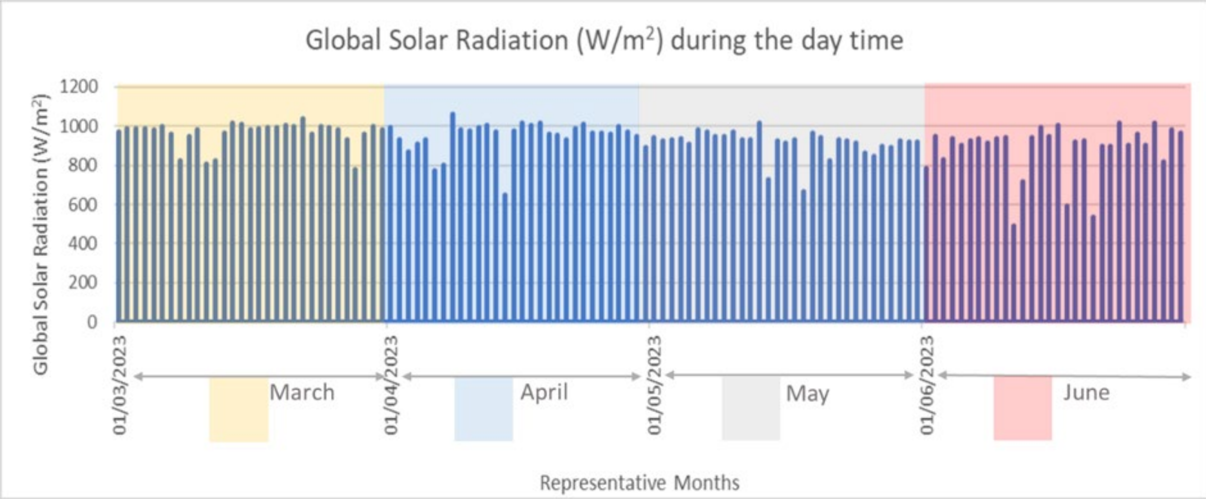


Figure 10 Global Solar irradiance profiles from March to June 2023. (Data was obtained from the weather station on site)

3.2 Analysis of Indoor environment

3.2.1 Indoor Air Temperature

Figure 11 presents the boxplot of indoor air temperature for all the studied rooms over the total period of measurements as well as the one for the outdoor conditions. The box represents minimum, maximum and average values of air temperatures in each classroom and outdoors.

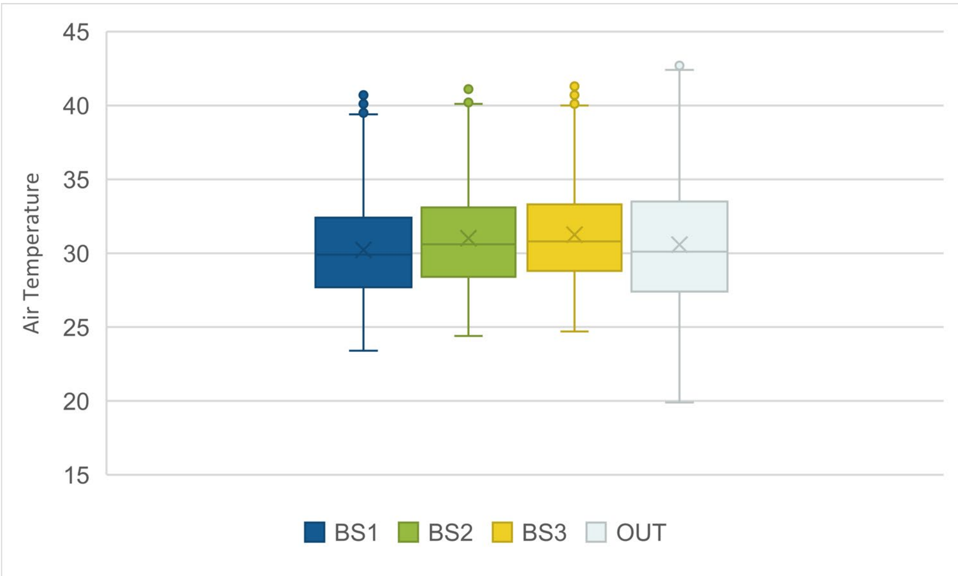
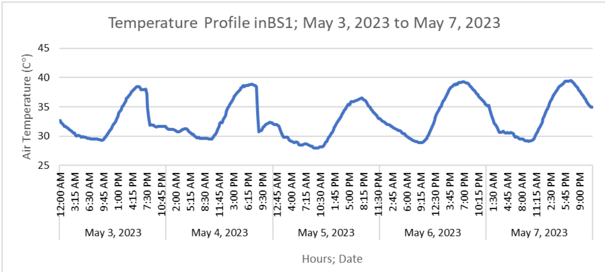


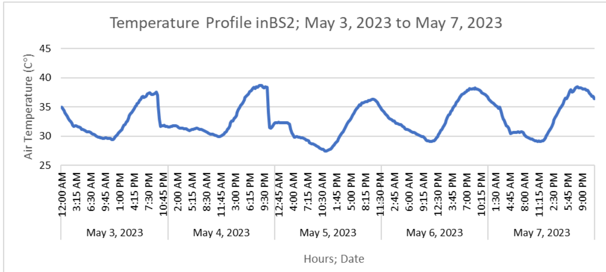
Figure 11 Boxplot of the air temperature for the indoor and outdoor conditions from the 2nd May 2023 to the 31st August 2023 for the BIT. Data were obtained from the sensors installed in the classrooms and the weather station on site.

The distribution of the air temperatures is similar for all the studied rooms. The mean value of air temperature is between 30 and 31°C. The maximum air temperature reaches up to 41.3°C (for only a few times).

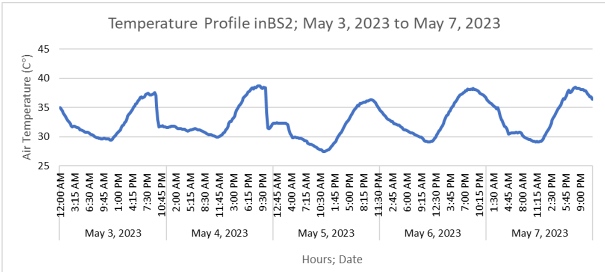
Figure 12 shows that the temperature profile of indoor sensors in BS1, BS2, BS3 and outdoor is similar in the observed week, highlighting a slight difference of temperature between the outdoor and the indoor environment, which is coherent with the fact that the windows are kept open during the day and closed at night.



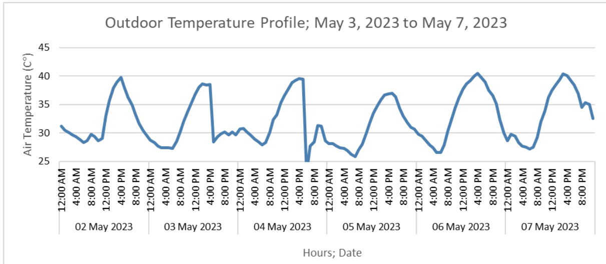
(a)



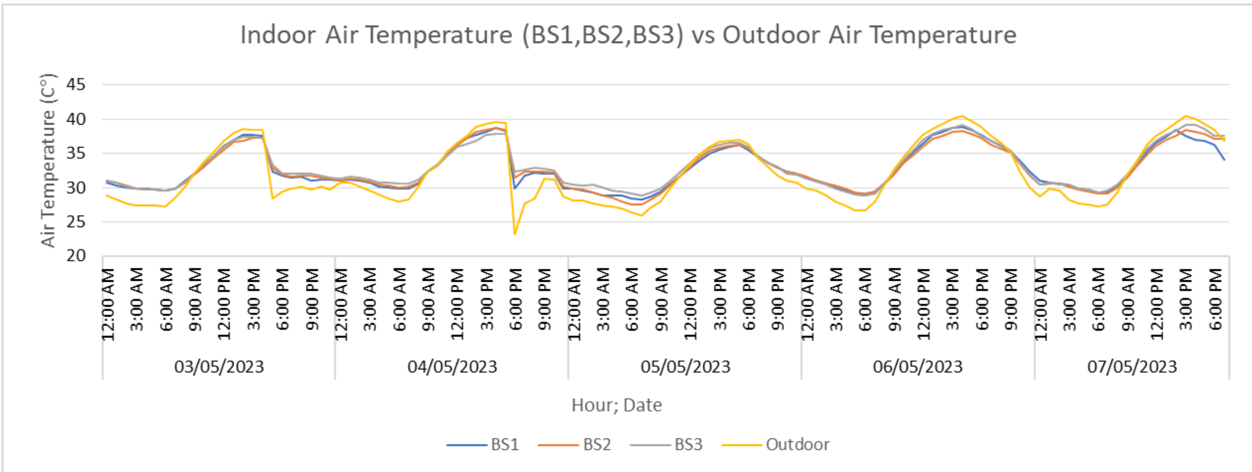
(b)



(c)



(d)



(e)

Figure 12: (a) Outdoor air temperature profile from 3rd May till 7th of May, (b) Air temperature profile in BS1 from 3rd May till 7th of May (c) Air temperature profile in BS2 from 3rd May till 7th of May (d) Air temperature profile in BS3 from 3rd May till 7th of May (e) Representative chart overlaying the indoor air temperature of all three classroom and outdoor air temperature from 3rd May till 7th of May

3.2.2 Number of hours / frequencies within a certain temperature range

This section provides information on the occurrence per temperature bins of air temperature in various monitored rooms during occupied hours, as well as outdoor conditions. The data is presented in bins of 2°C.

Table 3 Frequency of air temperature ranges in BIT. Data was obtained from the weather station on site.

2nd May 2023 to August 2023 Occupation time: 7:00am to 5:00pm	INDOOR CONDITION						OUTDOOR CONDITIONS	
	BS1		BS2		BS3		weather station	
Range	No. of Hours	Fq	No. of Hours	Fq	No. of Hours	Fq	No. of Hours	Fq
T<20°C	0	0%	0	0%	0	0%	0.3	0%
20°C≤T<22°C	0	0%	0	0%	0	0%	7.0	0%
22°C≤T<24°C	13	1%	0	0%	0	0%	60.8	3%
24°C≤T<26°C	231	10%	59	3%	40	2%	183.8	10%
26°C≤T<28°C	405	17%	300	17%	230	13%	290.5	16%
28°C≤T<30°C	557	24%	403	23%	430	24%	340.0	19%
30°C≤T<32°C	489	21%	392	22%	413	23%	276.8	15%
32°C≤T<34°C	297	13%	267	15%	312	17%	229.8	13%
34°C≤T<36°C	166	7%	167	9%	189	11%	169.5	9%
T≥36°C	194	8%	184	10%	182	10%	236.5	13%

In the examined spaces, the ambient air temperature is between 26 and 34 °C for around 77% of the time. The temperatures exceed 36°C in all the rooms for about 10% of the time. The temporary decrease to 26°C occurs solely from 7am to 8am. The highest recorded temperature, above 40°C, is consistently reported at 2pm for BS1, BS2 and BS3.

3.2.3 Number of hours / frequencies by relative humidity range

This section provides information on the occurrence of relative humidity in bins of 10% RH for monitored rooms during occupied hours only, as well as for outdoor situations.

Table 4 Frequency of relative humidity ranges in BIT. Data was obtained from the weather station on site.

May 2023 to August 2023 Occupation time: 7:00am to 5:00pm	INDOOR CONDITION						OUTDOOR CONDITIONS	
	BS1		BS2		BS3		weather station	
Range	No. of Hours	Fq (%)	No. of Hours	Fq(%)	No. of Hours	Fq(%)	No. of Hours	Fq(%)
[0,10%]	2	0%	1	0%	3	0%	3	0%
[10,20%]	21	1%	22	1%	19	1%	22	1%
[20,30%]	81	3%	76	4%	67	3%	80	4%
[30,40%]	200	8%	193	10%	199	10%	171	9%
[40,50%]	351	14%	335	17%	386	19%	283	15%
[50,60%]	463	18%	413	21%	455	23%	341	19%
[60,70%]	542	21%	423	22%	448	23%	343	19%
[70,80%]	557	22%	371	19%	344	17%	267	14%
[80,90%]	354	14%	119	6%	61	3%	202	11%
[90,100%]	0	0%	0	0%	0	0%	131	7%

In the BS1 room, the relative humidity levels typically fluctuate between 40% and 90% for most of the occupied hours. in BS2 the relative humidity levels fluctuates between 30% to 80%, with occasional instances where it surpasses 80% during specific time periods. In BS3 the relative humidity levels fluctuate between 40% to 80%, with few instances where it surpasses 80%. The outdoor environment experiences a significant range of relative humidity, varying from 40% to 80% over a considerable number of hours.
In general, the findings indicate that both indoor and outdoor environments exhibit a significant number of hours with high level of relative humidity, but also periods of low humidity and correspondingly high fluctuation of temperature between day and night, which are favorable to Nocturnal ventilative cooling.

3.3 POE results

Many sessions of POE surveys were conducted during the hot season starting from 29/03/2023 to 31/05/2023. 1117 responses were collected and are analyzed in the sections below. Table 5 shows a synthesis of the surveys carried out. It is observed maximum surveys were carried out for BS1 equal to 562 (or 41%) data, and 381 and 372 surveys were performed in BS2 and BS3. However, the survey changed with the month and the highest number of surveys were performed in April, equal to 778, followed by May with 450 and March only 87 surveys in total. The detailed schedule of the POE surveys is reported in Figure 13.

Table 5 Consideration of months and no. of days for POE survey

Classroom	No. of Days	March	No. of Days	April	No. of Days	May
BS1	3	✓	6	✓	0	✕
BS2	0	✕	1	✓	7	✓
BS3	0	✕	6	✓	2	✓

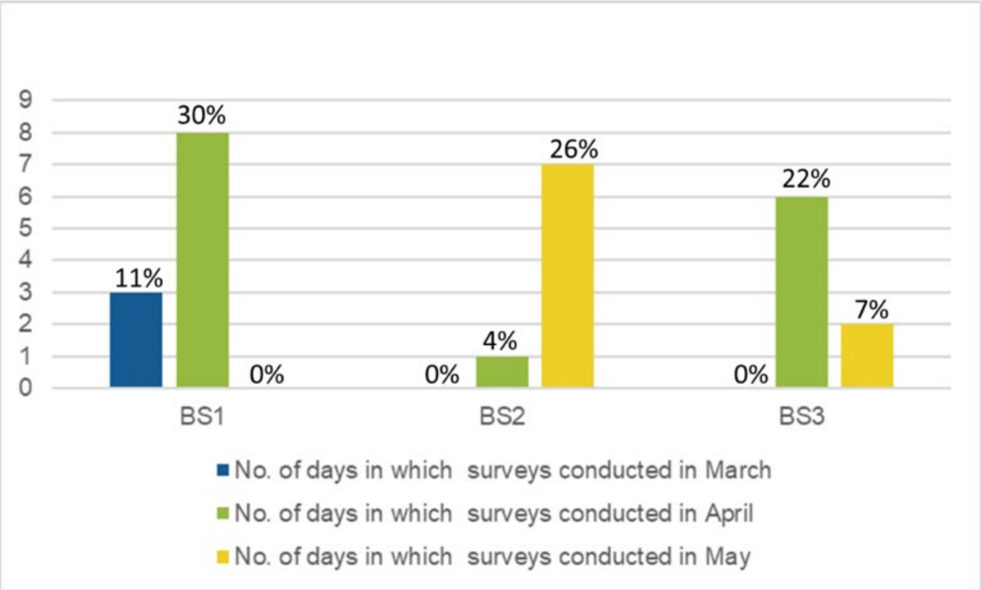


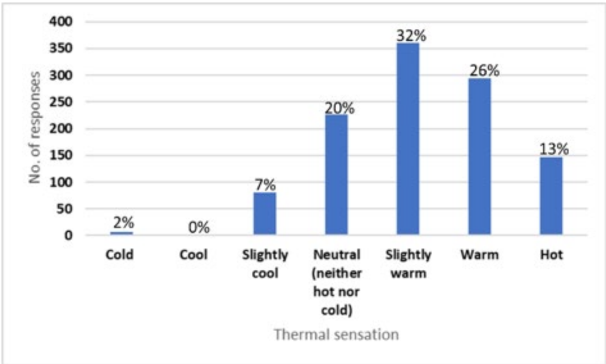
Figure 13 Consideration of months and no. of days for POE survey

3.3.1 Thermal sensation, thermal comfort judgement and thermal preference

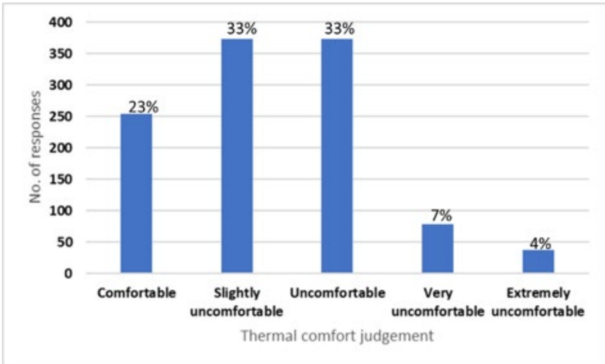
Figure 14 presents the results obtained in terms of thermal sensation (a), thermal comfort judgement (b) and thermal preference (c). The figures are related to the three classes together.

Across the various dates of the survey, a considerable proportion of responses expressed a neutral opinion regarding thermal sensation (about 227), while the widest portion of responses (360), reported feeling slightly warm, 294 felt warm and 146 felt hot. Hence, in terms of vote on the -3 to + 3 ASHRAE scale, the range -1 to +1 (slightly cool to slightly warm), which is assumed by e.g Fanger to be a comfortable range, was voted in 59% of responses. If air velocity had been higher this percentage would have substantially increased, as it appears from the responses to the questions about air velocity.

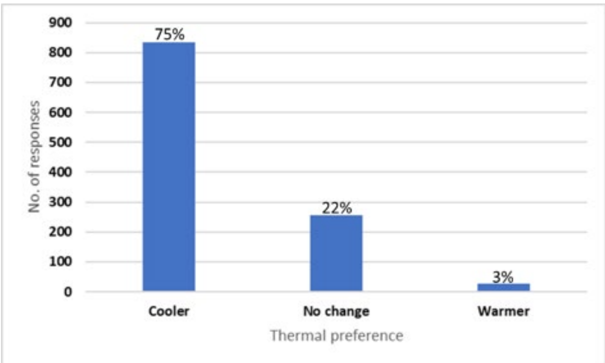
In terms of thermal comfort judgement, the 254 respondents reported to be comfortable, 374 slightly uncomfortable, 374 uncomfortable, 78 very uncomfortable and 37 extremely uncomfortable. Majority of responses (835 out of 1117) expressed a preference for being cooler.



(a)



(b)



(c)

Figure 14: (a) Thermal sensation; (b) Thermal comfort judgement; (c) Thermal preference

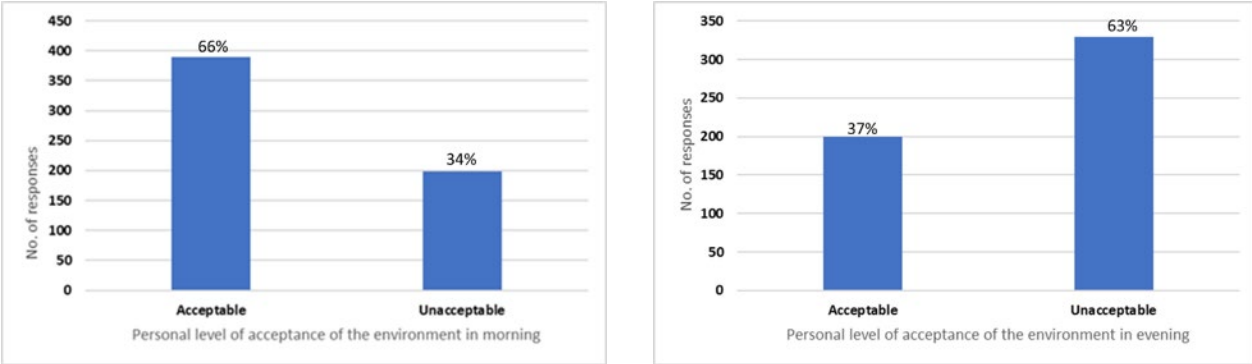
3.3.2 Acceptance of the natural environment in the morning and afternoon.

The findings also suggest that a significant proportion of the individuals surveyed experienced varying levels of comfort in relation to the timing of the day, specifically morning or evening, this is shown in Figure 15.

The results that were obtained for the choice in terms of personal acceptance of the surroundings. Overall, a higher number of surveys 604 were performed in the morning, compared to 513 in the afternoon. Based on the results, it is evident that individuals exhibit a higher degree of acceptation towards the indoor environment in the morning hours ranging from 9 am till 11 am with 399

ABC21 is funded by the
EU's H2020 programme

responses (66%) as acceptable compared to the afternoon hours ,2pm to 5pm, with only 190 (37%) finding the environment acceptable, which is coherent with the indoor measured temperature showing a peak in the afternoon.

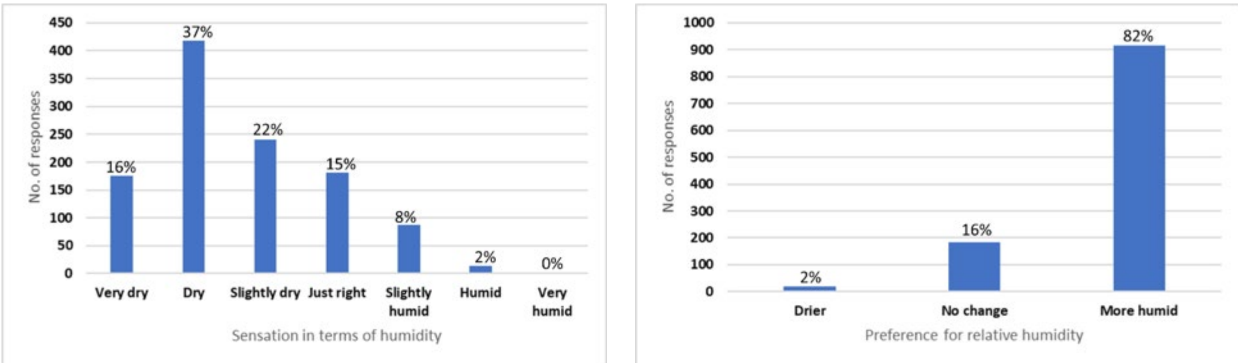


(a) *(b)*

Figure 15 : (a) percentage of acceptance of the environment in morning (b) percentage of acceptance of the environment in the afternoon in the surveyed rooms of BIT.

3.3.3 Sensation and preference for the air humidity

The results for the sensation (a) and preference (b) regarding air humidity are presented in Figure 16. The data reveals that 16% (179 responses) data falls within the category of very dry, 37% (413 responses) for dry, 22% (246 responses) for slightly dry, 15% (179 responses) for just right, 8% (89 responses) for slightly humid, 2% (11 responses) for humid and 0% for very humid. The majority of individuals surveyed expressed a preference for an increase in air humidity, with 82% (916 responses) of respondents indicating this inclination, 16% (179 responses) want no change while 2% (22 responses) people wanted to have a drier environment.



(a) *(b)*

Figure 16: (a) Humidity sensation chart and (b) Preference for air humidity

3.3.4 Sensation and preference for the air velocity

Figure 17 to Figure 22 present the results obtained for the sensation and preference in terms of air velocity.

In the month of March, 87 responses were documented during the post-occupancy evaluation (POE) surveys in classroom BS1. Among them, 67 **(77%) responses** expressed **preference for more air movement** 3 respondents (20%) wanted no change and 3 respondents (3%) less air movement.
8 respondents (9%) reported the air being very still, 25 respondents (29%) still, 25 respondents (29%) slightly still, 23 respondents (26%) just right, 5 respondents (6%) slightly draughty and 1 respondent (1%) draughty.

The results are coherent with the data obtained from the sensors installed in the observed rooms and on the days when POE surveys were conducted. Wind velocity outdoors (d) is significantly higher than the air velocity inside the rooms, which remains mostly between 0,1 and 0,3 m/s (c), where 0,1 m/s corresponds to practically no air movement.

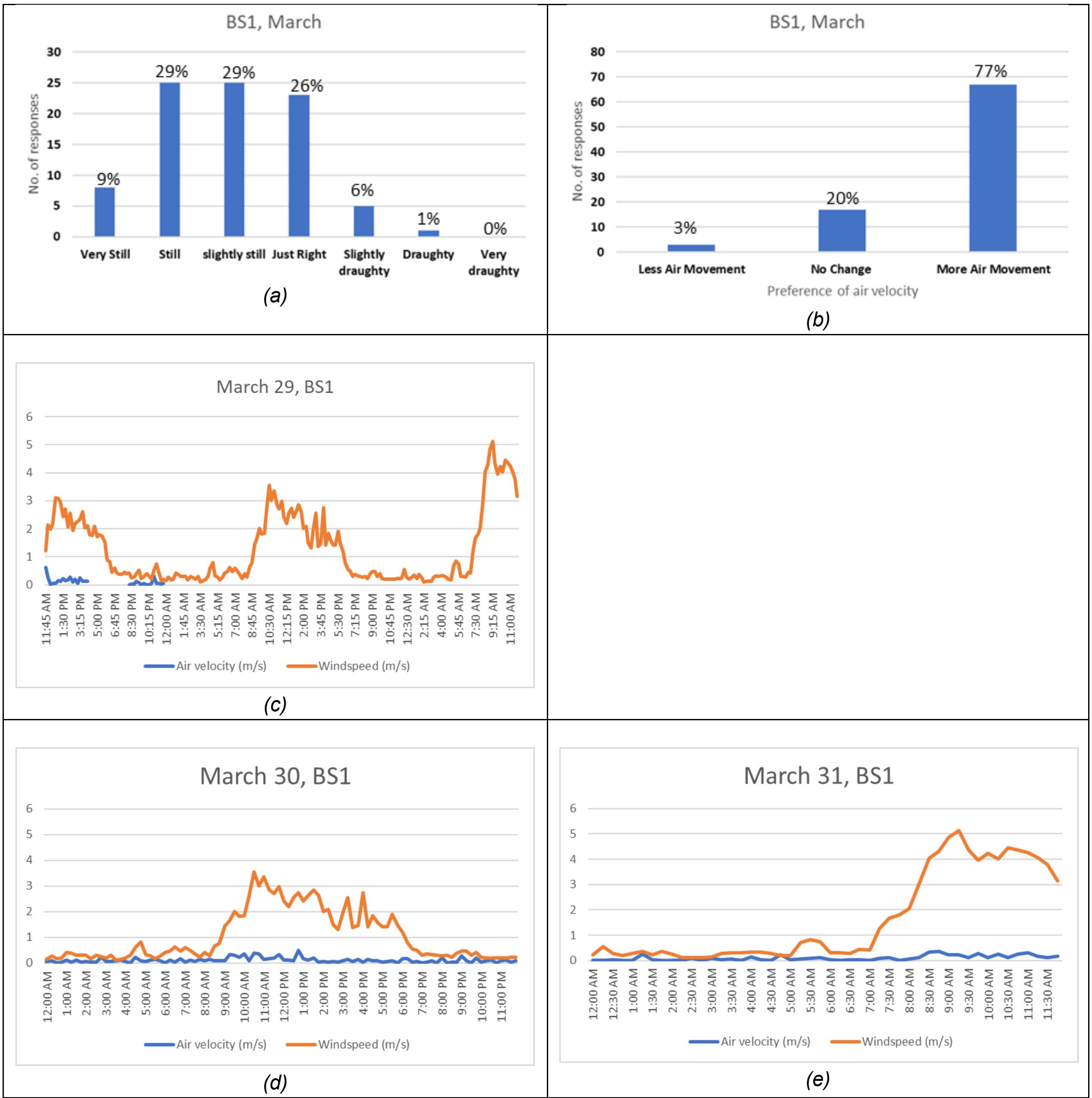
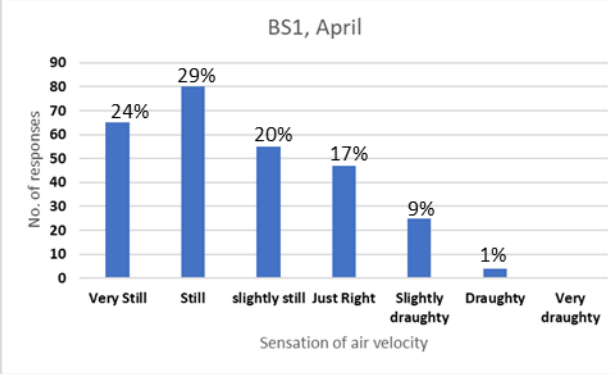


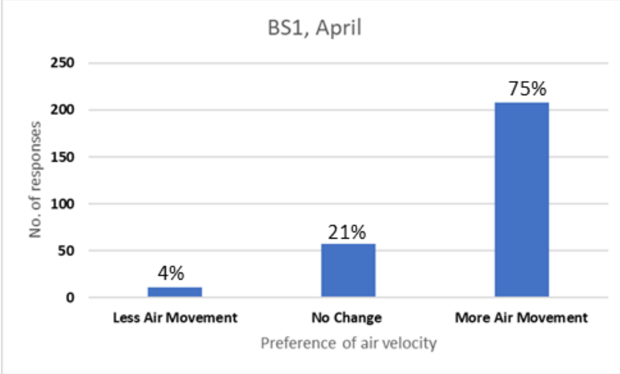
*Figure 17 A comparison: (a) Sensation and (b) preference in terms of air velocity inside **BS1** in the month of **March** (c;d;e;) indoor air velocity in **BS1** based on data obtained from sensor installed in the room compared with outdoor wind speed from TAHMO weather station on the surveyed days of **March**.*

In the month of April, 276 responses were documented during the post-occupancy evaluation (POE) surveys in classroom BS1. Among them, 208 (**75%) surveyed individuals expressed their preference for more air movement**, 57 respondents (21%) wanted no change and 11 respondents (4%) less air movement.

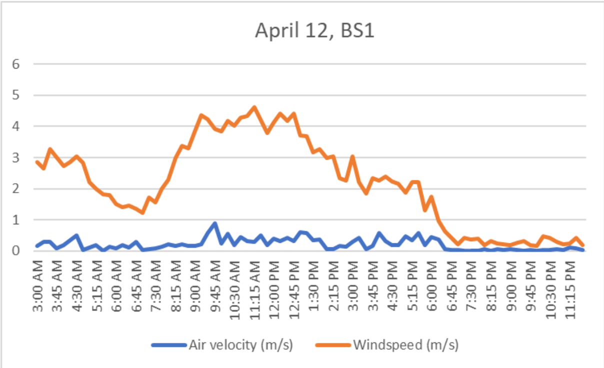
65 respondents (24%) reported the air being very still, 80 respondents (29%) still, 55 respondents (20%) slightly still, 47 respondents (17%) just right, 25 respondents (9%) slightly draughty and 4 respondent (1%) draughty.



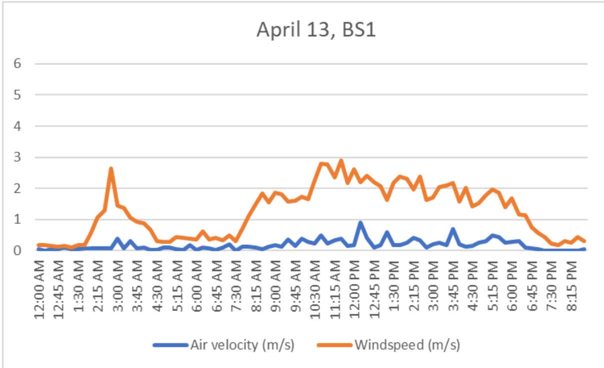
(a)



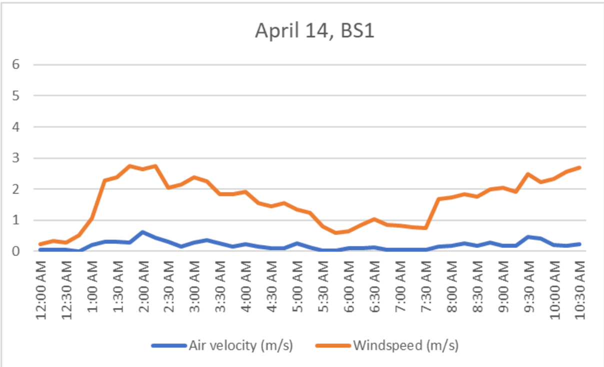
(b)



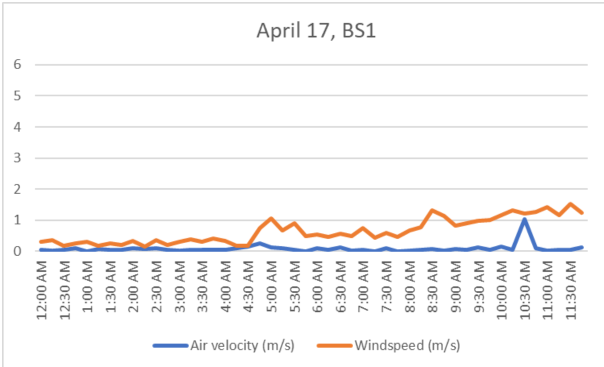
(c)



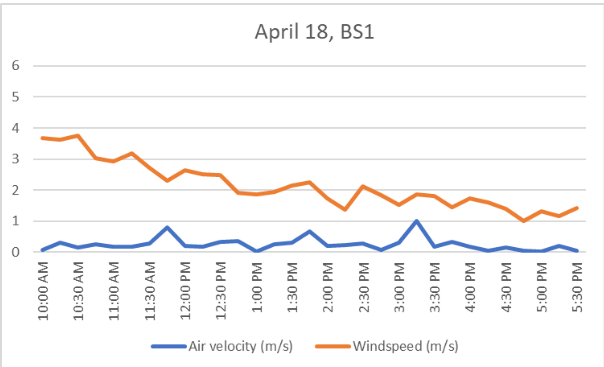
(d)



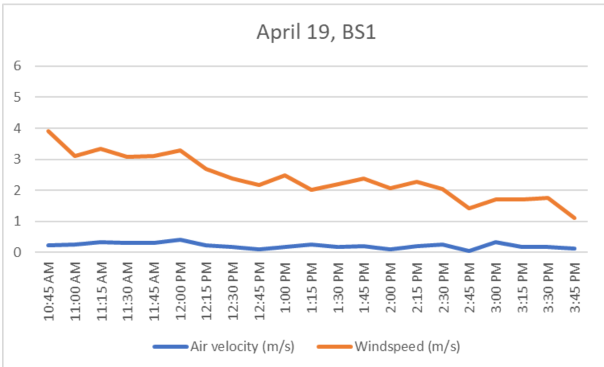
(e)



(f)



(g)



(h)

Figure 18 A comparison (a) Sensation chart and (b) preference in terms of air velocity inside ***BS1*** *(c;d;e;f;g;h) air velocity in* ***BS1*** *based on data obtained from sensor installed in the room compared with wind velocity from TAHMO weather station on the surveyed days of* ***April****.*

In the month of April, 23 responses were documented during the post-occupancy evaluation (POE) surveys in classroom BS1. Among them, 11 (**48%) surveyed individuals expressed their preference for more air movement**, 10 respondents (43%) wanted no change and 2 respondents (9%) less air movement.

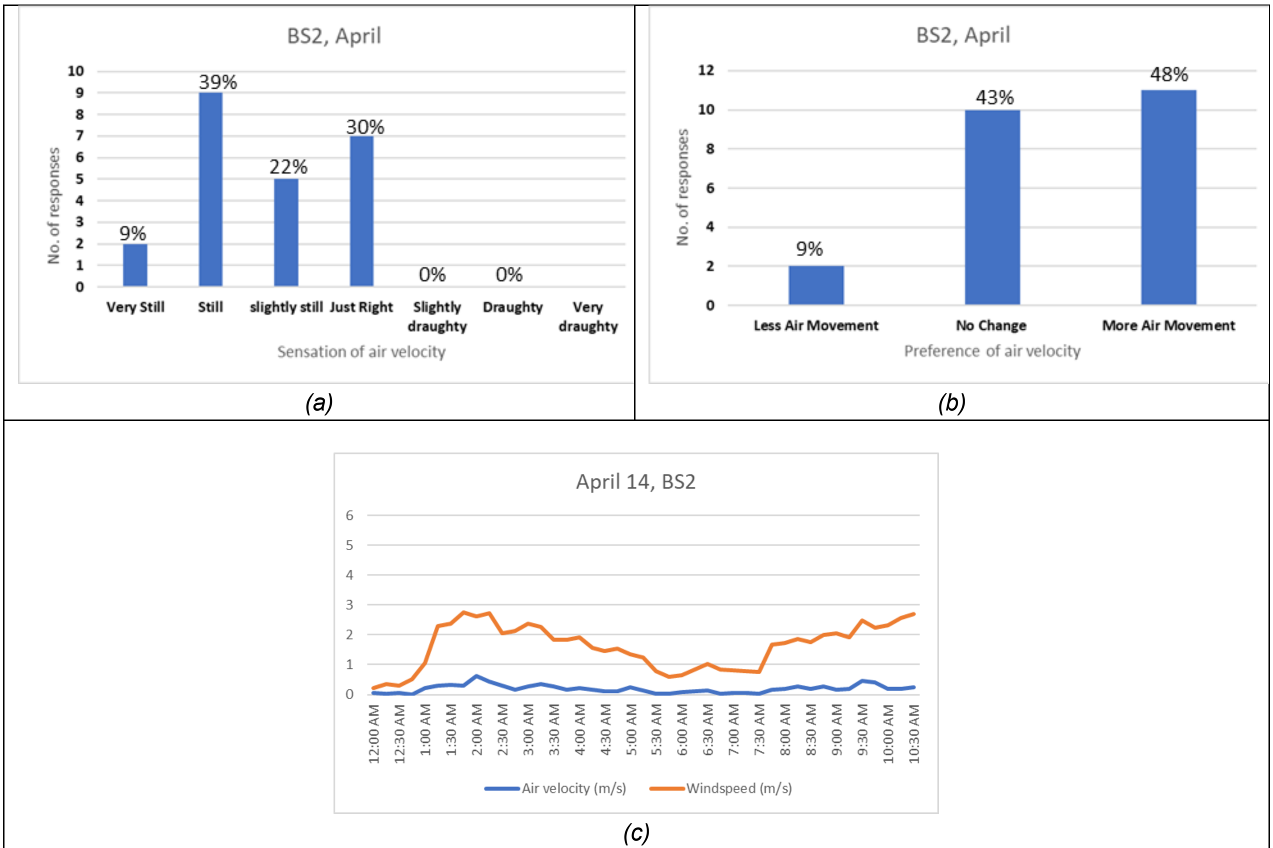
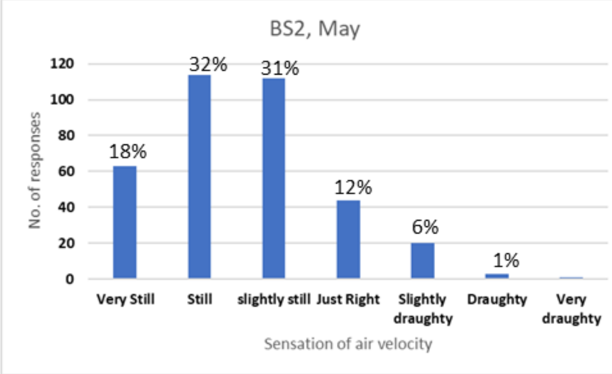


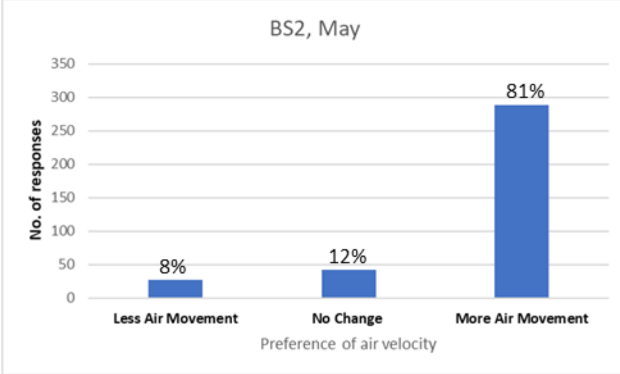
*Figure 19 A comparison (a) Sensation chart and (b) preference in terms of air velocity inside **BS2** (c) air velocity profile in **BS2** based on data obtained from sensor installed in the room compared with wind velocity from TAHMO weather station on the surveyed days of **April.***

In the month of May, 357 responses were documented during the post-occupancy evaluation (POE) surveys in classroom BS1. Among them, 288 (**81%) surveyed individuals expressed their preference for more air movement**, 42 respondents (12%) wanted no change and 27 respondents (8%) less air movement.

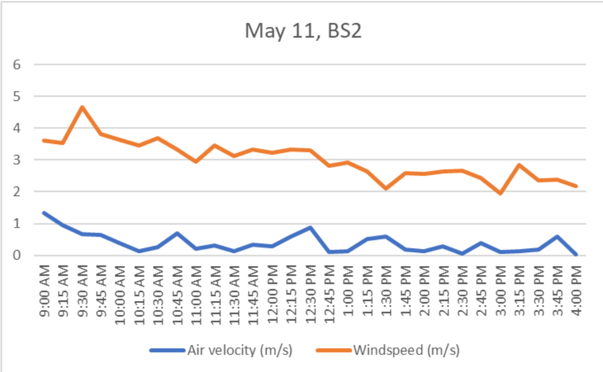
63 respondents (18%) reported the air being very still, 114 respondents (32%) still, 112 respondents (31%) slightly still, 44 respondents (12%) just right, 20 respondents (6%) slightly draughty and 3 respondent (1%) draughty, and 1respondent (0.3%) very draughty.


BS2, May
No. of responses
120
100
80
60
40
20
0
18%
32%
31%
12%
6%
1%
Very Still
Still
slightly still
Just Right
Slightly draughty
Draughty
Very draughty
Sensation of air velocity

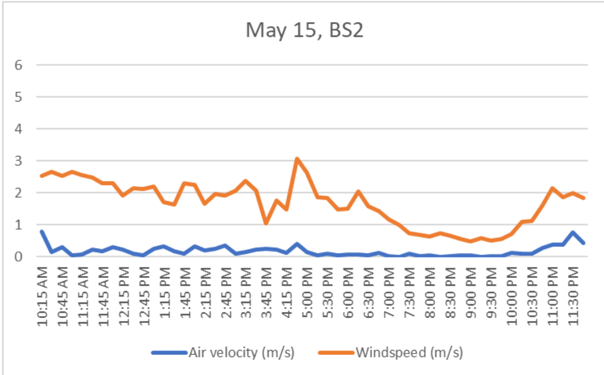
(a)


BS2, May
No. of responses
350
300
250
200
150
100
50
0
8%
12%
81%
Less Air Movement
No Change
More Air Movement
Preference of air velocity

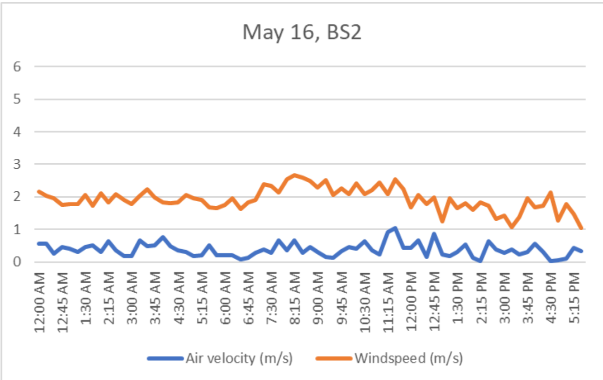
(b)


May 11, BS2
6
5
4
3
2
1
0
Air velocity (m/s)
Windspeed (m/s)

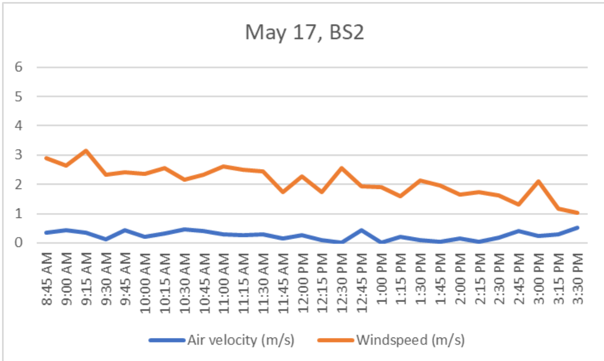
(c)


May 15, BS2
6
5
4
3
2
1
0
Air velocity (m/s)
Windspeed (m/s)

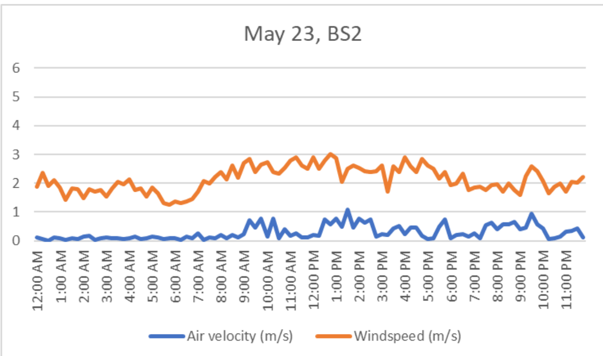
(d)


May 16, BS2
6
5
4
3
2
1
0
Air velocity (m/s)
Windspeed (m/s)

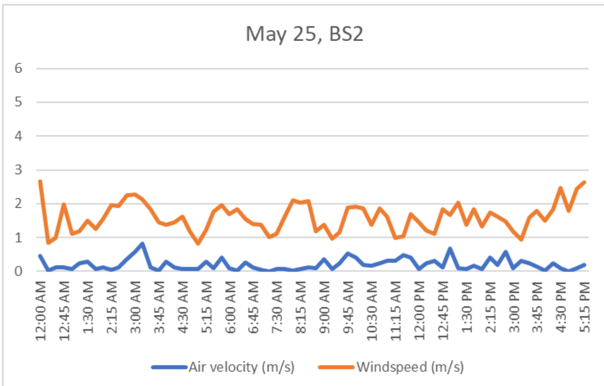
(e)


May 17, BS2
6
5
4
3
2
1
0
Air velocity (m/s)
Windspeed (m/s)

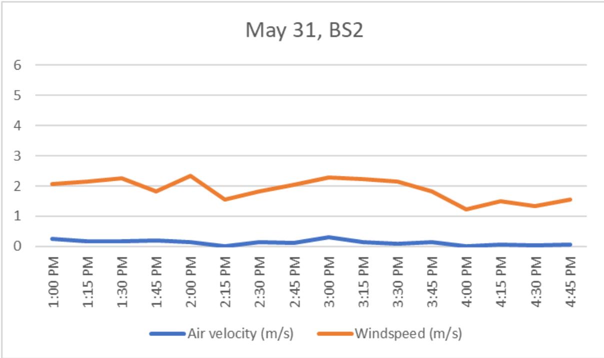
(f)


May 23, BS2
6
5
4
3
2
1
0
Air velocity (m/s)
Windspeed (m/s)

(g)


May 25, BS2
6
5
4
3
2
1
0
Air velocity (m/s)
Windspeed (m/s)

(h)



(i)

*Figure 20 A comparison (a) Sensation chart (b) preference in terms of air velocity inside **BS2** (c;d;e;f;g;h;i) air velocity in **BS2** based on data obtained from sensor installed in the room compared with wind velocity from TAHMO weather station on the surveyed days of **May**.*

In the month of April, 278 responses were documented during the post-occupancy evaluation (POE) surveys in classroom BS2. Among them, 219 **(79%) surveyed individuals expressed their preference for more air movement**, 34 respondents (12%) wanted no change and 25 respondents (9%) less air movement.

65 respondents (23%) reported the air being very still, 116 respondents (42%) still, 63 respondents (23%) slightly still, 26 respondents (9%) just right, 7 respondents (3%) slightly draughty and 1 respondent (0.3%) draughty.

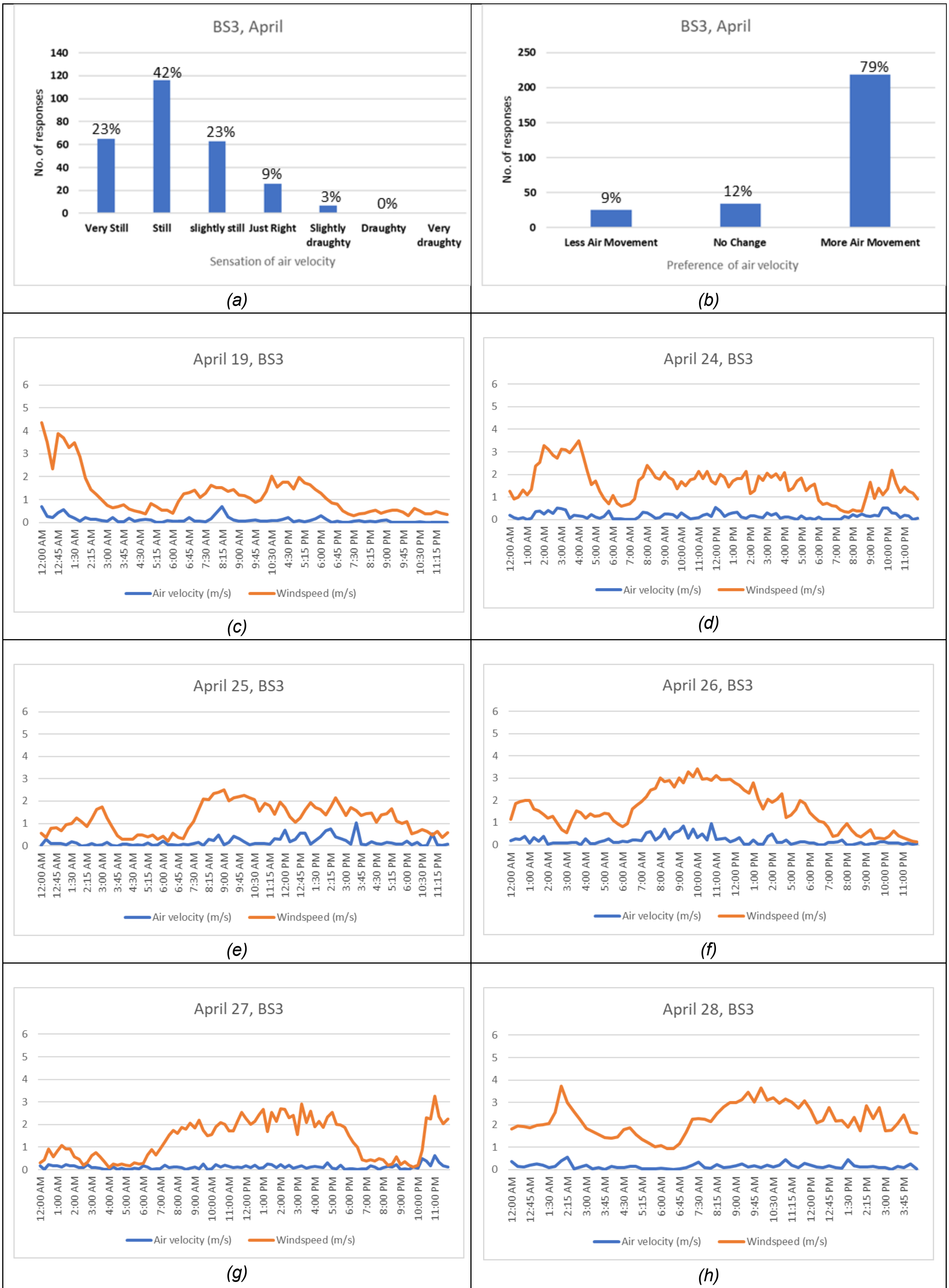


*Figure 21 A comparison (a) Sensation chart (b) preference in terms of air velocity inside **BS3** (c,… h) air velocity profile in **BS3** based on data obtained from sensor installed in the room compared with wind velocity from TAHMO weather station on the surveyed days of **April**..*

In the month of May, 92 responses were documented during the post-occupancy evaluation (POE) surveys in classroom BS3. Among them, **74 (80%) surveyed individuals expressed their preference for more air movement**, 10 respondents (11%) wanted no change and 8 respondents (9%) less air movement.

7 respondents (8%) reported the air being very still, 33 respondents (36%) still, 31 respondents (34%) slightly still, 15 respondents (16%) just right, and 6 respondents (7%) slightly draughty.

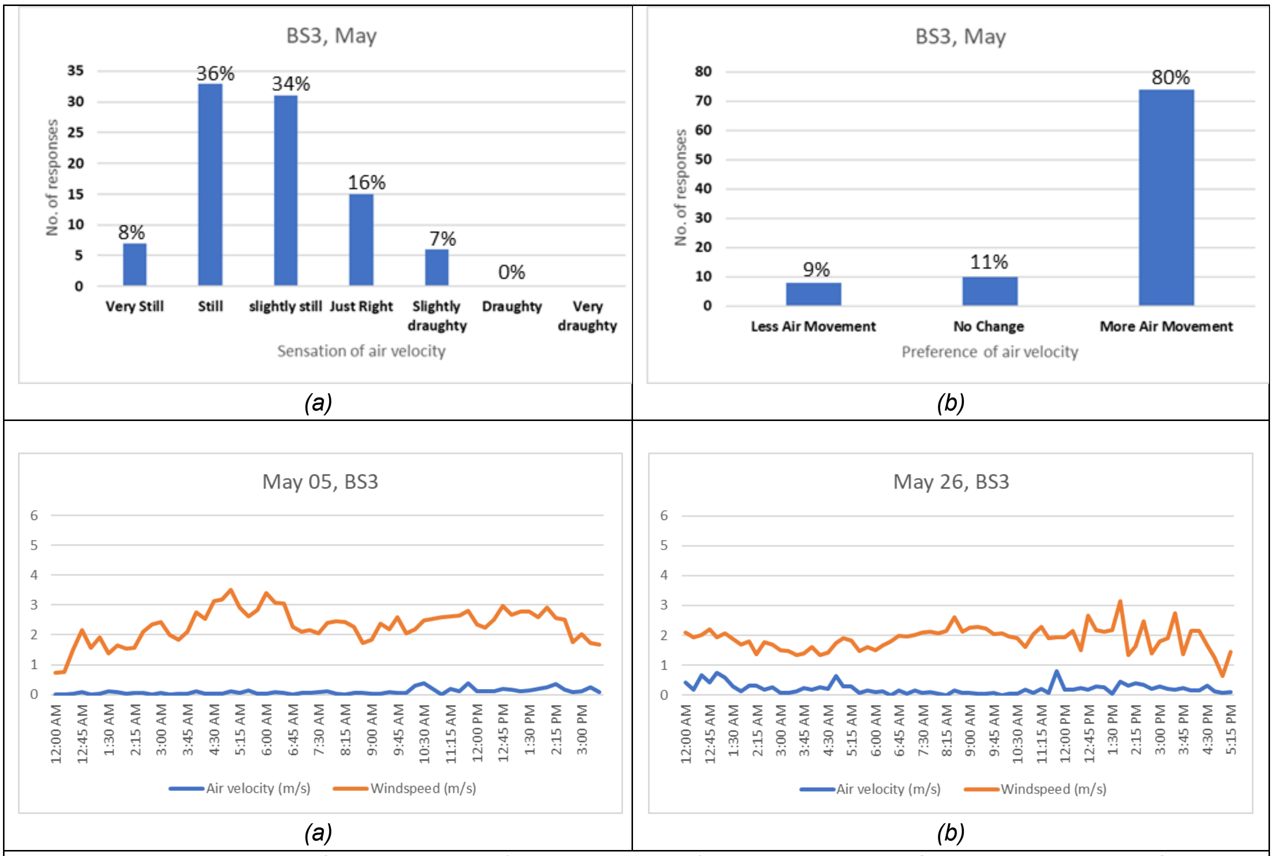


*Figure 22 A comparison (a) Sensation (b) preference in terms of air velocity inside **BS3**, (c) air velocity in **BS**3 based on data obtained from sensor installed in the room compared with wind velocity from TAHMO weather station on the surveyed days of **May**.*

4. Lessons learned and Recommendations

The analysis presented in this chapter (measurement of physical variables and occupants' surveys) has been performed during the months (March to June) which present high maximum daily temperatures and medium humidity, hence challenging conditions. This should be kept in mind while considering the results of the Post Occupancy Survey.

Across the various dates of the survey, a considerable proportion of responses expressed a neutral opinion regarding thermal sensation (about 227), while the widest portion of responses (360), reported feeling slightly warm, 294 felt warm and 146 felt hot.

Hence, in terms of vote on the -3 to + 3 ASHRAE scale, the range -1 to +1 (slightly cool to slightly warm), which is assumed by e.g. Fanger to be a comfortable range, was voted in 59% of responses. If air velocity had been higher this percentage would have substantially increased, as it appears from the responses to the questions about air velocity, where a preference for more air movement was expressed in over 75% of responses.

In terms of thermal comfort judgement, the 254 responses reported to be comfortable, 374 slightly uncomfortable, 374 uncomfortable, 78 very uncomfortable and 37 extremely uncomfortable. Majority of responses (835 out of 1117) expressed a preference for being cooler.

The measured indoor air velocity is modest, predominantly in the range 0,1 to 0,3 m/s, where 0,1 practically corresponds to no air movement. The designers' expectation of achieving comfort ventilation (air velocity on people during occupied hours) thanks to the ample openings in the walls and roof, does not appear to have materialized.

The actual reason for a scarce effect of cross and stack ventilation should be investigated and corrected. A possible problem might come from the dense configuration of the structures that shade the hallways surrounding the classrooms on one side (Figure 23 (a-b-c) made of local eucalyptus wood. On the other side (d) there are movable horizontal louvers which might prove more permeable to air.

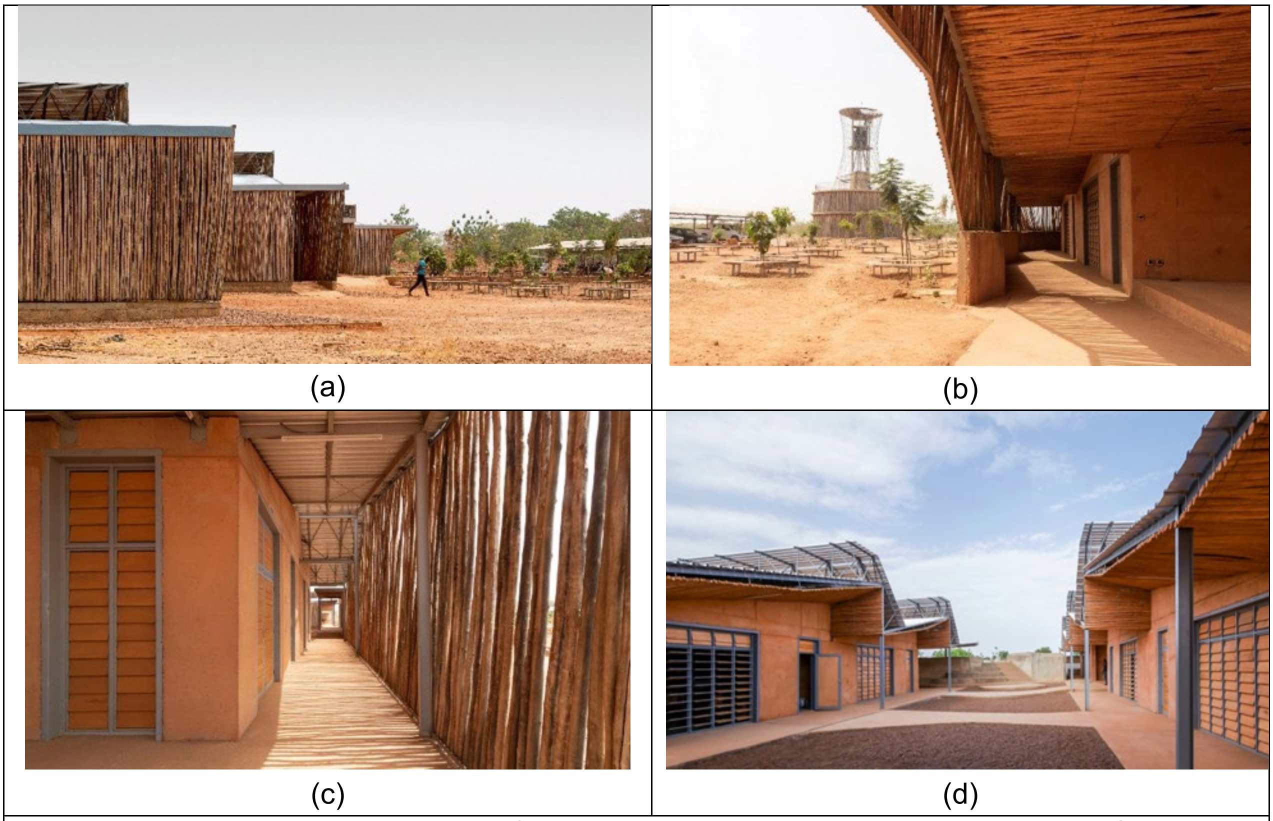


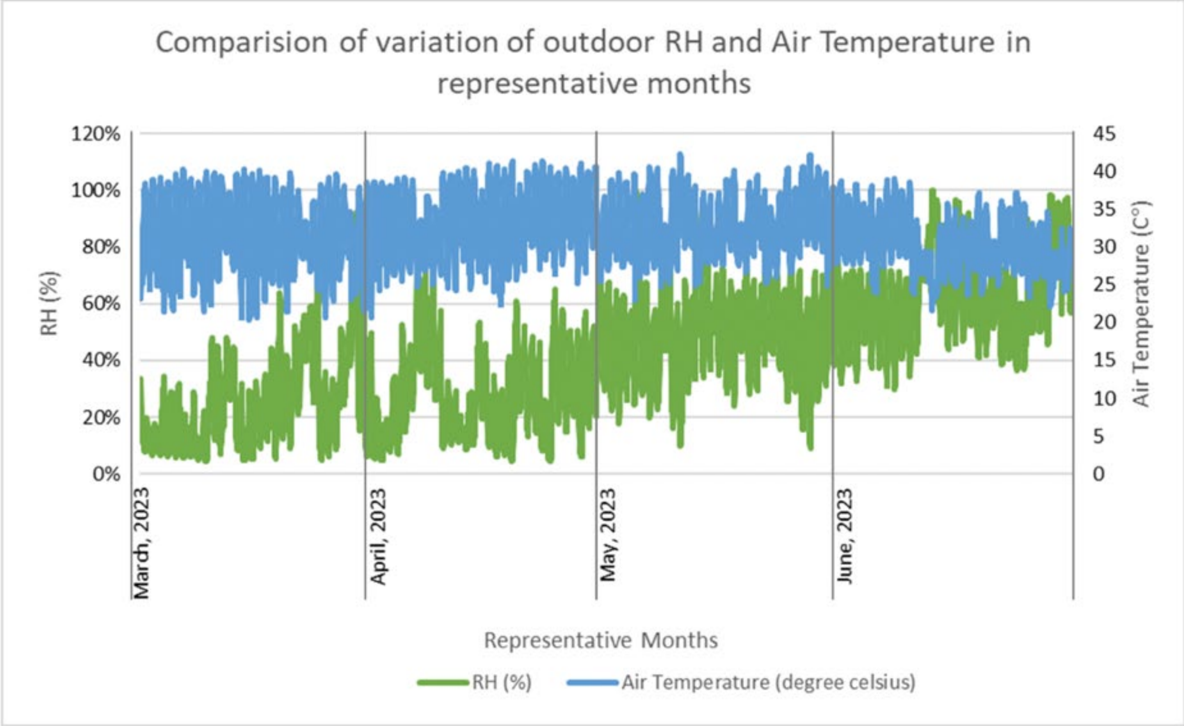
Figure 24 (a-b-c) the hallways shades made of local eucalyptus wood surrounding the classrooms. (d) Shading with horizontal louvers

Possible improvements, subject to further analysis, might be achieved by:

- Creating interruptions in the eucalyptus shading structure in order to reduce the resistance to the air flow
- Adding solar chimneys in order to enhance the stack effect
- Installing ceiling fans appropriately sized and positioned to guarantee the desired air velocity (in the order of 1 m/s) when the wind and stack driving forces are insufficient.

Given the fact that in some months (e.g. March, April and part of May) air humidity is quite low, and correspondingly the day night temperature swing is considerable, indoor air and operative temperatures might be reduced significantly by:

- Performing night ventilative cooling to cool down the masses by fully opening the louvers at night. The louvers seem to already have a robust structure and hence prevent intrusions also when open. During the day, depending on the conditions, louvers might be kept partially closed to reduce the flow of warm air, and air velocity might be obtained by the action of the ceiling fans
- Sustained air flow of external air might be kept also during the day if, taking profit of the low humidity, evaporative cooling systems could be installed at the windows. In the months when humidity is low, simple, direct evaporative cooling (rather than more complex indirect double stage) might be appropriate.



(a)

In fact, according to the weather data, the months of March, April, May and June show a number of hours when the outdoor temperature is high while relative humidity is quite low (20-40%). Some hours are found to have a relative humidity as low as 8%. This information is coherent with the views of occupants, where they found the environment very dry in these months (Figure 16) and expressed a preference to have a more humid air. This reinforces the suitability of direct evaporative cooling, which at the same time reduces air temperature and increases its humidity.

Additionally, with more relevant modifications, the building might be connected to other low temperature sinks (besides cool night air when available):

- Deep sky, by installing cooling systems based on the recently developed surfaces for daytime (and nighttime) radiation to the sky. Details about these type of surfaces can be found in the ABC21 guidelines, in the specific chapter devoted to this.
- Ground exchange, enhanced by soil cooling by shading and evaporation, as proposed originally by Givoni. Details about this passive system can be found in the ABC21 guidelines, in the specific chapter devoted to this.

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

ILET DU CENTRE (LA RÉUNION)

ABC21 is funded by the EU's H2020 programme

Authors

Name	Email	Institution
Virginie Grosdemouge	Virginie.grosdemouge@univ-reunion.fr	UR
François Garde	francois.garde@univ-reunion.fr	UR

Revision

Version	Date	Author	Description of changes
V0	30.05.2023	Virginie Grosdemouge and François GARDE	Draft of the document

CONTENTS

1. Presentation of Ilet du Centre

Name	Ilet du Centre
Architect / Designer	APA / 2APMR
Location	-21.55, 55.28
City	Saint-Pierre
Country	La Reunion, France
Building type	Office + Apartments
Climate zone (Köppen–Geiger)	Aw
Description	This 4 storeys building project of housing and offices has been completed in 2008. It was designed by making the best use of the performances of the passive climatic comfort. Neither the offices, nor the apartments are air-conditioned. The project followed a global approach of environmental quality largely inspired by the traditional creole architecture. All the spaces are naturally cross ventilated and are surrounded but native trees. Walls and windows are shaded with light materials. An innovative passive solution has been designed to sort out the problem of intimacy and the access of the apartments. The concept of "urban veranda" coupled with the vegetation allows to create thermal buffer spaces and barriers that act as filters and cool the hot air coming from the surroundings. Car parks are underneath the buildings to minimize the mineral surfaces around the buildings and to plan native trees instead. In terms of energy efficient systems, ceiling fans are installed in all apartments. Domestic hot water is produced by solar thermal panels. An integrated PV plant produced 25 % of the final energy consumed. This project is the result of preliminary experiments on the devices of the climatic comfort in urban city center and tropical climate. "Ilet du Centre" received "contemporary solar habitats" prize by the French renewable energy observatory Observ'ER.
Main bioclimatic strategies	Vegetation (native species) around the buildings. Cross natural ventilation of all spaces, wooden urban veranda (buffer spaces). Shading of walls and windows. Car parks underneath the buildings. Management of rainwater. Ceiling fans installed in all spaces.

ABC21 is funded by the EU's
H2020 programme

2. Main passives features

2.1 Vegetation

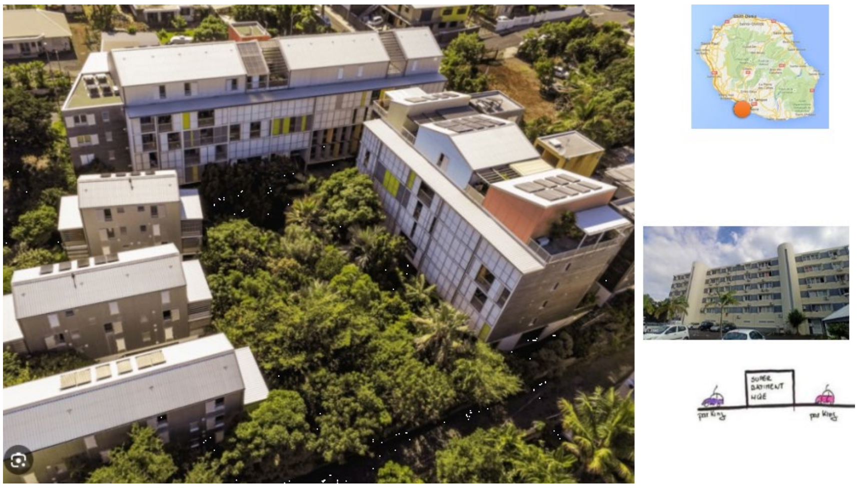


Figure 1 : Native trees has been planted in the heart of the project to cool the outside air. Car parks are located underneath the buildings

2.2 Urban veranda

Figure 2 : The innovative concept of "urban veranda" creates a thermal buffer space that allow the tenants to have access to their apartment thanks to outdoor walkways at each level. Native trees have been planted between the urban veranda and the street (on the right handside) to create a first barrier against the heat island effect of the street. The second barrier is ensured by the veranda before the air get into the apartments.

2.3 Solar shadings

Figure 3 : Light materials (wood or aluminium) are used for solar shadings. Large vertical aluminium louvers have been designed on the veranda side of each apartment to preserve the intimacy of the tenants, to protect the veranda from solar radiation and in the same time to keep the cross natural ventilation by allowing the air to get through the louvers

2.4 3D view of a 1 bedroom unit

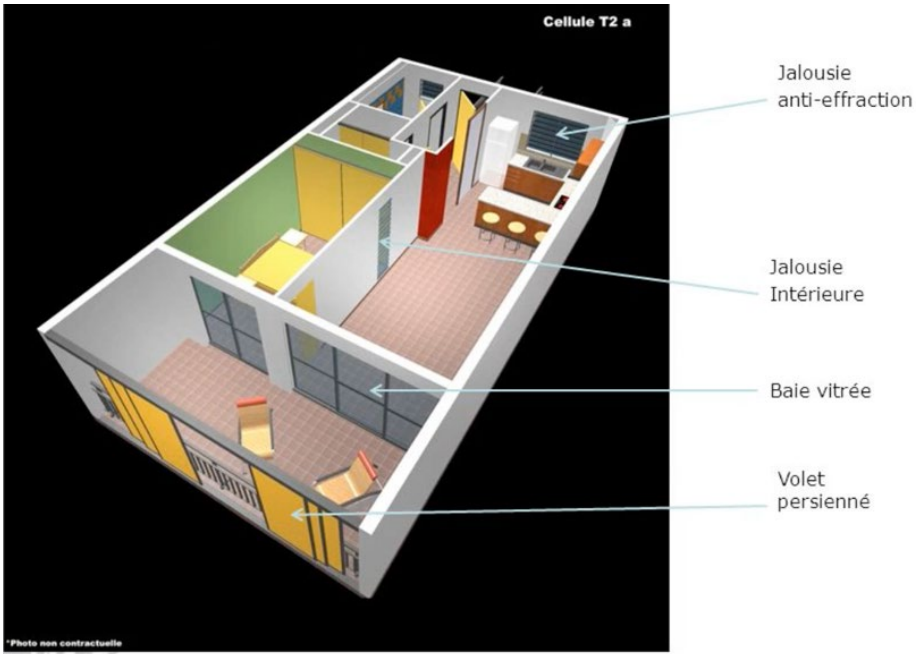


Figure 4 : Each units are naturally cross ventilated thanks to sliding glazed doors (living room) and glass louvers (kitchen and front door).

3. Results of measurements.

As mentioned before, one of the main innovative passive strategies of this project was to create different barrier/thermal buffer spaces between the street and the apartments.
The hot air from the mineral street is filtered :

- Firstly by the garden and the trees (2);
- Secondly by the urban veranda (3).

Measurements have been carried out in March (one of the hottest month in La Reunion) to assess the performance of those passive strategies.
Figure 5 below shows the evolution of the temperature profiles for a specific day in March and for different sensors installed near the street (1), in the garden (2), in the urban veranda (3) and finally in one apartment at the ground level (4 and 5).
All sensors installed outside are protected against solar radiation.

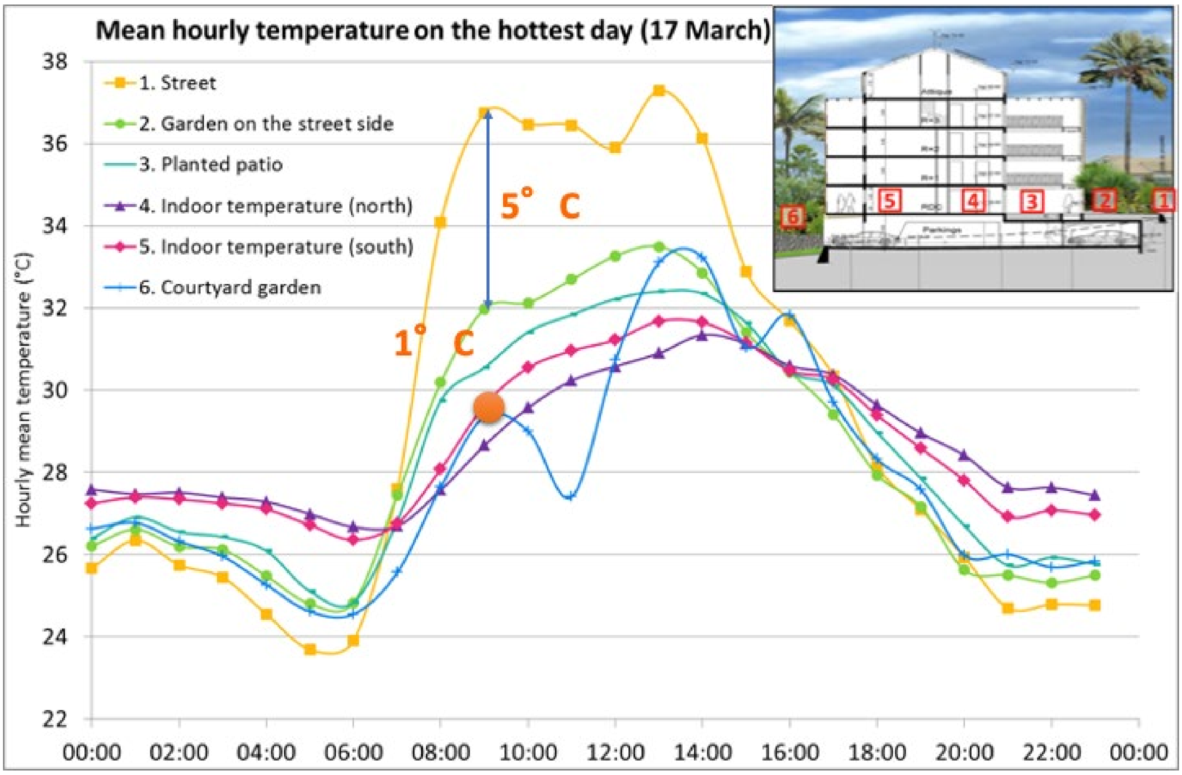


Figure 5 : Air temperature profiles for different locations (street, garden, planted patio/urban veranda, indoor apartment)

The analysis of the different temperature shows that :

- The air temperature in the street can reach 37°,5C;
- The garden on the street side reduces the air temperature by 5°C
- The planted patio / urban veranda reduce the air temperature by an additional 1°C
- The indoor temperature in the apartment never exceeds 32°C;
- At 10am, the temperature in the apartment is 30°C, which is 7°C below the air temperature of the street.

4. Lessons learnt and recommendations

Lessons learnt :

Planting trees around the building reduce the air temperature by 5°C.

The concept of urban veranda is strongly appreciated by the tenants because it preserves their intimacy and at the same time it acts as a thermal buffer space and shades the main façades. It reduces also the air temperature by an additional 1°C.

The apartments are really comfortable with an indoor temperature 6°C below the outdoor air temperature.

POE :

A post occupant evaluation has been made and generally occupants are very satisfied by the design (comfort, garden, view). The negative point is the exterior acoustic due to the traffic.

Solutions sets to replicate for other building projects :

The solutions sets are suggested for future building projects are the following ones :

- Vegetation and native trees around the building (Car parks underneath the buildings);
- Narrow buildings, 5-6 storeys max ;
- Detached corridors / urban veranda with low inertia materials;
- Solar shading devices that allows natural ventilation (vertical opaque louvers) ;
- Natural cross ventilation mandatory with large openings/glass louvers (25% of porosity);
- Ceiling fans must be installed systematically in all the apartments;
- Density is possible with 5-6 storeys building.

ABC21 is funded by the EU's
H2020 programme

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MONITORING CAMPAIGN RESULTS

TEMPLATE FOR MONITORING DATA ANALYSIS

WP3 – PERFORMANCE INDICATORS AND GUIDELINES FOR XXI CENTURY BIOCLIMATIC BUILDINGS AND DISTRICTS

D.3.9B

Report

Public

ABC 21 project

This document has been developed as part of the project titled "**ABC 21 – Africa-Europe BioClimatic buildings for XXI century**".
The sole responsibility for the content of this presentation lies with the authors. This report reflects only the author's view. The Executive Agency for Small and Medium sized Enterprises is not responsible for any use that may be made of the information it contains.
The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 894712.

Document information

Name:	Report on thermal comfort measurement campaign
Date:	XX.0X.2023
Work Package:	WP3: Performance indicators and guidelines for xxi century bioclimatic buildings and districts
Task:	T3.4: Case studies of European and African Bioclimatic Buildings

Authors

Name	Email	Institution
Virginie Grosdemouge	Virginie.grosdemouge@univ-reunion.fr	UR
François Garde	francois.garde@univ-reunion.fr	UR
Silvia Erba	silvia.erba@polimi.it	PoliMi

Revision

Version	Date	Author	Description of changes
V0	08.03.2023	Silvia Erba	Draft of the document
V1	13.03.2023	Virginie Grosdemouge	Revision and new propositions
V2	23.03.2023	Virginie Grosdemouge	Revision of the document after partners meeting

Executive summary

This technical report provides guidelines for processing the data and presenting the outputs from the thermal comfort measurement campaigns.

Abbreviations

Term	Name
AMEE	Agence marocaine pour l'efficacité énergétique (Moroccan agency for Energy Efficicency
AUI	Al Akhawayn University in Ifrane
DEEC	Direction de l'Environnement et des Etalblissements Classés/Ministère de l'Environnement et du Développement Durable
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EE	Energy Efficiency
EED	Energy Efficiency Directive (EU)
EEB	Energy Efficiency in Buildings (ECOWAS)
EEEP	ECOWAS Energy Efficiency Policy
NW	North West
EPBD	Energy Performance of Buildings Directive (EU)
FC.ID	Faculdade de Ciências da Universidade de Lisboa
Net ZEB	Net Zero-Energy Building
nZEB	Nearly Zero-Energy Building
PoliMi	Politecnico di Milano
UN-Habitat	United Nation Human Settlement Programme
UR	University of La Reunion

CONTENTS

ABC21 is funded by the EU's H2020 programme

1. Presentation of the case study

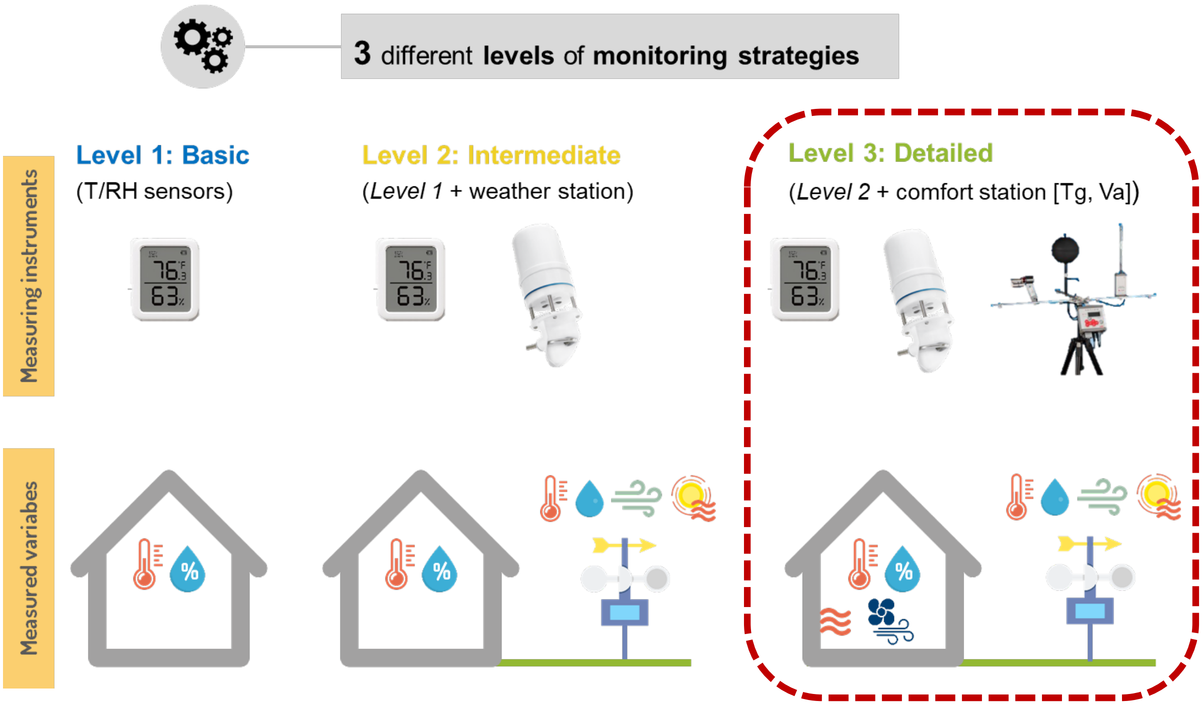
This section should include a short description of the project (see example below – information was extracted from the templates)

Name	xxx
Architect / Designer	xxxx
Location	xxx
City	xxxx
Country	xxx
Building type	xxx
Climate zone (Köppen–Geiger)	xxx
Description	………
Main bioclimatic strategies	……..

2. Material and method

2.1 Monitoring campaign level

Please specify here the level of monitoring according to the figure **by moving the red dotted rectangle below**



2.2 Data acquisition and equipment

This section gives information about the **monitoring devices installed** and the **duration of the monitoring campaign.**

Monitoring campaign: start date: dd/mm/yyyy End date: dd/mm/yyyy

Collection of weather data: (please tick the right option)

- ☐ National weather station close to the site : precise the distance from the site: …km
- ☐ TAHMO weather station on site
- ☐ Outdoor temperature and relative humidity in a solar radiation shield

Please provide a plan with the location of the weather data collection system (see Fig1 below)

Issues encountered: (please tick the right option and complete if needed)

- ☐ Missing data: Please specify period of missing data or percentage of missing data.
- ☐ Shortage
- ☐ Wifi connection
- ☐ Others: ……………………

2.2.1 Sensors and weather station location

This section gives information about the location of the sensors inside the building (and outside in case of a weather station) based on:

- a floor plan : or ground plan of the building with indication of the **orientation** and **location** of the sensors for thermal comfort assessments,
- picture of the sensors installed
- Sensors name should be given and used for the graphs of the next section

See examples below

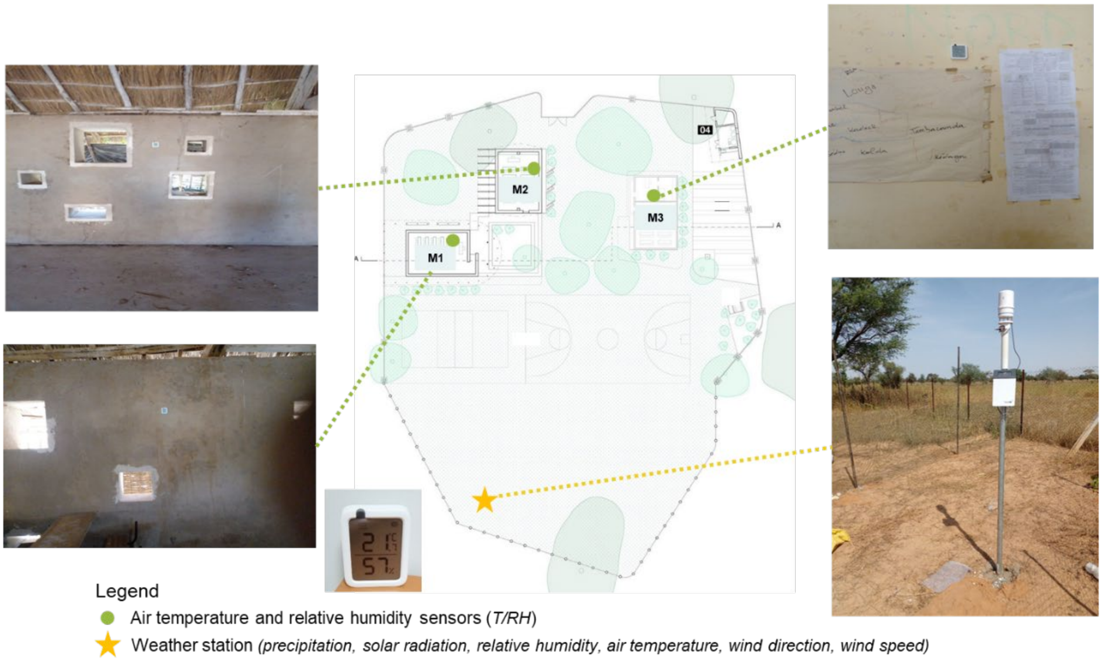


Figure 1: Sensors location for the Mbakadou school

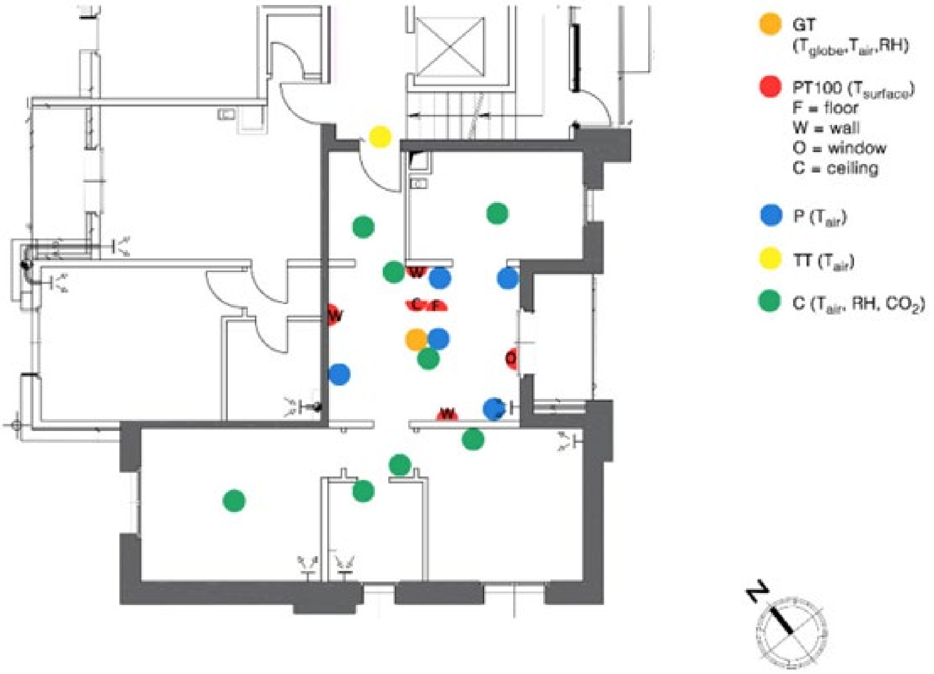


Figure 2: Sensor location for the Botticelli project

2.2.2 Sensors specification (All sensors)

Details about the sensors are given in the table below (see example)

Table 5. Sensors' specifications.

Sensors	Code in Figure 3	Measured Quantities	Accuracy	Resolution
Capetti (mod. WSD20TH2CO)	C	Air temperature, Relative humidity, CO_2 concentration	T: ± 0.2 °C HR: ± 2.0% CO2: 0 ÷ 2000 ppm: < ± 50 ppm 0 ÷ 5000 ppm: < ± 50 ppm 0 ÷ 10,000 ppm: < ± 100 ppm	T: 0.01 °C HR: 0.05%RH CO_2: 1 ppm
Capetti (mod. WSS00T)	P	Air temperature	±0.2 °C	0.01 °C
Pt100 (mod. ESU403.1)	W(wall); F(floor); C(ceiling); O(window)	Surface temperature	±0.1 °C	0.01 °C
Globe-thermometer output Pt100–LSI (mod. EST131) [emissivity: 0.95; diameter: 15 cm]	GT	Globe-thermometric temperature	±0.15 °C	0.01 °C
Tinytag (mod. TGU-4500)	TT	Air temperature	T: ±0.2 °C (for T: −10 ÷ 30 °C)	0.01 °C

2.3 Post Occupancy Evaluation Surveys (Level 3 - comfort station)

This section includes general information concerning the surveys (for the concerned buildings). These questions should be answered:

- when did they start? Which days /time?
- How many surveys have been collected in total?
- Category of the respondents: please choose between students, teachers, owner of the residential building, employees/ office workers.
- Short description about the recipients, age (if available) and other info

Examples are given below:

This study is based on a total of 370 questionnaires surveys conducted at different period of the year. 55% of the respondents were women.

Date	Time	Number of responses	Respondents information					
			category	Number of men	Mean clo value of men	Number of women	Mean clo value of women	Mean age
November 2017	10:00 – 12:00 am	19	students	5	0.34	7	0.38	25
January 2018	1:00-2:00 pm	102						
February 2018	10:00 – 12:00 am	66						
March 2018	1:00-2:00 pm	23						
June 2018	10:00 – 12:00 am	79						
October 2018	1:00-2:00 pm	50						
January 2018	10:00 – 12:00 am	31						
Total		**370**						

	Height (cm)	Weight (kg)	BMI (kg/m2)	Icl (clo)	Metabolism (met)
Mean	169,2	69,3	24,1	0,37	1,79
Standard deviation	10,1	14,3	4,2	0,09	0,94
Minimum	123,0	24,0	13,8	0,19	0,80
Maximum	196,0	135,0	44,6	0,81	8,00

3. Results and discussion

3.1 Boxplot (Level 1, 2 & 3)

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

Please insert boxplot of **air temperature** for ALL the studied rooms over the **total period** of measurements as well as the one for the outdoor conditions.

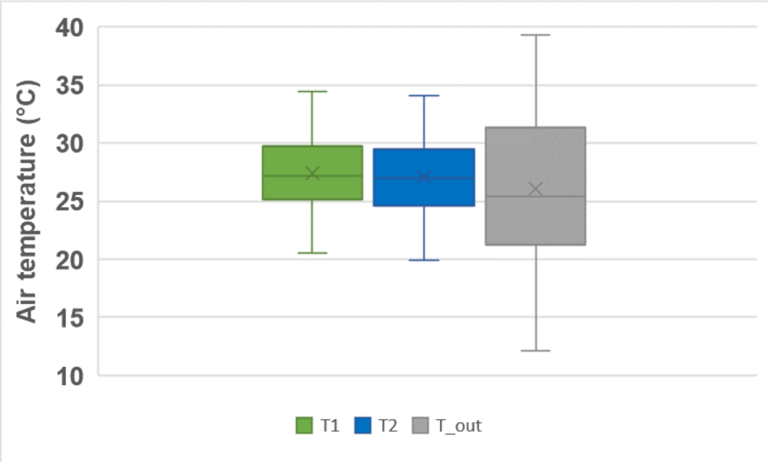
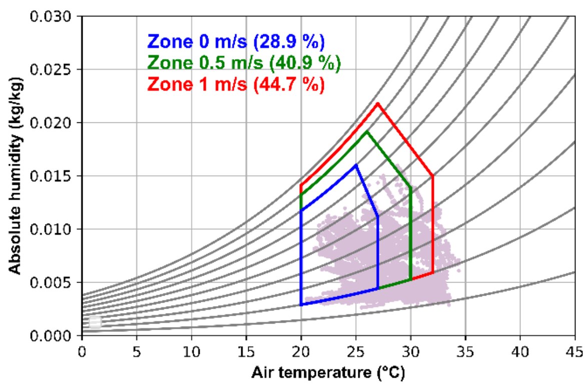


Figure 3: Boxplot of the air temperature for the indoor and outdoor conditions from the 11th of November to the 10th January for the Mbakadou school

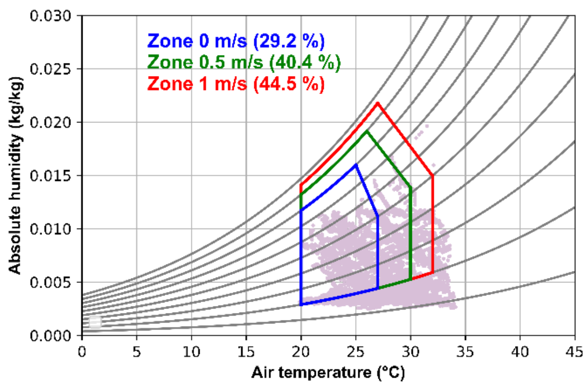
3.2 Givoni comfort zone (Level 1, 2 & 3)

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

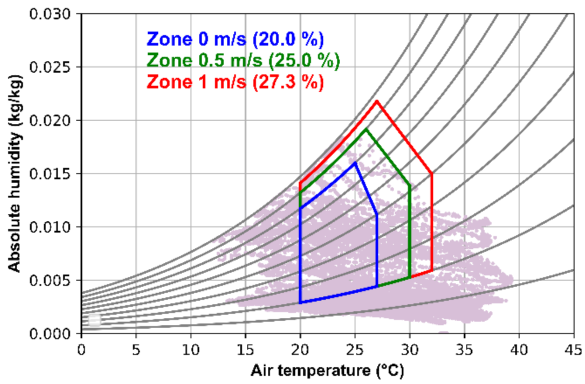
Please insert the **givoni comfort zone** for **each room** over the **total period** of measurements as well as the one for the outdoor conditions over the same period **DURING THE OCCUPIED HOURS** and **comment the results**



(a)



(b)



(c)

Figure 4: Givoni comfort zones for the conditions in (a) building 1 , (b) building 2 and (c) for the outdoor conditions from the 11th of November to the 10th January for the Mbakadou school

3.3 Number of hours / frequency within a certain temperature range (Level 1, 2 & 3)

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

please keep these temperature intervals bins of 2°C – from 22 to 36 °C

Frequency should be calculated by **monitored rooms during THE OCCUPIED HOURS only** and for **the outdoor conditions.**

Hot period (8th Feb. to 30th Apr. 2016) Occupation time: 8:00am to 6:00pm	ROOM 1		OUTDOOR CONDITIONS	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
Ta<22°C	**0**	0%	**0**	0%
22°C≤Ta<24°C	**0**	0%	**0**	0%
24°C≤Ta<26°C	**75**	8%	**75**	8%
26°C≤Ta<28°C	**487**	54%	**487**	54%
28°C≤Ta<30°C	**334**	37%	**334**	37%
30°C≤Ta<32°C	**12**	1%	**12**	1%
32°C≤Ta<34°C	**0**	0%	**0**	0%
34°C≤Ta<36°C	**0**	0%	**0**	0%
Ta≥36°C	**0**	0%	**0**	0%

3.4 Number of hours / frequency by relative humidity range (all level of monitoring)

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

Frequency should be calculated by **monitored rooms during THE OCCUPIED HOURS only** and for **the outdoor conditions.** Please keep these Bins of 10% from 0 to 100 %

Hot period (8th Feb. to 30th Apr. 2016) Occupation time: 8:00am to 6:00pm	ROOM 1		OUTDOOR CONDITIONS	
Range	Nb of Hours	Frequency	Nb of Hours	Frequency
[0,10%[	**0**	0%	**0**	0%
[10,20%[	**0**	0%	**0**	0%
[20,30%[	**75**	8%	**75**	8%
[30,40%[	**487**	54%	**487**	54%
[40,50%[	**334**	37%	**334**	37%
[50,60%[	**12**	1%	**12**	1%
[60,70%[	**0**	0%	**0**	0%
[70,80%[	**0**	0%	**0**	0%
[80,90%[	**0**	0%	**0**	0%
[90,100%[	**0**	0%	**0**	0%

3.5 Analysis of a representative week

Short definition: a week with the **same successive days** in terms of **solar radiation (sunny days)** and **same diurnal variation of air temperature**; If possible no rain.

3.5.1 Air temperature profile (all level of monitoring)

Data for the interior are extracted from the T/RH sensors and from the weather station for the outside.

Air temperature inside the rooms should be plotted for **a typical hot week** (from Monday to Sunday) along with the **outdoor air temperature** (from TAHMO weather station or closest official meteorological weather station). (see example below)
Please pay attention to the name of the sensors
For the indoor air temperature → line in colour
For the outdoor air temperature → dashed line in grey

A short analysis should be included.

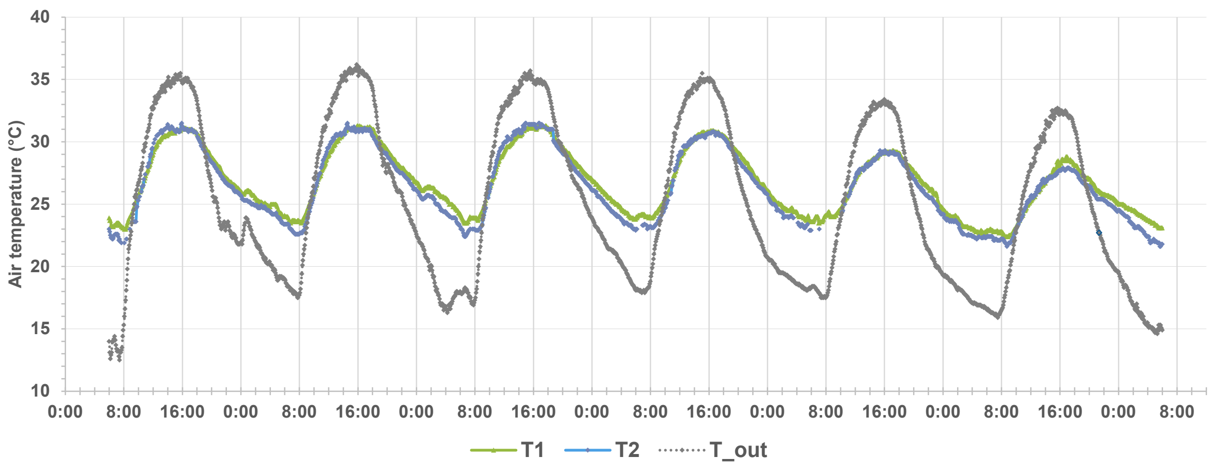


Figure 5: Air temperature profiles for the Mbakadou school from the 28th Nov. to 3rd Dec

3.5.2 Wind profile (Level 2 and 3)

Data are extracted from the weather station.

Wind speed measured by the weather station on site should be **plotted for the same typical hot week than section before.** (see example below)
A short analysis should be included.

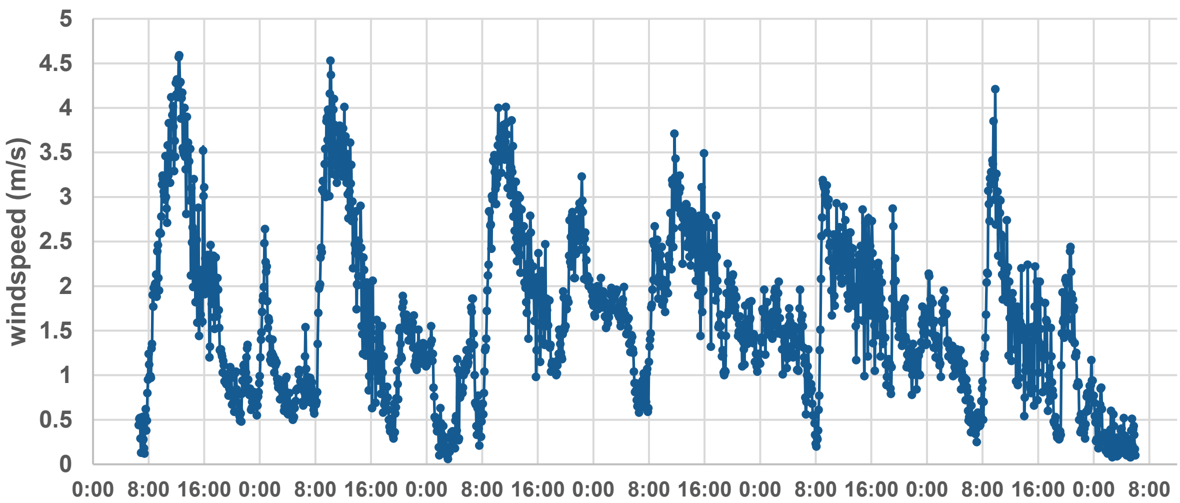


Figure 6 : Wind speed profiles from the 28th Nov. to 3rd Dec at Mbakadou school

3.5.3 Solar radiation profile (Level 2 and 3)

Data are extracted from the weather station.

Global solar radiation measured by the weather station on site should be plotted **for the same typical hot week than section before**. (see example below)
Please pay attention to the name of the sensors

A short analysis should be included.

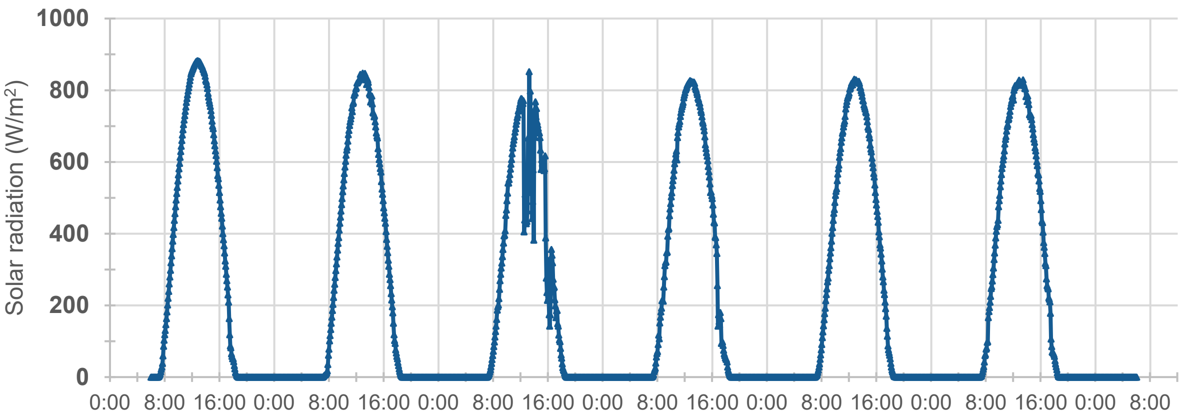


Figure 7 : Solar radiation profiles from the 28th Nov. to 3rd Dec at Mbakadou school

3.6 Operative temperature and comfort boundaries (Level 3 only – with continuous measurements)

Data are extracted from the comfort station.

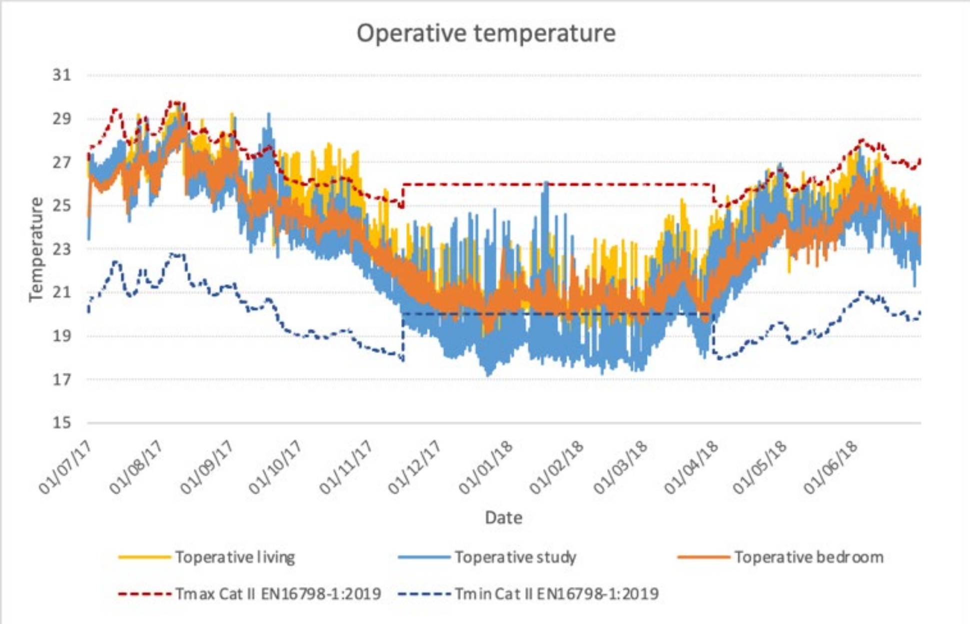


Figure 2 Operative temperature and comfort boundaries (EN16798-1:2019) (Fanger comfort model for heating season from 15/11 to 31/03 and adaptive comfort model the cooling season from 01/04 to 14/11, II comfort category)

Provide a short description of the data collected. Here, Fanger and adaptive comfort model have been used for assessing the data (thresholds in the figure). For each case study, we need to choose the most appropriate thermal comfort models and limits.

3.7 POE results (Level 3)

For this section, data are extracted from the comfort station and the responses to the questionnaire.

3.7.1 Air temperature and black globe temperature profile for the surveyed dates

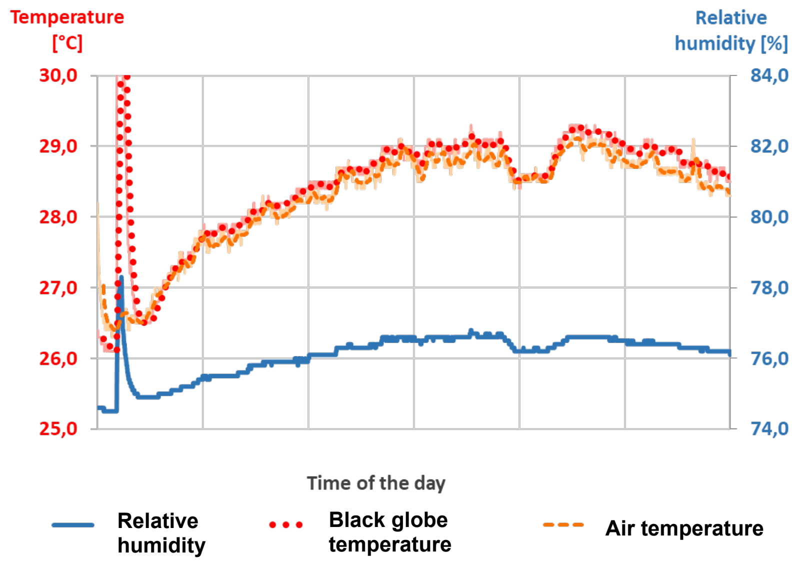


Figure 8: Air temperature and black globe temperature profile for the 21st Nov 2015 in the Moufia lecture theater, La Reunion.

3.7.2 Air velocity variations for the surveyed dates (Level 3)

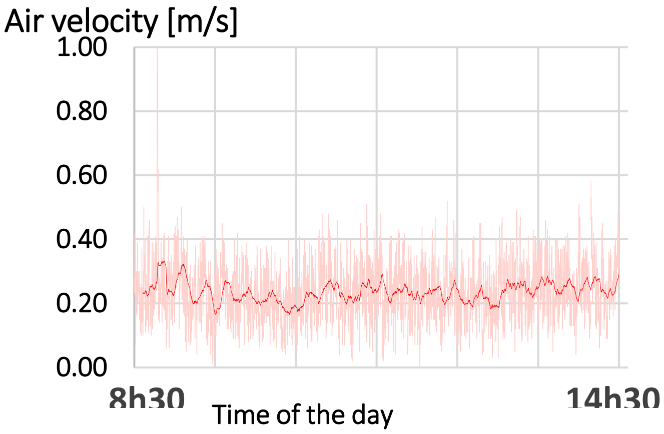
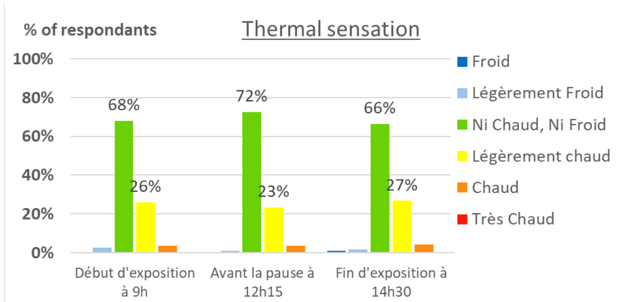


Figure 9: Air velocity variations for the 21st Nov 2015 in the Moufia lecture theater, La Reunion.

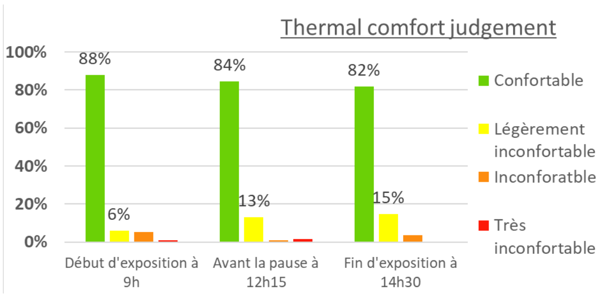
3.7.3 Thermal sensation, thermal comfort judgement and thermal preference

Table 1 : statistics over the surveyed period (mean air temperature, mean black globe temperature, mean relative humidity and mean air velocity)

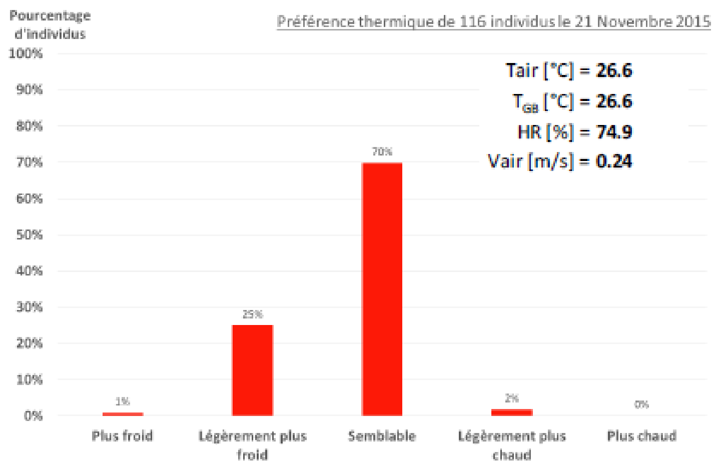
	DE	AP	FE
T_{air} [°C]	26.6	28.8	28.4
T_{GB} [°C]	26.6	29.0	28.6
HR [%]	74.9	76.6	76.2
V_{air} [m/s]	0.24	0.24	0.26



(a)



(b)

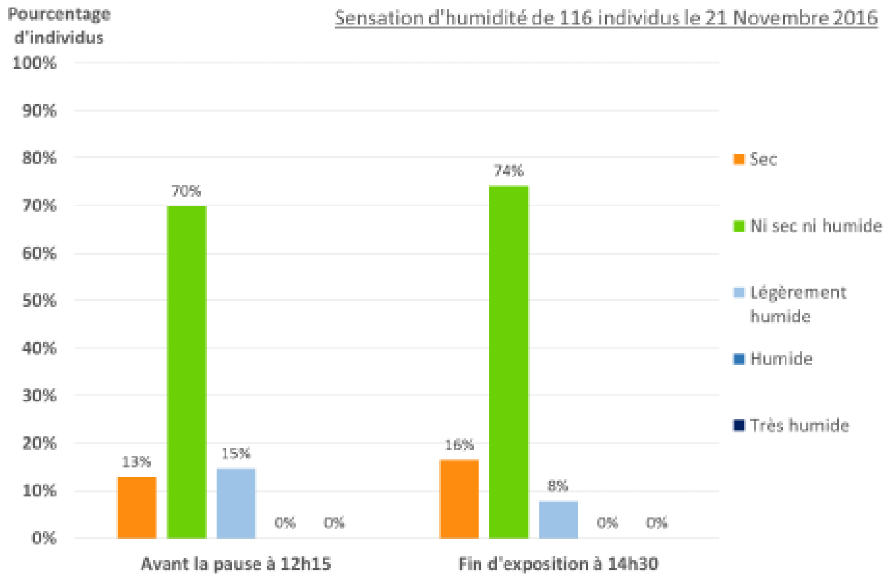


(c)

Figure 10 : (a) Thermal sensation and, (b) thermal comfort judgement and (c) thermal preference for the 21st Nov 2015 in the Moufia lecture theater, La Reunion.

ABC21 is funded by the EU's H2020 programme

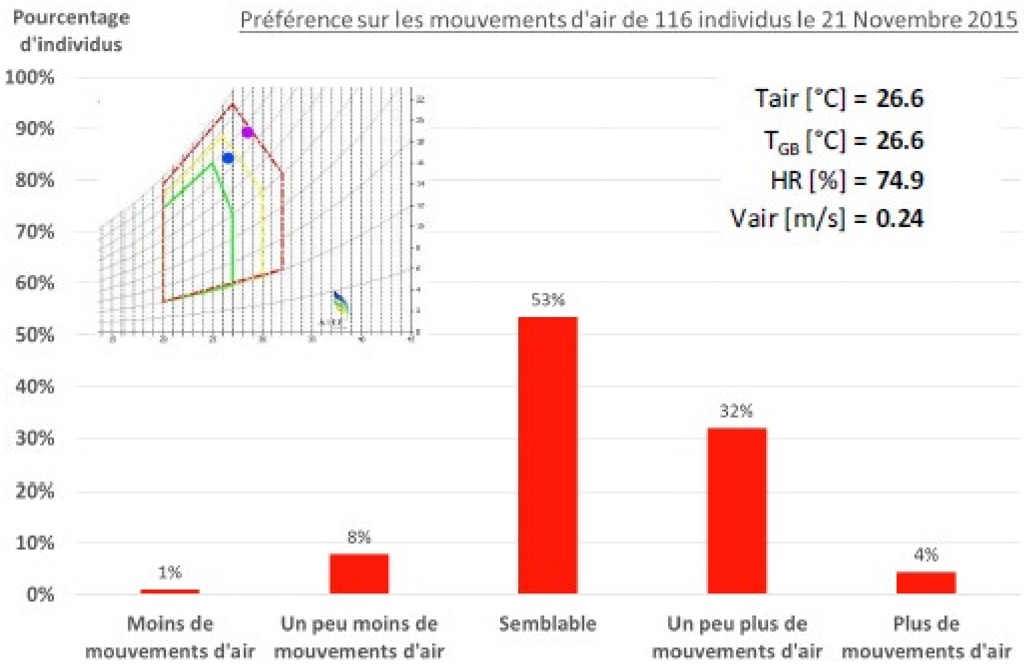
3.7.4 Sensation and preference for the air humidity



III.A.iii.4 – Diagramme représentant la sensation d'humidité des 116 individus ayant répondu au questionnaire ; plus de 70% ressentent l'air « Ni sec, ni humide » alors que l'humidité relative est élevée à plus de 76%

Tair [°C] = **29.0**	Tair [°C] = **28.6**
T_{GB} [°C] = **28.8**	T_{GB} [°C] = **28.4**
HR [%] = **76.6**	HR [%] = **76.2**
Vair [m/s] = **0.24**	Vair [m/s] = **0.26**

3.7.5 Sensation and preference for the air velocity



4. Key performance indicators

BUILDING ANALYSIS AND KEY PERFORMANCE INDICATORS	
Thermal comfort indicators	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
	6. Percentage of time inside the Givoni comfort zone of 0m/s
	7. Number of hours within a certain temperature range
Energy performance indicators	1. Energy needs for heating: - [kWh/m²/year]
	2. Energy needs for cooling: - [kWh/m²/year]
	3. Energy use for lighting: - [kWh/m²/year]
	4. Energy needs for sanitary hot water: - [kWh/m²/year]
	5. Total Primary energy use: - [kWh/m²/year]
	6. Renewable Primary energy generated on-site: - [kWh/m²/year]
	7. Renewable Primary energy generated on-site and self-consumed: - [kWh/m²/year]
	8. Renewable Primary energy exported to the grid: - [kWh/m²/year]
	9. Ratio of renewable primary energy over the total primary energy use (with and without compensation): - %
	10. Delivered energy (from electricity bills) : - [kWh/m²/year]

11. Lessons learnt and recommendations

Based over the monitored data analysis and feedbacks from users

Africa-Europe BioClimatic buildings for XXI century

THERMAL COMFORT MEASUREMENTS GUIDELINES

WP3 – PERFORMANCE INDICATORS AND GUIDELINES FOR XXI CENTURY BIOCLIMATIC BUILDINGS AND DISTRICTS

ABC 21 PROJECT

This document has been developed as part of the project titled "**ABC 21 – Africa-Europe BioClimatic buildings for XXI century**".

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 894712.

DATE

June 16th 2022

AUTHORS

Name	Email	Institution
Virginie Grosdemouge	Virginie.grosdemouge@univ-reunion.fr	UR

REVIEW

Name	Email	Institution
Silvia Erba	silvia.erba@polimi.it	POLIMI

CONTENTS

1 Introduction

This report proposes guidelines for the instrumentation and evaluation of the thermal comfort inside buildings.

The measurement instrumentation used for the evaluation of the thermal environment shall meet the requirements given in the standard "NF EN ISO 7726: Ergonomics of the thermal environment- Instruments for measuring physical quantities".

2 Methodology

2.1 Long term measurement – Temperature and Relative Humidity Sensors

2.1.1 To Do

Room(s)

In educational buildings, a selection of classrooms, special work-rooms, meeting rooms and offices should be done.

In residential (or hostels) buildings, sensors should be placed in the bedrooms and living rooms of the selected apartments/houses.

Height & location

The different temperature and humidity sensors shall be placed at the heights where the person normally carries out his activity, that are indicated in the table below.

Location of sensors	Recommended Heights	
	Sitting activity	Standing activity
Head level	1,1m	1,7m
Abdomen level	**0,6m**	**1,1m**
Ankle level	0,1m	0,1m

The abdomen level is the one to be preferred.

If it is not possible, the sensors should be placed in a position such as that the thermal exchanges are more or less identical to those to which the person is exposed. (generally, between **1,5 to 2 m above the floor**).

Generally, sensors for temperature and humidity are placed in the **occupied zone** or in the **middle of the room.** The sensors could be fixed on a **non-exposed wall** of the room at a height of **1,5m**, as a last resort.

When the environment is too heterogeneous or too large, the physical quantities shall be measured at several locations or around the user(s).

ABC21 is funded by the EU's H2020 programme

Time step

A **time-step** of **15min average** should be used for the time resolution.

Time span

The **time span** should be at least **1 month by season** or if possible **1 year**, **after the 1st year of use.**

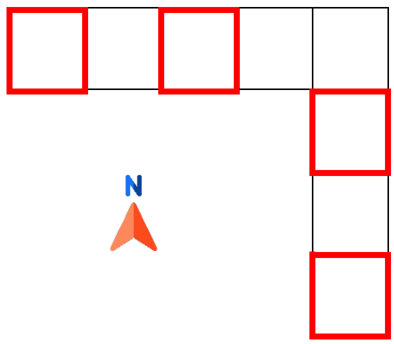
2.1.2 To avoid

- ☒ **Wet rooms**: bathrooms and kitchens, where the relative humidity could be too high
- ☒ **Exposure to the sun**: Sensors must not be exposed to direct sunlight
- ☒ **Sun exposed walls and rooms' corners**: the sensors should not be fixed on exposed walls or in corners as they can influence the measure of temperature.
- ☒ All **sources of thermal disturbance** such as electrical devices (lamps, laptops, tv, screens, air conditioning systems,).

2.1.3 Sampling

It is not mandatory to instrument all the apartments of a multi-apartments building or all the rooms of an office building or a school. A **representative sample of rooms** could be done in terms of:

1. Orientation of the main facades (North/South/East/West);
2. Number of exterior walls exposed to the sun: units at the extremity of the building VS centred units



3. Number of storeys so as to consider the possible disparities in terms of wind of shadow masks. If the number of storeys is superior to 3, the repartition of sensors should be: 1 in a unit at the first floor, 1 at a middle floor and 1 at the last floor under the roof.

The sample should consider rooms with supposed good interior conditions and rooms with thermal comfort issues.

2.1.4 Installation tips

We recommend to number all the temperature and relative humidity sensors and to list the location of each one on a piece of paper and a excel document, with the location on the floor plan of the building and photos of the installation. See example below:

Sensor	Location	Floor	Orientation	Height	Comments	Photo
1	Meeting room	1	N/S	2.0m	At the middle of the room. Suspended	
2	Project room	1	N/S	1.5m	Fixed on a non-exposed wall	
3	Room A300	1	E/W	2.0m	At the middle of the room. Suspended	
4	Secretary Office	1	E/W	1.1m	Fixed on the office closet	

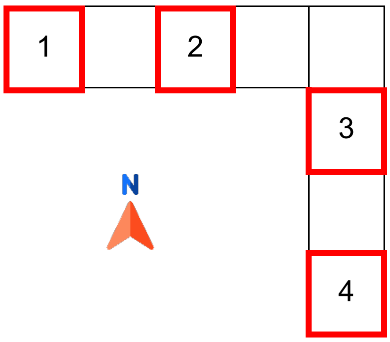


Fig.1: Location of the sensors on the floor plan of the first floor of the X building.

2.2 Spot Measurement – Thermal comfort station

The indoor thermal environment parameters that will be collected are the air temperature, the relative humidity, the black globe temperature and the air velocity.

The data loggers and sensors must be **placed away from direct sunlight** to avoid any impact from solar radiation and rainfall.

If possible, the sensors should be placed in the **middle of the room**.

If all subjects maintained a **sitting position** while **filling the spot questionnaires**, the height of measuring points has to be set were set at **0.6m**. If they are **standing,** the sensors should be placed at a height of **1.1 m above the floor.**

In addition, the globe temperature sensor placed in a given environment does not indicate the temperature instantaneously. It requires a certain period to **reach equilibrium**. The standard black copper globe requires around **20 min** to reach equilibrium. **Data obtained from the first 20min should not be used.** The sensors should be placed in the studied room at least **20 min before doing the spot questionnaire surveys.**

Measurements should be done at different moment of the day.

The air velocity measurements should be done at 10-second intervals and averaged over 1 minute.

2.3 Questionnaires surveys

There are various types of questionnaire possible. It is suggested to always use questionnaires which are in line with the established and most updated Comfort Standards, as e.g ASHRAE 55:2020 (ANSI/ASHRAE 2020). This would allow the much needed comparability of results and the exchange of lessons learned. In particula this choice is needed in order to obtain comparability with the ASHRAE Global Comfort Database II. (Földváry Ličina et al. 2018).

From ASHRAE 55:2020 :

*"**Point-in-time ("right-now")** surveys are used to evaluate thermal sensations of occupants **at a single point in time**. Thermal comfort researchers have used these surveys to correlate thermal comfort with environmental factors such as those included in the PMV model: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. A sample point-in-time survey is included in Figure L-1. This is a thermal sensation survey that asks occupants to rate their sensation (from "hot" to "cold") on the ASHRAE seven-point thermal sensation scale. The scale units are sometimes designated "TSENS." One may, however, ask the direct question "Is the environment thermally acceptable?" with a scale of "very unacceptable" to "very acceptable." The scale is best divided into seven scale units or more. Sometimes preference scales for temperature and air movement are also used (e.g., these scales are common in the comfort field study database found in ASHRAE RP-884, Towards an Adaptive Model of Thermal Comfort and Preference): "Prefer to be:" "cooler/no change/warmer" "Prefer": "less air movement/no change/more air movement"*

*"A second form of thermal environment survey, a **satisfaction survey**, is used to evaluate thermal comfort response of the building occupants **in a certain span of time**. Instead of evaluating thermal sensations and environmental variables indirectly to assess percentage dissatisfied, this type of survey directly asks occupants to provide satisfaction responses. An example thermal satisfaction survey is included in Figure L-2. It asks occupants to rate their satisfaction with their thermal environment (from "very satisfied" to "very dissatisfied") on a seven-point satisfaction scale. Acceptability is determined in two ways: by the percentage of occupants who have responded "neutral" through "very satisfied" (0, +1, +2, or +3) with their environment or by taking a slightly broader view of acceptability, including the percentage who have responded (–1, 0, +1, +2, +3). The basic premise of the satisfaction survey is that occupants by nature can recall instances or periods of thermal discomfort, identify patterns in building operation, and provide "overall" or "average" comfort votes on their environment. The surveyor may identify a span of time for the respondents to consider. The occupants provide the time integration. Questions to identify the nature (causes) of dissatisfaction may be included in satisfaction surveys (e.g., questions 7a through 7e in Figure L-2).*

2.3.1 General satisfaction surveys

As defined above, general satisfaction surveys have the objective of tracking the **general evaluation of the indoor environment** by the occupant. (Noris, Napolitano, et Lollini 2013). Simultaneous measurements of physical parameters are not required.

They should be conducted in the same year as measurement, and done by a significant number of occupants. The survey must be conducted **at least one year after the building is fully occupied** and if possible to conduct it **two times a year in different seasons** (summer/winter).

An example of questionnaire made by Georges Baird is given below in a French version (Baird 2009) (Lenoir, Baird, et Garde 2012). The English version can also be provided.

Though comprehensive, the part on thermal comfort of this example questionnaire is not strictly coherent with the most updated Standards. We recommend, even in case of general satisfaction surveys to follow more strictly the most updated standards, e.g. ASHRAE 55:2020.

Questionnaire d'évaluation du bâtiment

Cette enquête est menée dans le but d'améliorer la définition et la conception de futurs bureaux et espaces de travail. Les informations recueillies sont considérées comme hautement confidentielles par l'équipe en charge de l'enquête. Les rapports d'enquête utilisent des compilations d'information et ne révèlent en aucun cas l'identité des personnes ayant participé.

Les questions concernent ce bâtiment. Répondez SVP au plus grand nombre de questions possible. Inscrivez vos commentaires dans les espaces prévus à cet effet ou bien sur une feuille séparée. Merci pour votre aide.

Information:
Pour toute information complémentaire, contactez SVP George Baird
Courriel: George.Baird@vuw.ac.nz

Informations générales

Nota Bene : L'age et le sexe sont des paramètres importants quant aux besoins des occupants d'un bâtiment. Votre nom nous est utile pour la résolution éventuelle des problèmes qui pourraient apparaître.

Quel est votre âge…? *Cochez SVP* Moins de 30 ans [1] [2] Trente ans ou plus

… et votre sexe? *Cochez SVP* Masculin [1] [2] Féminin

Inscrivez SVP votre nom… *Nom de famille, puis prénom*

… et la dénomination du service auquel vous appartenez. *Department*

Ce bâtiment est-il votre lieu de travail habituel ? *Cochez SVP* Oui [1] [2] Non

Sinon, quel est-il…? *Base habituelle, si différente de ce bâtiment*

Cochez cette case si vous êtes un prestataire externe. Prestataire [1]

Précisez SVP si votre espace de travail est…? *Cochez SVP*
Occupé par vous seul [1]
Partagé avec une autre personne [2]
Partagé avec 2 à 4 personnes [3]
[4] Partagé avec 5 à 8 personnes
[5] Partagé avec plus de 8 personnes

A votre place habituelle, êtes-vous assis à proximité d'une fenêtre? *Cochez SVP* Oui [1] [2] Non

Depuis combien de temps travaillez-vous dans ce bâtiment? *Cochez SVP* Moins d'un an [1] [2] Un an ou plus

Depuis combien de temps travaillez-vous a votre emplacement actuel? *Cochez SVP* Moins d'un an [1] [2] Un an ou plus

Dans une semaine type, combien de jours passez-vous dans ce bâtiment ? *Nombre de jours par semaine dans le bâtiment*

Dans une journée type, combien d'heures passez-vous dans ce bâtiment ? *Nombre d'heures par jour dans le bâtiment*

Dans une journée type, combien d'heures passez-vous à votre bureau ou bien dans l'espace de travail qui vous est alloué ? *Nombre d'heures par jour à votre bureau*

Combien d'heures par jour passez-vous habituellement à travailler sur ordinateur? *Nombre d'heures par … votre écran*

Votre avis sur le bâtiment en général

Conception du bâtiment Toutes choses considérées, que pensez-vous de la conception du bâtiment dans son ensemble…?
Cochez SVP Insatisfaisant [1] [2] [3] [4] [5] [6] [7] Satisfaisant
Toutes choses considérées, que pensez-vous de la conception du bâtiment dans son ensemble…?

Vos besoins Dans le bâtiment pris dans son ensemble, les commodités correspondent elles à vos besoins… ?
Cochez SVP Insatisfaisant [1] [2] [3] [4] [5] [6] [7] Satisfaisant
Commentaires sur vos besoins en général

Espace Dans le bâtiment pris dans son ensemble, que pensez-vous de l'utilisation de l'espace… ?
Cochez SVP Inefficace dans l'ensemble [1] [2] [3] [4] [5] [6] [7] Efficace dans l'ensemble

Image Quel est à votre avis l'image que le bâtiment, pris dans son ensemble, donne aux visiteurs… ?
Cochez SVP Mauvaise [1] [2] [3] [4] [5] [6] [7] Bonne

Propreté Que pensez-vous de l'état de propreté du bâtiment …?
Cochez SVP Insatisfaisant [1] [2] [3] [4] [5] [6] [7] Satisfaisant

Disponibilité de salles de réunions
Cochez SVP Insatisfaisant [1] [2] [3] [4] [5] [6] [7] Satisfaisant
Commentaires à propos des salles de réunions

Les capacités de rangement sont-elles appropriées… ?
Cochez SVP Insatisfaisant [1] [2] [3] [4] [5] [6] [7] Satisfaisant

A propos de votre travail

Décrivez SVP brièvement vos activités professionnelles dans ce bâtiment…?
Description de votre tâche (Indiquez SVP la dénomination de votre poste)

Ce dont vous avez besoin pour travailler

Spécifiquement pour votre tâche, quelle est la qualité des commodités à votre disposition…?
Cochez SVP Très mauvaise [1] [2] [3] [4] [5] [6] [7] Très bonne

Pouvez-vous SVP donner quelques exemples de ce qui nuit à votre efficacité…?
Nuisances

…et des exemples de ce qui fonctionne bien habituellement… ?
Ce qui fonctionne bien

Votre bureau ou votre espace de travail

Le mobilier Pouvez-vous SVP indiquer si le mobilier à votre disposition est approprié …?
Cochez SVP Très mauvaise [1] [2] [3] [4] [5] [6] [7] Très bonne

La taille de votre bureau Disposez-vous de suffisamment de place à votre bureau ou à votre espace de travail habituel…?
Cochez SVP Pas assez [1] [2] [3] [4] [5] [6] [7] Trop
Commentaires sur votre bureau ou votre espace de travail

1 / 2

Confort Dans cette partie du questionnaire, il s'agit de savoir si vous trouvez le bâtiment confortable en hiver et en été.

En HIVER, comment décririez-vous les conditions typiques à votre emplacement de travail habituel? Si vous n'avez jamais travaillé à cet emplacement en hiver, ne cochez aucune case pour ces questions et reportez-vous directement aux questions sur la température en été.

La température en hiver *Cochez SVP une case pour chacune des échelles suivantes.*

Inconfortable	1	2	3	4	5	6	7	Confortable
Trop chaud	1	2	3	4	5	6	7	Trop froid
Stable	1	2	3	4	5	6	7	Varie au cours de la journée

L'air en hiver

Calme	1	2	3	4	5	6	7	Courant d'air
Sec	1	2	3	4	5	6	7	Humide
Frais	1	2	3	4	5	6	7	Vicié
Inodore	1	2	3	4	5	6	7	Transporte une odeur

Les conditions en hiver

Insatisfaisant dans l'ensemble	1	2	3	4	5	6	7	Satisfaisant dans l'ensemble

En ETE, comment décririez-vous les conditions typiques à votre emplacement de travail habituel? Si vous n'avez jamais travaillé à cet emplacement en été, ne cochez aucune case pour ces questions et reportez-vous directement aux questions sur la température en hiver.

La temperature en été *Cochez SVP une case pour chacune des échelles suivantes.*

Inconfortable	1	2	3	4	5	6	7	Confortable
Trop chaud	1	2	3	4	5	6	7	Trop froid
Stable	1	2	3	4	5	6	7	Varie au cours de la journée

L'air en été

Calme	1	2	3	4	5	6	7	Courant d'air
Sec	1	2	3	4	5	6	7	Humide
Frais	1	2	3	4	5	6	7	Vicié
Inodore	1	2	3	4	5	6	7	Transporte une odeur

Les conditions en été

Insatisfaisant dans l'ensemble	1	2	3	4	5	6	7	Satisfaisant dans l'ensemble

Bruit Comment décririez-vous les conditions acoustiques à votre emplacement de travail habituel ?
Cette question fait référence à une année entière.
Cochez SVP une case pour chacune des échelles suivantes.

Le bruit en général	Insatisfaisant	1	2	3	4	5	6	7	Satisfaisant
Le bruit causé par vos collègues	Pas assez	1	2	3	4	5	6	7	Trop
Le bruit causé par d'autres personnes	Pas assez	1	2	3	4	5	6	7	Trop
Les autres bruits provenant de l'intérieur du bâtiment	Pas assez	1	2	3	4	5	6	7	Trop
Le bruit venant de l'extérieur	Pas assez	1	2	3	4	5	6	7	Trop

Pouvez-vous SVP estimer le degré de gêne que vous causent des interruptions impromptues ...

Interruptions impromptues	Aucune	1	2	3	4	5	6	7	Très fréquentes

Commentaires sur le bruit et les sources de bruit

Eclairage Comment décririez-vous la qualité de l'éclairage à votre emplacement de travail habituel?
Cochez SVP une case pour chacune des échelles suivantes.

L'éclairage en général	Insatisfaisant	1	2	3	4	5	6	7	Satisfaisant
La lumière naturelle	Pas assez	1	2	3	4	5	6	7	Trop
L'éblouissement causé par des sources lumineuses	Aucun	1	2	3	4	5	6	7	Trop
L'éclairage artificiel	Pas assez	1	2	3	4	5	6	7	
L'éblouissement causé par des sources lumineuses	Aucun	1	2	3	4	5	6	7	

Commentaires sur l'éclairage et la lumière

Confort en général Toutes choses considérées, quelle est votre appréciation générale du confort à l'intérieur de ce bâtiment ?
Cochez SVP

Insatisfaisant	1	2	3	4	5	6	7	Satisfaisant

Commentaires sur le confort

Efficacité au travail *Essayez SVP de juger ce bâtiment sur la base de votre expérience dans les bâtiments en général*

Pouvez-vous SVP estimer quel est à votre avis l'impact de l'environnement créé par le bâtiment sur votre efficacité au travail?
Cochez SVP une case pour chacune des échelles suivantes.

Productivité diminuée de ...	-40% ou moins	-30%	-20%	-10%	0	+10%	+20%	+30%	+40 % ou plus	Productivité augmentée de
	1	2	3	4	5	6	7	8	9	

Commentaires sur la productivité

Santé Observez-vous une modification dans votre état de forme lorsque vous êtes dans le bâtiment ? *Essayez SVP de juger ce bâtiment sur la base de votre expérience dans les bâtiments en général*
Cochez SVP

En moins bonne forme	1	2	3	4	5	6	7	En meilleure forme

Commentaires sur la santé

Réglages individuels Quelle est l'étendue de vos moyens d'action sur les aspects suivants de votre environnement de travail... ?
Cochez SVP une case pour chacune des échelles suivantes.

Importance du contrôle *Cochez la case si vous y attachez une importance particulière*

Chauffage	Pas de réglage individuel	1	2	3	4	5	6	7	Réglage à volonté	1
Climatisation	Pas de réglage individuel	1	2	3	4	5	6	7	Réglage à volonté	1
Ventilation	Pas de réglage individuel	1	2	3	4	5	6	7	Réglage à volonté	1
Lumière	Pas de réglage individuel	1	2	3	4	5	6	7	Réglage à volonté	1
Bruit	Pas de réglage individuel	1	2	3	4	5	6	7	Réglage à volonté	1

...ez des commentaires ...taires sur les sujets ...ouvez-vous SVP les ...r une feuille séparée.

Pouvez-vous SVP déposer ce questionnaire à un emplacement bien visible; il sera récupéré plus tard dans la journée.

D3.9 Part B Annex

2.3.2 Spot or Point-in time (“right-now”) surveys: questionnaires with measurements

Spot or or Point-in time surveys are short questionnaires with the objective to receive feedback from the occupant about their sensations and preferences right at the moment when the survey is answered. (Noris, Napolitano, et Lollini 2013). These types of questionnaires are generally correlated with simultaneous measurements of the indoor environmental variables, i.e., air temperature, relative humidity, air velocity and mean radiant temperature (black globe temperature). Specific measuring instruments for indoor air quality and comfort levels are required.

Physical and subjective measures should be done “at times of the day when conditions are representative of the environments to which people are exposed. Conditions to which people are exposed can be influenced by outside weather and it could be necessary to measure throughout the day or to carry out a long-term survey across the year.” (EN ISO 28802:2012).

As a result, the questionnaires should be distributed at least **twice a day** on the days the measurements are conducted, namely, in the **morning** and in the **afternoon.**

“If only one set of measurements is possible, then it is recommended to conduct the survey at a time when most dissatisfaction is expected, based upon preliminary information” (EN ISO 28802:2012). For instance, measurements could be done during a day or a week of the hottest month.

The subjective judgement scales of the following questionnaire were developed according to the EN ISO 28802:2012 and the EN ISO 10551:2019 standards. The different activities and the corresponding metabolic rate are based on the ISO 8996:2021 standard. Typical garments and their insulation values have been chosen based on the EN ISO 9920:2009 standard.

A n analysis of historical development of questionnaires and comfort models up to 2010 can be found in (Pagliano et Zangheri 2010).

THERMAL COMFORT QUESTIONNAIRE for point-in-time surveys.

Information for Participants

*This survey is done in the framework of the **European project** titled "**ABC 21 – Africa-Europe BioClimatic buildings for XXI century**". ABC 21 aims to increase the **energy performance**, the **quality of life** and **sustainability** of **West-African** buildings through the identification, strengthening and effective deployment of **affordable bioclimatic designs** and **local materials** under the challenging **African climate** and **urbanization** context.*
*The person who gave you this questionnaire will **measure physical parameters** in parallel of this questionnaire, such as the temperature of the air, the relative humidity, the air velocity and the radiant temperature. This questionnaire asks you about your perception, sensation and preference of your thermal environment in your **present location** and in the **present conditions**. The survey is voluntary.*

The important points are:

1) ***There are no right or wrong answers***
2) ***We value your opinion***
3) ***If a question doesn't make sense then let us know, but try to answer by choosing the most appropriate response***
4) ***We will not ask you to identify yourself, so your answers are entirely confidential***
5) ***You are entitled to a brief summary of the findings: you can obtain this by contacting us***

THIS SURVEY SHOULD TAKE ABOUT 5 MINUTES TO FILL IN

Date: ____ / ____ / ____ **Time:** ____ : ____

Season: ◯ **Hot season** ◯ **Rainy season** ◯ **Cold season**

Location (city and country):

Surveyed building :

Surveyed room:

PART 1- Subjective judgement of thermal environments

Please answer the following questions concerning YOUR COMFORT and SATISFACTION with your environment.

A- AIR TEMPERATURE

1. How do **YOU** feel at this **precise moment**? (mark appropriate box): I am feeling....

◯	◯	◯	◯	◯	◯	◯
Cold	Cool	Slightly cool	Neutral (neither hot nor cold)	Slightly warm	Warm	Hot

2. Do **YOU** find this...?

Comfortable | Slightly uncomfortable | Uncomfortable | Very uncomfortable | Extremely uncomfortable

3. **Right now**, would **YOU** prefer to be...? (mark appropriate box):

Cooler | No change | Warmer

4. How do you judge this environment on a personal level **at this moment**?

Acceptable | Unacceptable

B- RELATIVE HUMIDITY

5. How do **YOU** find the air humidity at this **precise moment**? (mark appropriate box):

Very dry | Dry | Slightly dry | Just right | Slightly humid | Humid | Very humid

6. **Right now**, would **YOU** prefer the air to be...? (mark appropriate box):

Drier | No change | More humid

C- AIR VELOCITY

7. How do **YOU** find the air velocity in your place at this **precise moment**? (mark appropriate box):

Very still | Still | Slightly still | Just right | Slightly draughty | Draughty | Very draughty

8. **Right now**, would **YOU** prefer to have...? (mark appropriate box):

Less air movement | No change | More air movement

9. How do you judge the air movement on a personal level **at this moment**?

Acceptable | Unacceptable

PART 2 – Environmental controls

Please answer the following questions concerning YOUR environmental controls on the building's equipments at the exact time and place where you are surveyed. If the equipments described do not exist, please tick the box "Not applicable".

10. Now, the internal door is:	Open	Closed	Not applicable (NA)
11. Now, the external door is:	Open	Closed	Not applicable (NA)
12. Now, the air conditioning system is:	On	Off	Not applicable (NA)
13. Now, the windows are:	Open	Closed	Not applicable (NA)
14. Now, the blinds/curtains are:	Open	Closed	Not applicable (NA)
15. Now, the fans of your room are:	On	Off	Not applicable (NA)

PART 3 – Personal information (demographic data, activity, clothing insulation)

These data are necessary for the study of thermal comfort from a physiological point of view.

16. Age [year] : ____________________

17. Weight [in kg]: ___________________

18. Height [in cm]: ___________________

19. Sex: Male Female

20. Occupant's Activity Level (Tick the one that is most suitable): **What were you doing 20 to 30 min ago before completing this questionnaire?**

- ◯ Reclining, sleeping
- ◯ Seated relaxed
- ◯ Standing at rest
- ◯ Sedentary activity (office, dwelling, school)
- ◯ Eating
- ◯ Car driving
- ◯ Domestic work (shaving, washing, dressing)
- ◯ Walking
- ◯ Running
- ◯ High domestic work (tinkering, cooking, etc.)

21. What is your **position right now?** ◯ Seated ◯ Standing

22. Occupant's clothing's insulation: Please tick the most suitable choice of piece of garment you are wearing now.
We are only interested in the thermal value of the clothes. We want to know how much insulation you have on to protect you from the environmental conditions.

UNDERWEAR	
Briefs	
Panties	
Bra	
Singlet, tank top	
Shirt, long sleeves	
Pants, long-legged	

SHIRTS	
Sleeveless, scoop-neck	
Short sleeves	
Lightweight, long sleeves	
Normal, long sleeves	
Flannel shirt, long sleeves	
T-shirt, short sleeves	

SUNDRIES	
Cap / hat	
Kufi/ African hat	
Turban	
Scarf/shawl	
Hijab	
Others:……………	

DRESSES & SKIRTS	
Light skirt (summer)	
Heavy skirt (winter)	
Light dress, short sleeves	
Winter dress, long sleeves	
Sleeveless, scoop neck	
Boiler suit	

JACKETS, VESTS & SMOCKS	
Light summer jacket	
Vest	
Jacket	
Single-breasted suit jacket	
Double-breasted suit jacket	
Suit-vest	

WINTER OUTDOOR CLOTHING	
Coat	
Down Jacket	
Parka	

TROUSERS & COVERALLS	
Short shorts	
Knee length Shorts	
Lightweight trousers	
Normal trousers	
Thick trousers	
Sweat pants	
Work coveralls	

TRADITIONAL CLOTHES	
Boubou (wide-sleeved robe)	

FOOTWEAR & LEGWEAR	
Socks	
Thick long socks	
Pantyhose	
Slippers	
Thongs / sandals	
City shoes	
Sneakers	
Boots	

23. Comments

3 References

ANSI/ASHRAE. 2020. *Standard 55-2020. Thermal Environmental Conditions for Human Occupancy*. https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy.

Baird, George. 2009. « Incorporating User Performance Criteria into Building Sustainability Rating Tools (BSRTs) for Buildings in Operation ». *Sustainability* 1 (4): 1069-86. https://doi.org/10.3390/su1041069.

Földváry Ličina, Veronika, Toby Cheung, Hui Zhang, Richard Dear, Thomas Parkinson, Edward Arens, Chungyoon Chun, et al. 2018. « Development of the ASHRAE Global Thermal Comfort Database II ». *Building and Environment* 142 (septembre): 502-12. https://doi.org/10.1016/j.buildenv.2018.06.022.

Lenoir, Aurélie, George Baird, et François Garde. 2012. « Post-occupancy evaluation and experimental feedback of a net zero-energy building in a tropical climate ». *Architectural Science Review* 55 (3): 156-68. https://doi.org/10.1080/00038628.2012.702449.

Noris, Federico, Assunta Napolitano, et Roberto Lollini. 2013. « Measurement and Verification Protocol for Net Zero Energy Buildings ». IEA Solar Heating and Cooling Programme. https://doi.org/10.18777/ieashc-task40-2013-0003.

Pagliano, Lorenzo, et Paolo Zangheri. 2010. « Comfort Models and Cooling of Buildings in the Mediterranean Zone ». *Advances in Building Energy Research* 4 (1): 167-200. https://doi.org/10.3763/aber.2009.0406.

ABC21 is funded by the EU's H2020 programme