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Africa-Europe Bioclimatic Collaboration 21

Africa-Europe BioClimatic buildings for XXI century

IMPROVING THE ENERGY PERFORMANCE AND SUSTAINABILITY

OF AFRICAN AND EUROPEAN BUILDINGS

AND ENHANCING THE QUALITY OF LIFE OF THEIR OCCUPANTS

www.abc21.eu

ABC 21 project

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Authors

Name	Email	Institution
Susanne Kuchar	susanne.kuchar@e-sieben.at	e7 energy innovation & engineering
Camilla Rampinelli	camilla.rampinelli@e-sieben.at	e7 energy innovation & engineering
Silvia Erba	silvia.erba@polimi.it	Politecnico di Milano
Lorenzo Pagliano	lorenzo.pagliano@polimi.it	Politecnico di Milano
Asmae Khaldoune	a.khaldoune@aui.ma	Al Akhawayn University in Ifrane
Radouan Yessouf	r.yessouf@amee.ma	AMEE Agence marocaine pour l'efficacite energetique
Ernest Dione	ernes.dione@gmail.com	DEEC Ministere de l´environnement et du developpement durable
Guilherme Carrilho da Graça	gcg@ciencias.ulisboa.pt	Faculdade de Ciências da Universidade de Lisboa
João Carlos Simões	jcsimoes@ciencias.ulisboa.pt	Faculdade de Ciências da Universidade de Lisboa
Francois Garde	francois.garde@univ-reunion.fr	University of la Reunion
Virginie Grosdemouge	virginie.grosdemouge@univ-reunion.fr	University of la Reunion

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Executive summary

"a future of low-impact buildings is not only necessary

but also elegantly achievable"

Edward Mazria, 2022[1]

Europe and Africa are both facing challenges in the building construction and housing sector.

Europe is struggling with an aging building stock, whose rapid and radical transformation is needed to meet the goals of reducing energy use and protecting the climate.

African countries are facing an acute housing shortage, with the **continent's population projected to double by 2050**, problematic access to efficient use of clean energy for achieving thermal comfort and for cooking, and the fastest urbanization rate in the world.

Various forms of **climate disruption** and prolonged heat waves are affecting the planet. These effects are significant in the South of Europe and severe in Africa. New constructions and retrofit interventions should be designed following concepts that will make **buildings robust against expected climatic changes during their lifetime**, the next 50 to 100 years.

In the last decades, globalization, and the erroneous perception of infinite abundance of cheap energy and environmental space where to dissipate energy and waste materials, have led to **inadequate design solutions**, culminating in buildings whose conception is essentially disconnected from local climate and context, overly glazed, unshaded, based on materials with high embedded energy and often imported from very distant places.

In this context, there is a growing need for comfortable and affordable building space with high environmental performance. ***Bioclimatic architecture*** and ***passive systems***, coupled with the use of **bio- or geo-sourced local building materials**, offer a feasible and effective response to the above threats, and they constitute an emerging trend in the innovative parts of the construction sector. An **adapted institutional and training framework** might be a key to a faster revival and update of those approaches.

Development of simple, effective, **well documented, open access software** focused on passive design can bring new support to pre-design and design-phase predictions of bioclimatic building performance.

"Bioclimatic architecture", according to Baruch Givoni, a master of this type of architecture, involves architectural design and choice of materials aiming at providing comfort while minimizing energy use. To achieve these aims, different architectural features need to be properly designed:

- the layout of the building and its orientation,
- the number, size, location, and details of its windows,

- the shading devices,
- the thermal resistance and heat capacity of its envelope.

The proper use of the above means results in a **minimization of the diurnal indoor average temperature, which remains anyway higher than the diurnal outdoor average temperature**.

B. Givoni also provides a definition for ***passive cooling systems***, which can transfer heat from the building and occupants to the available environment heat sinks, thus **lowering the indoor average temperature below the outdoor average**.

Proper architectural *bioclimatic design* in a region with hot climate can be thus considered as a precondition for the application of *passive cooling systems*, such as:

- comfort ventilation,
- nocturnal ventilative cooling,
- radiant cooling to the sky,
- direct evaporative cooling,
- indirect evaporative cooling,
- soil cooling,
- cooling of outdoor spaces.

ABC 21 has pursued the following four interconnected objectives:

(1) Identify and document African and European affordable bioclimatic designs, passive systems, and bio- or geo-sourced materials.

(2) Document and promote innovation in state-of-the-art surface coatings, future weather files, design techniques and tools adapted to the new and changing climate conditions and the new knowledge about thermal comfort codified in recent updates of Comfort Standards.

(3) Document sustainable and affordable supply of bio- or geo-sourced construction materials produced by local actors.

(4) Perform exchange activities for policymakers on low-cost and effective bioclimatic construction.

The **analysis of housing needs, construction practices and urbanization trends**, confirmed that **Africa faces a significant housing deficit**, risking the expansion of slums in parallel to climate-inadequate construction in disorderly urbanization. Improved monitoring of the situation and its evolution is needed.

In Europe, housing, though abundant, **poses challenges for low-income groups**. Recent policies on housing quality in Africa have made progress but have limitations, including debt issues and environmental impacts.

Stable financing opportunities, via e.g. levies on energy, and government clear regulation and incentives are needed on both continents to improve the deployment of bioclimatic envelope design, passive cooling systems, and local materials, on both continents.

The **assessment of the regulatory and training infrastructure** for energy efficiency in buildings in the EU, and North-West Africa revealed both similarities and differences among the regions. In the EU, there are European Directives and guidelines, but differences in chosen indicators and key concepts among member States makes comparison and transfer of lessons difficult. Africa misses building codes in certain areas, has a number of ongoing promising regulatory processes, and has sometimes chosen simpler yet more effective roads, e.g. by giving priority to the level of ***energy needs for heating and cooling***, which is univocally determined by physics, rather than the level of (total or non-renewable) primary energy, which involves primary energy factors which are affected by uncertainties (e.g. evolution of energy mix in the future) and assumptions beyond physics.

Both continents have not yet produced reliable, **officially certified, and openly available future weather files** representing the local manifestation of **global warming** and increased frequency of extreme events.

Regarding **education and training programs**, the EU has continent-wide programs focusing on Energy Efficiency in buildings and urban planning, but both EU and Africa show low awareness regarding the significance of bioclimatic principles and passive systems in general and in their education and training programs. The present fracture between engineering and architecture disciplines (with notable exceptions) is a relevant barrier to the development of "low impact buildings elegantly achieved" and **strong investments should be made in curricula** which focus on training professionals with **high competence in building physics in parallel and synergy with architectural and urban disciplines**.

Bioclimatic constructions have a rich history in Europe and Africa, but in recent years there has been a loss of expertise. The ABC 21 project aimed at promoting local bioclimatic approaches and design strategies by collecting and analyzing best design practices, compiling an overview of low-impact materials, and conducting a screening of existing infrastructure for production of these materials in Northwest Africa and the EU. The findings highlighted the need for programs to consolidate the current **revival of bioclimatic design by a generation of innovative African architects**, to update previous guidelines considering the availability of new materials and the evolution of weather patterns, to **strengthen infrastructure and enhance the certification procedures** of bio- and geo-sourced materials to meet the demands of the 21st century.

The project hence examined various **bio- and geo-sourced materials** for construction in terms of their mechanical, physicochemical, and thermal performances. Earth and clay-based materials, stone-based materials, and plant-based materials were compared, and their respective properties highlighted.

The project reviewed some **promising policies** and proposed **a policy assessment tool**, for the promotion of bioclimatic design and passive techniques.

The study highlighted the importance of progressing towards:

- the use of a **common set of building performance indicators** and definitions (as in EN-ISO 52000), with corrections to the ambiguous concept of net-zero energy over a year.

- the use of the **most recent comfort models** (as in ASHRAE 55:2020)

- to adoption of a **correct interpretation of low or (nearly) zero energy** concept, utilizing 3 indicators rather than only one (primary energy), with priority to lowering "***energy needs for heating and cooling***", as recommended in EN-ISO 52000-2 and in line with "energy efficiency first" principle.

It also emphasized the need for **policies beyond individual buildings, including districts and cities**. Financing options and investment prioritization were discussed, considering short-term returns and long-term cost reduction.

Consistent use of standardized concepts, definitions, and nomenclature in the building sector is crucial for improved comfort and energy efficiency. It reduces communication difficulties and misunderstandings, which may lead to costly errors. To address this, three documents were developed, providing a common framework based on European and International standards. **Key Performance Indicators (KPIs)** were analyzed to assess high **energy performance** buildings, able to distinguish the **priority phase of minimizing *energy needs for heating and cooling***, from the subsequent and complementary one of fulfilling the residual needs with renewably sourced energy. KPIs were also proposed for **thermal comfort**, visual comfort, acoustic comfort, and indoor air quality, offering guidelines for bioclimatic design in warm climates. Concepts for **flexibility in time of the request of energy** were reviewed, finding a need for further work adapted to cooling dominated climates.

Future weather data are vital for building design in the context of climate change. Simplified weather indicators and detailed hourly weather files are essential for the bioclimatic design process. **ABC 21 produced, for a city in each partners' territory, future weather files for the two future climate periods** (2040-2060 and 2080-2100). The methodology for creating the weather files was described in detail.

Weather indicators can be useful to guide building design under climate change. ABC 21 reviewed the definitions of heating and cooling degree-days as weather indicators and presented the indicators that assess the **natural ventilation cooling potential** and the availability of weather indicators' data.

The ABC 21 project has realized **measurement campaigns** and **post occupancy evaluations** in a set of bioclimatic buildings. The recommended procedure to carry out thermal comfort assessments includes: (1) objective methods based on **physical measurements**; (2) subjective methods based on standardized **occupants' surveys** to investigate their satisfaction with the indoor environment. After the phase of identification and installation of the sensors in the buildings, the main variables influencing indoor thermal comfort (air temperature, mean radiant temperature, air velocity and, with a lower influence, relative humidity) have been monitored for some weeks/months; in parallel periodic surveys of occupants' sensations and preferences have been conducted. **Air velocity** is an essential element of comfort in bioclimatic buildings, where ***comfort ventilation*** and ***nocturnal ventilative cooling***[2] are among the main passive strategies.

Some **weather stations** have been also installed, through a collaboration with TAHMO, the Trans-African Hydro-Meteorological Observatory which aims to develop a vast network of weather stations across Africa.

To provide **inspiring examples of European and African Bioclimatic buildings**, 24 case studies were collected in ABC 21. They were selected for their ability to exemplify various bioclimatic approaches and show a description of environmental data, passive solutions used, and, where available, post occupancy evaluation and user feedback. In some cases, the project also conducted a **detailed monitoring campaign,** based on the above-mentioned methodology.

The **technical guidelines** produced within ABC 21 represent an effort to respond to the development and refinement of our knowledge about **thermal comfort**, the use of simple technologies such as **ceiling fans** which have evolved to incorporate airfoiled blades with sophisticated aerodynamic design, the availability of **new modelling tools**, some **traditional construction materials** manufactured using local resources (such as raw earth, which benefit now of better compression methods), **new materials** able to achieve a net transfer of energy to the deep sky event during daytime, while being exposed to direct solar radiation.

The guidelines offer an **updated view of the future of bioclimatic architecture** (which might be *the* architecture in a climate-compatible future of humanity) under the new boundary conditions of XXI century, while taking advantage of accumulated wisdom and the work of the pioneers of XX century.

ABC 21 project developed a set of materials and tools to support the design of bioclimatic buildings: (1) the **open-access handbook "Sustainable Building Design for Africa",** a **comprehensive and updated new publication** with design concepts ad exemplification **drawings** targeted to consultants and designers (architects and engineers) and other stakeholders (such as developers and urban planners); (2) the improvement and adaptation of a simplified interface for Building Energy Simulation tool energyplus, interface previously developed by POLIMI and UN-Habitat for the East African Community; (3) a **MOOC (Massive On-line Open Course),** summarizing the main contents of the handbook, which represents an update of the existing version prepared by POLIMI for the East African Community.

The project organized a **series of 6 webinars** covering various topics related to bioclimatic design and sustainable building practices. The discussions **with external experts and practitioners** during the webinars provided valuable inputs that were utilized in the project's ongoing work, ensuring that the project benefited from diverse perspectives and experiences. These webinars also served as platforms for knowledge exchange, facilitating discussions on key aspects of bioclimatic design and sharing practical insights and experiences. The **recordings** of these webinars will continue to contribute to the dissemination of knowledge beyond the project itself and are available on the project website.

The **International Conference on Bioclimatic Materials and Buildings (ICBMB), organised by ABC 21,** brought together experts from Africa and Europe to discuss policies, materials, design, indicators and weather files, and case studies related to energy-efficient buildings. Representatives from the Ministry of Habitat of Morocco, the EU Directorate General for Energy, and the UN emphasized the importance of effective policies and bioclimatic approaches in promoting comfortable and energy-efficient buildings. Networking opportunities were abundant, and plans are underway for the second edition of the conference. The event gathered over 100 participants, with about 50 abstracts and 30 recorded presentations, and articles are being reviewed for publication.

Based on the **lessons learned** from ABC 21 here are some key takeaways for future activities on bioclimatic buildings. These recommendations aim to optimize the design, performance, and sustainability of bioclimatic buildings via:

- **Early consideration of bioclimatic principles for buildings and districts:** Incorporate bioclimatic principles in the early stages of a project, considering not only the building itself but also the layout, pathways, and public spaces to provide shading and reduce heat absorbing paved surfaces. Increase the presence of vegetation to reduce temperature of air and surfaces around the building.
- **Insulation and solar shading:** Focus on insulating the roof and external walls to minimize heat loss and unwanted solar gain. Implement solar shadings carefully designed according to latitude of the building and orientation of each facade.
- **Natural ventilation:** Design for and manage natural ventilation effectively throughout the year, considering both summer and winter conditions. Stack-driven natural ventilation systems can be highly effective to complement wind driver when insufficient. Natural ventilation may be used to deliver ***comfort ventilation*** (i.e. increasing air velocity on the skin of building's occupants) or ***nocturnal ventilative cooling*** (i.e. cooling at night the masses, to deliver comfort during the next day)
- **Ceiling fans:** Install efficient ceiling fans in all rooms, especially in warm climates, as one of the ways (always available) to achieve ***comfort ventilation***, particularly on days without wind, and to reduce air stratification when heating systems are on.
- **Integration of local materials:** Incorporate local materials within contemporary structures to achieve good comfort results. Embrace the use of natural, reused, or recycled materials to significantly reduce embodied energy.
- **User training and awareness:** Provide periodic user training to ensure occupants are informed about how to effectively use the passive features incorporated in the building. Clear information and awareness-raising are essential to encourage sustainable behavior[3].
- **Involvement of occupants:** Involve future occupants from the start of the design process in a discussion about the design objectives of the building and the potentialities of passive techniques
- **Measurement and monitoring:** Systematically measure the delivered energy consumption (overall and, wherever possible, by subsystems) to compare with calculations/simulations, identify anomalies, and improve knowledge of building behavior. **Clear nomenclature/indicators** and feedback on performance is essential for reproducibility and continuous improvement.
- **Assess comfort of building occupants** via standardized, internationally recognized measurement and interview procedures, as highlighted e.g. in ASHRAE 55:2020. A report on comfort indicators and assessment methods (in the guidelines) are available from ABC21.

ABC 21 project implemented a **comprehensive dissemination strategy** to reach various stakeholders, including policymakers, designers, manufacturers, construction companies, and the public. Key communication activities included the project website, articles in journals, policy briefs, events and conferences, workshops and webinars, and press releases. Personalized invitations and newsletters were sent to the project's contact network, and prominent websites and platforms were utilized for visibility, such as Build-Up (The European portal for energy efficiency and renewable energy in buildings) and Construction 21. **Social media channels** such as LinkedIn and Twitter played a crucial role in sharing updates and fostering discussions; events like the ICBMB conference served as milestones for knowledge exchange. Despite the challenges of the pandemic, the project successfully adapted to virtual spaces, ensuring broader audience engagement.

TABLE OF CONTENTS

1. Background

Current forecasts indicate that more than **half of the global population growth until 2050 will occur in Africa[4],** leading to acute housing shortage and the fastest urbanization rate in the world. Sustainable development goals dictate that this growth should result in minimal, or even positive environmental impact, while ensuring high standards of comfort and health for the populations. Unfortunately, the manifestation of globalization trends in building construction resulted in the adoption of inadequate design solutions for developing regions, copying designs that were already far from sustainable in their original regions (typically from colder northern climates). The obsession with large glazed, unshaded buildings is the most visible aspect of this trend. Most of those type of buildings performs badly even in Central Europe, yet we see a growing number of glass tower buildings in Africa[5].

The need to fight this cycle of inadequate construction practices both in Africa and the EU and prepare for climate change is clear. It is urgent to **study the best bioclimatic design and construction examples from warm regions** around the globe, combined with **local building materials**, and **passive and low-energy solutions** that have recently been developed, namely the new materials for daytime radiation to the sky.

Missing focus on design practices adapted to the local climate and context, buildings are now mostly able to meet comfort expectations only by using large amounts of energy. Whenever heating or cooling active systems fail or are turned off, buildings can maintain the indoor environment with the comfort band only for a few hours, and they can afterward rapidly get out of minimal safety conditions. **Improved retrofits and designs** of both buildings and cities across the European and African continents **are needed to ensure the comfort and health of citizens in the changing climate** and avoid the creation of **"systemic cooling poverty"**[6, 7].

The lack of successful applications of bioclimatic design principles in both Europe and Africa is surprising in a world where, when given the choice, most people show to prefer natural ventilation, passive solar heating, and daylight and, perhaps as a result, tend to show a larger thermal comfort band when in naturally ventilated buildings[8, 9]. Most design practitioners and sustainable architecture consultants struggle (sometimes successfully) to integrate bioclimatic principles in modern designs[10]**. Improved building design regulations and information exchange about good design examples, which can be replicated in other locations with similar climate, can be fundamental to insure sustainable development in Europe and Africa.**

New buildings should be designed following concepts that will make them robust against expected climatic changes during their lifetime, the next 50 to 100 years. Since **climate change is causing progressively harsher boundary conditions**, there is a growing need for and **renewed interest in bioclimatic principles and use of bio- or geo-sourced local building materials on both continents.**

The offer of **software models for thermal simulation** with captivating graphical interfaces is growing**, but some lack** precision in the terminology and **clear identification of the key variables** according to the physical definitions given in the International Standards, thus obscuring the interpretation of results. Furthermore, these models need hourly weather files as an input and those are relatively rare in Africa, and often based on overly old statistical weather data which bear little resemblance with the present weather in Europe. **Reliable, publicly certified weather files for future climatic situation** in 2050 and 2080 are missing in both continents. Also, there is very little information available on indoor comfort in buildings in Africa[11] and not much on bioclimatic buildings in Europe either. To support the uptake of bioclimatic buildings by policymaking, building industry and private and public clients, there is a strong need to provide **objective data** on their performance, **both in terms of energy use and achieved comfort conditions**. One should notice that reliable public data on iconic "modern global" buildings are also scarce, despite pretended sustainability.

While Europe and the global north have developed powerful simulation tools (sometimes overly complex and non-transparent) and low energy concepts (nZEB, Passivhaus, …) which - when adapted - might be useful for training and design in Africa, they have also produced and marketed high energy consuming buildings detached from context and climate. On the other hand, Africa has partly retained a tradition of locally and climate adapted architecture, and a wave of young architects is reviving that tradition with the aim to develop low energy models. These developments might inspire Europe in return [12, 13].

2. Goals and main directions

The project **"Africa-Europe BioClimatic buildings for the XXI century" (ABC 21)** implemented several interrelated actions aimed at improving the energy and comfort performance of buildings in Africa and Europe.

Identification and documentation of African and European affordable bioclimatic designs and local materials

ABC 21 identified and updated bioclimatic approaches for effective deployment in the challenging XXI century African climate and urbanization context. In addition, the project identified 24 case studies, and shares best practices and success stories, with a focus on the benefits of bioclimatic approaches. The project promoted measures to facilitate access to the best practical knowledge for building professionals (architects, engineers, construction companies). This effort strengthened the Africa-EU exchange and cooperation in bioclimatic approaches to sustainable and affordable housing, which are more resilient to the challenges of the XXI century.

Exchange activities for policymakers on low-cost and effective bioclimatic construction

These exchange activities strengthened cooperation between Europe and Africa, with emphasis on the Northwest African region, but also including inter-African exchanges that addressed a range of climatic and rural-urban contexts. The exchange activities provided a synthesis of the best knowledge for the policymaking process. Finally, efforts were made to identify conditions and tools (curricula, contract models) that would improve the capacity of partners countries and stakeholders.

Implementation of a detailed monitoring campaign on indoor comfort in buildings in Africa

Taking advantage of the collaboration with various actors established in ABC 21, the project collected existing information on the actual behavior of bioclimatic buildings. Objective and exhaustive data are rarely publicly available and also in this case only for part of the selected buildings quality data were available. Hence, additionally to collecting existing data, we monitored for some months in a selection of the case studies (in Senegal, Kenia, Portugal, Italy, and La Reunion) the main variables influencing comfort. In some case studies professional-grade weather stations were installed. The outcomes of the documentation of case-studies with clear KPIs, where raw data were available, and with additional measurements to fill some of the data gaps are a first important attempt at moving from generic descriptions often found in available gray literature to more objective and credible assessments, necessary to support learning from failures and replication of successes.

Promotion of innovation on state-of-the-art surface coatings and future weather files

ABC 21 analyzed the availability and applicability of state-of-the-art surfaces for **daytime net radiation to sky**. In addition, the project developed weather files for selected cities in Africa and Europe at the horizon 2040 and 2080. These files can be used in building design to evaluate the resilience capabilities of bioclimatic solutions under a climate change scenario.

3. Needs and potentialities in the building sector in NW-Africa and the EU

3.1 Housing needs, construction practices and urbanization trends

The situation of housing demand and supply is facing a lack of up-to-date statistical data both in African and European countries. This gap in housing statistics is partly linked to an outdated estimate of housing stocks, but also to the complexity of methods for projecting real housing needs.

In Africa, there is a clear housing deficit. Housing production by public and private companies remains very low and uncertain. The current housing deficit in Africa accounts for at least 51 million units, with large variation across countries.

The following table indicates the situation of housing backlog in several countries in Africa.

Table 1: Housing backlog and urbanization in Africa (Excerpt) (Bah, Faye, and Geh, 2018, [14])

Country	Housing backlog	Urbanization rate (2000-2015)	Urban share 2015 (%)
Algeria	1200 000	2.76	70.7
Burkina Faso	100 000	6.33	29.9
Morocco	600 000	1.92	60.2
Nigeria	17 000 000	4.78	47.8
Senegal	125 000	3.32	43.7
Togo	250 000	3.88	40.0

In Europe, the housing stock is generally high for all countries, unlike African countries. Although the housing stock in Europe is high, access to decent housing remains difficult for low-income groups and in certain geographical areas. (Pittini 2015[15]).

In Africa, the housing deficit is accompanied by the presence of considerable informal construction and large slums with very precarious shelters. A comparison of the estimated population living in slums in various world regions in 2015 and expected evolution till 2030 is presented in Figure 1. According to this UN estimate there a risk of further growth of the population living in slums in sub-Saharan Africa.

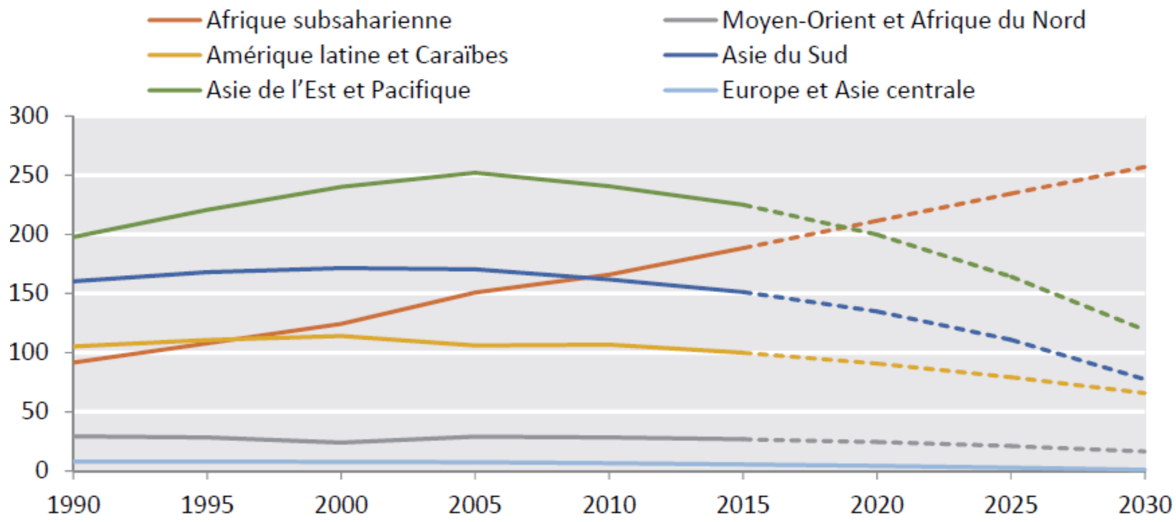


Figure 1: Slum Populations (per million) for various regions, according to UN estimations in 2014 (ONU, 2014)

Hence in Africa the quality of housing remains very average in most cases because of the large share of self-construction, little regulation and controls, and therefore the lack of use of the services of an architect/planner. The consequences of poor housing quality are lack of thermal comfort and safety for occupants and poor energy performance. In Europe, even with the progress of building regulation over decades, the building stock is not of the highest quality in terms of thermal comfort of occupants, carbon footprint and energy performance. There is a lack of affordable housing units in large cities and often insufficient basic services (instruction, culture, public transport, …) in smaller cities/villages where housing is more affordable.

Policies put in place in recent years in several African countries have led to progress: mass production of housing in the formal sector against a backdrop of a quantitative deficit and the formation of a new middle class. However, the limits of these policies are numerous with a significant and not always sustainable debt of buyers, poorly inclusive access conditions, a scarce environmental quality of housing, negative impacts on social inequalities, social diversity, or urban sprawl.

Same of those problems might be eased by applying the principles of ***bioclimatic architecture*** and ***passive systems***[16]:

- by applying bioclimatic principles at building level e.g. by limiting solar gain at the building level,
- by developing building forms that allow ***comfort ventilation*** and/or ***nocturnal ventilative cooling***, and including other passive systems such as evaporative cooling, ground exchange, radiation to the sky …, according to the climate.
- by using local bio- and geo-based materials,
- by revegetating the spaces inside and around buildings,
- by applying bioclimatic principles not only at building but also at district level.

Financing access to housing remains a major problem for Africa and Europe. Government, community, and associative initiatives are very diverse, but each one has its limits. One of the main obstacles to the supply of affordable housing in Africa is the lack of financing for developers, particularly small and medium size developers. Promoting alternative sources of financing for developers is crucial to increase the supply of affordable housing in Africa. In the report on policies, we discuss some options for financing in particular bioclimatic approaches to housing, e.g.: via earmarked levies on energy.

3.2 Training and regulatory infrastructure

The ABC 21 project aimed to provide **insight into the present regulatory infrastructure on energy efficiency in buildings across the regions of the EU, North Africa, and West Africa**. The selection of countries was made to include representative nations from each of these three regions, namely Germany, Spain, Portugal, France, Italy, Austria, Morocco, Tunisia, Egypt, Libya, Algeria, Ghana, Togo, Senegal, and Nigeria.

The objective was to identify and analyze the level of development of these infrastructures, examine the obstacles encountered, and put forward some recommendations.

In order to provide a comprehensive benchmark and analysis, we utilized both quantitative and qualitative data collection methods. The methods employed included **questionnaires, focused group discussions, interviews with key actors, and a review of existing documents** from relevant agencies and other public institutions.

The research conducted reveals significant disparities in the progress of Energy Efficiency regulations for buildings among the European Union, North Africa, and West Africa.

At the European Union level, national regulations are, in principle, aligned with European Directives and provide, in some cases, provisions favorable for bioclimatic buildings.

More effective support would come from:

- **a clearer common nomenclature**, fully **aligned to Standards**, (e.g.: EN ISO 52000:2017, ASHRAE 55:2020,…) in legislation, norms and mandated for building simulation tools.
- an explicit mandate to **reduce** "***energy needs for heating and cooling***" by improving envelope features, a mandate which is often missing or not in explicit focus.
- an explicit mandate to identify for which comfort objectives the building is designed or retrofitted and managed, promoting the adoption in warm periods of the "***adaptive comfort***" model when active cooling has not been installed or is not running, and the "**elevated air speed comfort zone method**" (see ASHRAE 55:2020).
- a public initiative to produce, certify and make **open access future weather files**.
- **making the EN and other Standards related to buildings open access**; their high price is presently a big barrier to capacity building and sharing of information with common language and definitions among the stakeholders and across states and regions.

In **Africa**, some countries have made progress in **developing building codes** with varying levels of application, and some of them are adopting the "***energy needs for heating and cooling***" as an explicit indicator, to be reduced, as e.g. Morocco.

In Europe few countries choose the clear indicator "**energy needs** for heating or cooling" **as the base for energy labelling**. E.g. Serbia, where the best energy classes (A+ and A) for new buildings are defined with a level of energy needs (8 and 14 kWh/m^2 y) even lower than under the voluntary label "PassivHaus" (15 kWh/m^2 y).

Table 2: Energy classes of "administrative and office buildings" in Serbia, for new buildings and major renovations. $Q_{H,nd}$ = *energy need for heating*

Upravne i poslovne zgrade		nove	postojeće
Energetski razred	$Q_{H,nd,rel}$ [%]	$Q_{H,nd}$ [kWh/(m²a)]	$Q_{H,nd}$ [kWh/m²a)]
A+	≤ 15	≤ 8	≤ 10
A	≤ 25	≤ 14	≤ 17
B	≤ 50	≤ 28	≤ 33
C	≤ 100	≤ 55	≤ 65
D	≤ 150	≤ 83	≤ 98
E	≤ 200	≤ 110	≤ 130
F	≤ 250	≤ 138	≤ 163
G	>250	>138	> 163

Yet statistical weather data for use in the design process are not widely available. One initiative to install in Africa a network of reliable, low maintenance **weather stations** is TAHMO, with which ABC21 has established a partnership. Data generated can be easily accessed. We could not find any initiative to generate, certify and make open access future weather files. **ABC21 has generated future weather files for the 2050 and 2080 horizons for a few selected locations**, as examples.

In West Africa, the **Economic Community of West African States** (ECOWAS) is proposing and developing regional measures for building energy efficiency, primarily due to the limited adoption of energy efficiency in existing building codes and regulations. Emphasis is placed on appliances and on utilizing renewable energy systems in buildings.

In parallel to the status of regulatory infrastructure, both public and private entities in the European Union have managed to provide a diverse array of **education and training programs** focused on Energy Efficiency (though sometimes with unclear KPI and targets, implying that the EU overall database on the building stock is progressing slowly) in buildings and urban planning, which include modules on bioclimatic architecture.

However, while there are programs addressing Energy Efficiency in buildings (and urban planning in North and West Africa, there remains a significant lack of awareness regarding the significance of bioclimatic architecture. The majority of offered curricula in North and West Africa focus on the application of Renewable Energy in buildings. It would be important to **reinforce the incorporation into training programs of building physics courses focused on the building fabric and reduction of *energy needs for heating and cooling***.

The current revival of bioclimatic architecture and use of local materials led by a **new generation of African architects** is a vital sign of hope for both Africa and Europe for the possibility to steer the course of architectural design and construction practices and be of inspiration also in training curricula.

Bioclimatic architecture and ***passive systems***, coupled with the use of bio- or geo-sourced local building materials, offer a feasible and effective response to the threats brought by climate disruption, and they constitute an emerging trend in the innovative parts of the construction sector. An **adapted institutional and training framework** might be a key to a faster revival and update of those approaches.

3.3 Existing craftsmanship of bioclimatic constructions and use of local materials

Europe and Africa have a **long history of bioclimatic constructions** and use of local materials, with an accumulated experience of thousands of years. However, in the last decades, a noticeable switch to construction disconnected from the surrounding climate occurred globally. This has led to a loss of expertise in the field, loss of local jobs, increase of greenhouse gases and CO_2 emission, and decrease of the energy efficiency of buildings, which public authorities are trying to cure by the introduction and tightening of building codes.

The ABC 21 project gave special interest to design strategies that involve local bioclimatic approaches, reduce energy consumption during material manufacturing, building construction and energy use during operation. As stated before, inspiring solutions already exist and just need to be revealed, protected, disseminated, and adapted to other regions. Therefore, **the aim of the project was to give more visibility to manufacturers and designers of bioclimatic constructions and local materials in Africa and Europe**.

First, a brief **overview of ecological materials** was compiled. These materials can be classified according to their origin into three classes: materials from geological origins, from vegetal origin and from animal origins. Examples of these are adobe bricks (mudbricks), earth plaster, rammed earth, compressed earth blocks, natural stones/rocks, cob-straw, bamboo, hempcrete, papercrete, and wool.

Some locally available materials offer low thermal conductivity, as straw, typha, wool, hempcrete, while the soil-based materials are serving as structural elements of construction till a certain height and as finishing materials. Tests are performed to ascertain thermal and mechanical properties, and guide improvements in the selection of raw materials and their treatment. Certification procedures should be reinforced in order to deliver additional reliability and allow more actors of construction to confidently adopt those materials. The African Bank states that the use of local materials, with their lower cost and reliance on local manpower would be beneficial to economy and State budgets, compared to imported materials.

Secondly, we performed a **screening of the existing infrastructure to produce construction materials and buildings in N-W Africa and EU** and compiled a list of manufacturers. The focus was on reviewing the size and typology of construction companies in Africa and EU specialized on materials with low embedded energy and locally produced.

The activities of production of bio and geo-based construction materials were presented as:

- A non-exhaustive list of manufacturers from Africa.
- A non-exhaustive list of manufacturers from the EU.

Provided information also includes:

- Contact.
- Exact type of activity, products, and services.

- Examples of buildings constructed with local materials.

Ultimately, **a wide variety of materials adapted to specific climatic conditions can be used to promote low-impact construction**. Most activities in Africa are informal, of small size, and many of them are not legally registered. In general, the number of activities involving large volumes are limited; infrastructure is still too weak to support a global change. The conclusion is that great effort must be made to continue the improvement of manufacture and certification of bio- and geo-based construction materials to meet the demands of the 21st century and to include them in formally accepted construction processes and codes, at the same time promoting the continuation of small-scale construction based on traditional experience and supported by modern building physics knowledge. This **opens opportunities for research, creativity,and new start-ups.** Figure 2 and Figure 3 show interesting geo-sourced materials and designs that meet the lifestyle and comfort of the 21st century

Figure 2 : Compressed earth blocks (CEBs) come in dozens of shapes. Source: http://www.naturalbuildingblog.com/more-info-on-compressed-earth-blocks-cebs/

Figure 3: A hotel, built with Compressed Earth Blocks, in Senegal. Source: http://www.elementerre-sarl.com/realisations/

Furthermore, the potential of different **bio- and geo-sourced materials as construction materials** in Europe and Africa was examined.

Earth and clay-based materials were assessed in terms of their mechanical, physicochemical, and thermal performances. Earth/clay-based building materials have relatively low mechanical strengths, with a compressive strength in the range of 1 to 6 MPa, and thermal conductivity that for some materials is less than 1 W/m·K. Earth and clay-based materials can be used in different building applications such as rammed earth constructions, earth bags, traditional and modern bricks etc.

Obtained results confirmed that **stone-based materials** are characterized by their high mechanical resistance properties. The conducted experiments gave results in the range of 25 to100 MPa, 3 to10 MPa, and 3,15 to 13 MPa for compressive, flexural, and tensile strengths, respectively.

Plant based materials like straw, typha, hempcrete and cork-based building materials can have a lightweight structure with a recorded density less than 0,95 g/cm^3, making them good insulating materials due to their low thermal conductivity. Following the same trend line, wood and bamboo materials also show strong mechanical threshold in terms of flexural, compressive, and tensile strength, as well as bending threshold. Wood and bamboo can be treated to increase the durability and resistance to degradation by insects or fungi, and in turn reduce the overall use of these resources by prolonging the life of manufactured elements and reducing the need for replacement.

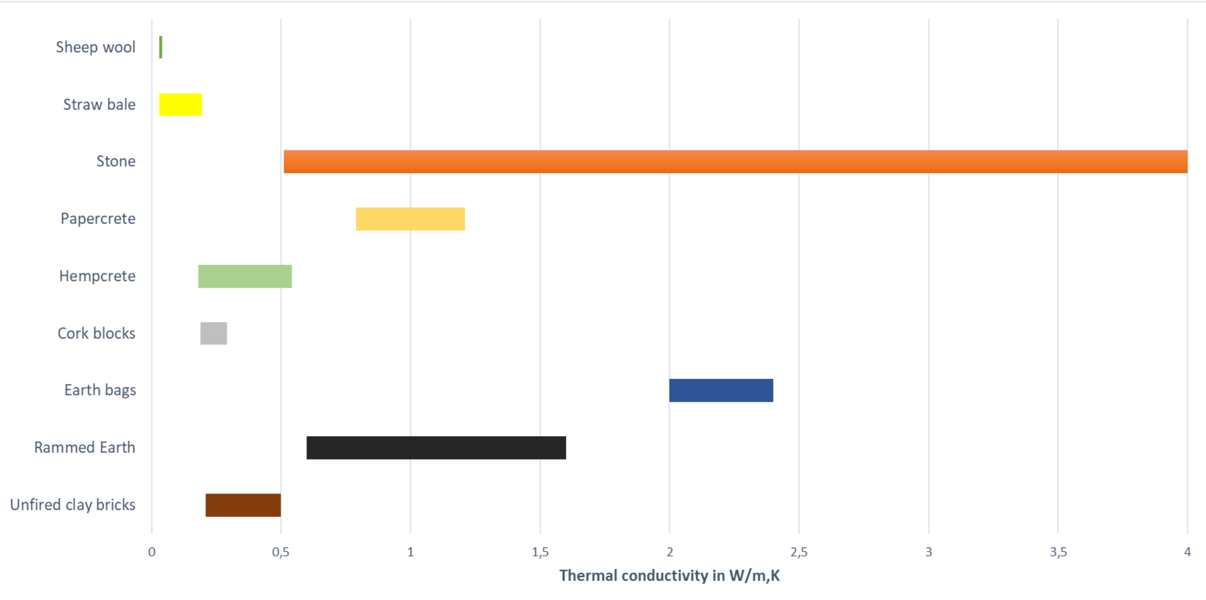


Figure 4: Thermal conductivity of examined materials (ABC 21)

Compressive strength is among the most important mechanical property in earth-based materials. Figure 5 shows a comparison of the compressive strength of different bio- and geo-sourced materials.

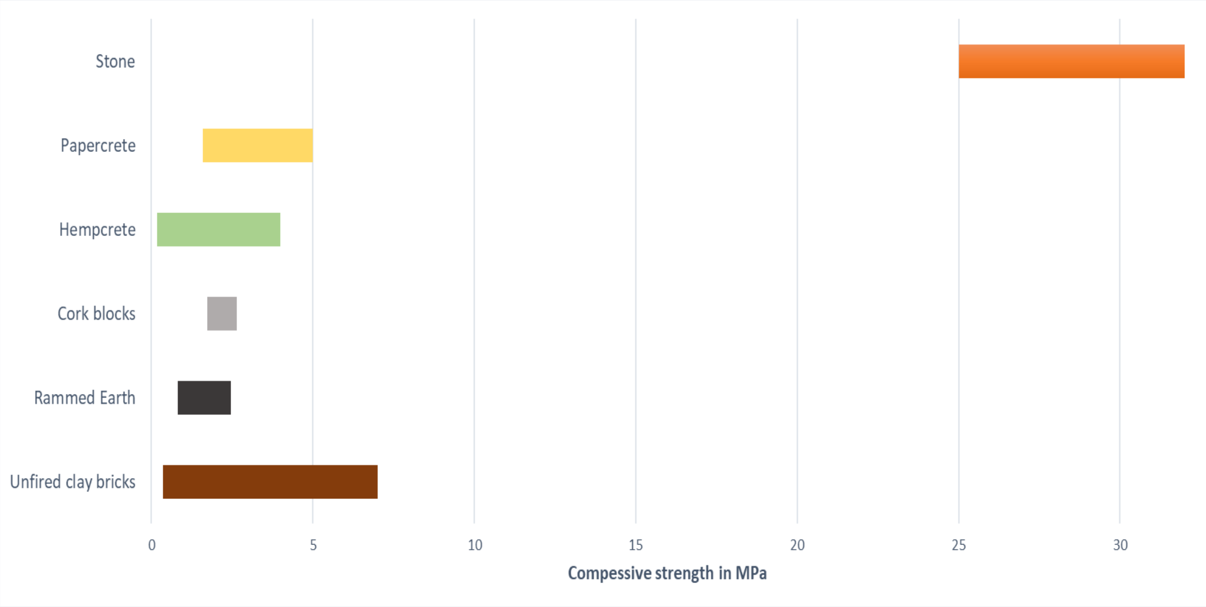


Figure 5: Compressive strength of different bio- and geo-based materials (ABC 21)

3.4 Policies supporting passive and bioclimatic approach, and development of local materials and production chains.

The project reviewed some successful or promising policies which might be effective in promoting highly comfortable buildings with minimal ***energy need for heating and cooling***, ***total primary energy*** use, and ***non-renewable primary energy*** use, with a particular focus on summer comfort and cooling dominated climates. At the same time, we also considered policies and institutional frameworks for the promotion of the use of local, low impact materials. The focus of the analysis has been methodological: the aim was to highlight some key points which might be useful in developing or assessing policies.

Some national implementations of the European Energy Performance of Buildings Directive (EPBD) were analysed according to a set of criteria, e.g.

- Uniformity in definition of overall building performance when expressed in terms of ***energy needs***, ***delivered energy***, ***total or non-renewable primary energy***, as univocally defined in EN-ISO 52000 – 2017.
- Explicit choice of a comfort model which might favor the use of the bioclimatic approach, with reference to the most recent standards e.g., ASHRAE 55-2020.
- Use of a physical energy balance (on a short interval time basis, such as a day or hour) rather than a nominal net zero balance over a year.

Europe (as the rest of Global North) has developed standardised building archetypes relying heavily on materials of high embodied energy (concrete, steel, glass) and raw materials which are getting scarce. We reviewed some experience and policies applied in Africa for qualifying and supporting bio- and geo- locally sourced materials.

For both continents, policies to support bioclimatic architecture under the XXI Century conditions will likely have to go beyond the building itself and involve district and city levels. Within the future climate, which will bring longer and longer periods of high temperature in summer, exacerbating the heat island effect in cities, efficient design and operation of buildings will be strongly connected with enabling/hindering conditions in cities. We presented a matrix of interaction of policies aimed respectively at building and district level with a view of highlighting the necessary synergies.

As for financing economic incentives and support programs, we discussed:

- ways to finance: via debt or general taxation versus via a levy on energy carriers, with their respective implications on state budget and stability of industrial policy over time
- ways to establish a priority of investments with a focus on reduction of risks and reduction of long-term costs (full consideration of environmental and social externalities, use of forward-looking indicators such as internal rate of return, cost of conserved energy, interest rate from the society perspective…, rather than of short term indicators as payback-time, marginal cost, interest rate from the private perspective…).

4. A common language for characterizing bioclimatic buildings.

4.1 Performance indicators for energy, demand flexibility and comfort

All the actors involved in the building sector, from designers to contractors, from regulators to policymakers **should use consistently the same set of physical concepts, definitions, nomenclature**.

This would ensure better results in terms of comfort levels and energy use and would be a prerequisite for devising clear design and construction guidelines allowing to obtain performance at a reduced cost.

Importantly, it will also reduce the costs involved in communication difficulties and misunderstandings leading to design and construction errors and subsequent costly remediation work.

Limitations arise from a non-uniformity in the definition of overall building performance in terms of ***energy needs***, ***delivered energy***, ***total or non-renewable primary energy***, and non-uniformity of nomenclature across countries, which creates a barrier to effective communication and comparability of performances of design approaches and techniques.

Three documents have been developed to offer a selection of the main concepts, definitions, and terminology regarding ***energy***, ***comfort***, and ***flexibility of demand*** over time. They are mostly taken from European and International standards to create a common framework as a necessary basis for effective design work, and its communication. Definitions and nomenclature can be found online at the ISO database of "terms and definitions" [17], see Figure 6 for an example.

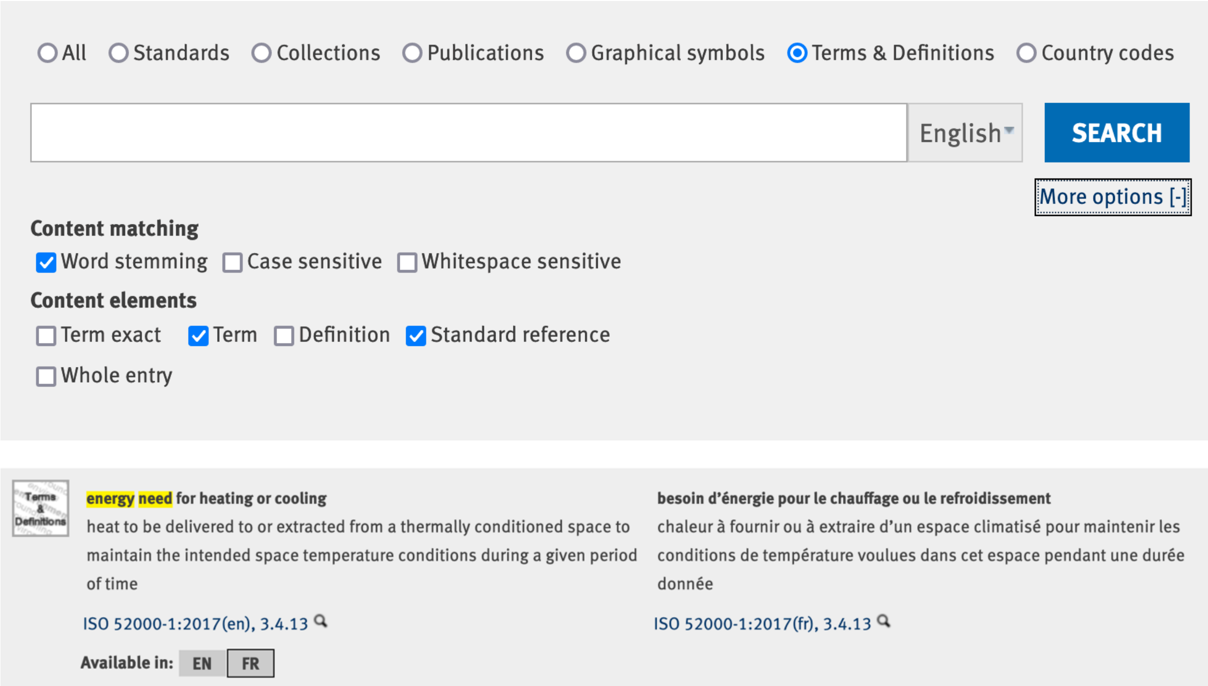


Figure 6: an example from the ISO database of "terms and definitions".

In addition, to support and simplify the identification of the energy levels in a sound manner, some visual representations have been provided in the ABC21 "Report on indicators of overall building energy performance" (see example in Figure 7).

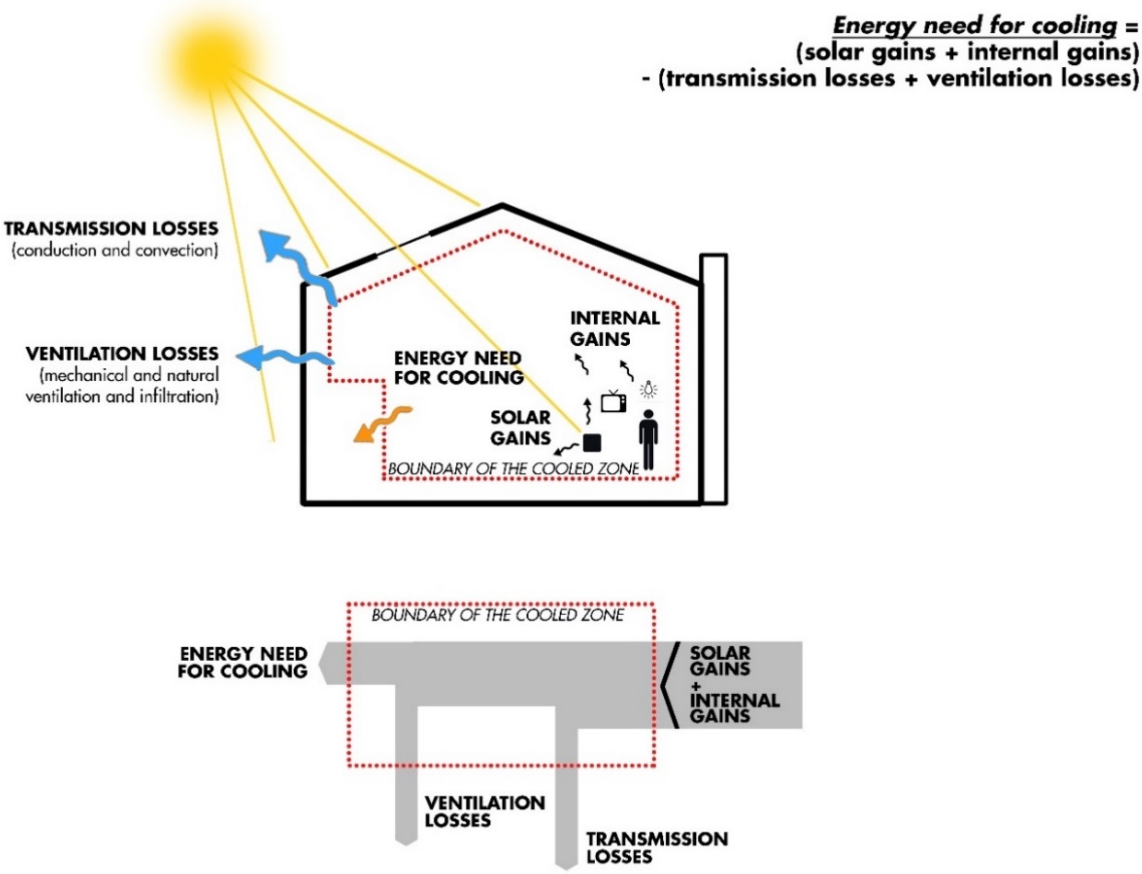


Figure 7: representation of "*energy need for cooling*" (Erba S., Pagliano L. 2021. ABC 21 project)

Quantifying building energy performance through the development and use of **Key Performance Indicators (KPIs)** is an essential step in achieving energy saving goals in both new and existing buildings. A set of energy KPIs has been analyzed to characterize high energy performance buildings, whose very low amount of ***energy needs*** are mainly covered by energy from renewable sources. A selection of the following indicators has been used to assess and compare the case studies selected in ABC 21 (see Examples of African and European bioclimatic buildings, chapter 5).

- Energy, focus on quality of the building fabric
  1. ***Energy needs for heating*** [kWh/(m^2 · y)]
  2. ***Energy needs for cooling*** [kWh/(m^2 · y)]
  3. Optional: ***Energy use for lighting*** [kWh/(m^2 · y)]
  4. Optional: Air tightness (ACH at 50 Pa difference or equivalent)
- Energy, focus on users' behaviour, and appliances
  1. ***Energy needs for sanitary hot water*** [kWh/(m^2 · y)]
  2. Total internal gains [kWh/(m^2 · y)]
- Total primary energy, focus on building fabric + systems
  1. ***Total primary energy*** use [kWh/(m^2 · y)]
  2. Provide values for present national ***primary energy factors*** – PEF (3 values for each flow of delivered energy: total, renewable, non-renewable)
  3. For renewable PEF distinguish between energy imported from the grid, self-consumed, or exported to the grid
- Renewable energy: on-site generation, export, and import
  1. ***Renewable primary energy*** generated on-site [kWh/(m^2 · y)]
  2. Renewable primary energy generated on-site and Self-consumed [kWh/(m^2 · y)]
  3. Renewable primary energy exported to the grid [kWh/(m^2 · y)]
- Non-renewable primary energy, or global primary energy balance
  1. ***Non-renewable primary energy*** use without compensation for exported energy [kWh/(m^2 · y)]
  2. Non-renewable primary energy use with 100% compensation for exported energy (consumption minus on-site generation in [kWh/(m^2 · y)]
  3. Renewable primary energy use considering the 100% renewable scenario [kWh/(m^2 · y)]. In this case it coincides with total primary energy use
  4. Ratio of renewable primary energy over the total primary energy use (with and without compensation) (%)

A list of **Key Performance Indicators (KPIs)** has been proposed in one of the ABC21 reports to determine thermal comfort, visual comfort, acoustic comfort, and indoor air quality in a standardised, comparable way. They have been used in the template for description of the case studies. Raw data and KPI values have been taken from existing documentation, when available, or monitored during the ABC21 study. For each specific case study, the most appropriate indicators have been selected from these lists in relation to the available-in-literature or measured or simulated data.

- **Thermal comfort indicators**
    1. Percentage of time outside an operative temperature range (Adaptive comfort model)
    2. Percentage of time outside an operative temperature range (Fanger PMV comfort model)
    3. Degree-hours (Adaptive comfort model)
    4. Degree-hours (Fanger comfort model)
    5. Percentage of time inside the Givoni comfort zone (with air velocity at 1 m/s)
    6. Percentage of time inside the Givoni comfort zone (with air velocity at 0 m/s)
    7. Number of hours within a certain temperature range
- **Acoustic comfort indicators**
    1. Airborne sound insulation
    2. Equivalent continuous sound level
    3. HVAC noise level
    4. Reverberation time
    5. Masking/barriers
- **Visual comfort indicator**
    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

Finally, ABC 21 addressed the concept of ***flexible building*** though a critical review of the main methodologies, definitions, and indicators available in literature and international standards (not yet easily accessible and familiar to those outside academia).

Indicators available in the literature can be grouped according to three types of metrics:

- the **quantity of energy** use that can be **shifted**.
- the temporal flexibility, i.e., **for how long time** the energy use can be **shifted**.
- the **cost or value** of utilizing this time-flexibility.

The **European Smart Readiness Indicator (SRI)** includes the notion of flexibility, but mainly considered as a result of controls on active systems. Mobile elements of the envelope are also considered, but **flexibility of energy use due to geometry, mass, night ventilation is not properly included.**

Improvements in this area are underway in other H2020 projects (e.g.: SATO) and research programs [18].

It is worth highlighting that the literature analysis has shown a lack of insights into indicators and examples of application related to cooling dominated climates.

4.2 Indicators and weather files for future climate

In a context of accelerated global warming, there is an **increased need to consider future weather data in the building design phase**. Ideally, this data must be available in two forms: **simplified weather indicators** and **detailed hourly weather files**. Those forms are crucial inputs for the early and late stages of modern building design processes.

Weather files can provide a comprehensive characterization of the local climate by including meteorological and solar radiation data elements (such as, dry-bulb outdoor air temperature, relative humidity, global horizontal irradiance, cloud coverage, wind speed and its direction, …). Building thermal simulation needs one year of hourly weather data for the building location. Weather data can have different formats and elements, a common one being the Typical Meteorological Year (TMY). TMY datasets/files are made of twelve representative months from 30 years of weather data for a specific location. The selection of these months is based on a statistical analysis of nine variables and their weighting factors. The goal is to identify 12 representative months and create a realistic annual weather file.

Weather file providers can collect data directly from weather stations or from satellites. The interpolated data has more uncertainty because it uses spatial interpolation models. Among the **nine weather databases** reviewed in ABC 21, **only four were open access** and only one (Climate One Building) had current weather data for all the locations in Africa and Europe in this project.

The open access weather databases do not provide files representing future climate. To generate future weather files, the morphing method is often used. It modifies the historical weather data (usually from a TMY file) by using predicted future monthly changes from Global Climate Models (GCMs) and Regional Climate Models (RCMs). The morphing method can show average weather changes, but not future weather patterns and extremes. The CCWorldWeatherGen tool is a simple way to produce future weather files using the **morphing method**. It needs a current climate file and **climate change factors from a climate model**. These factors must match the historical base climate of the historical weather file, for the procedure to be applicable. The climate change factors in the CCWorldWeatherGen tool are based on the IPCC projections for three periods: 2020, 2050 and 2080, with a baseline climate between 1961-1990.

The climate change projections are categorized according to the emission and concentration scenarios used to represent the 21st century. These scenarios are known as Representative Concentration Pathways (RCPs) and are based on assumptions about socio-economic, technological, energy, land use and cover, emissions of GHG and air pollutant. There are four RCPs corresponding to four levels of radiative forcing for the year 2100: 8,5 W/m^2, 6 W/m^2, 4,5 W/m^2 and 2,6 W/m^2. Considering the growing effects of climate change and the difficulties in emission reduction, the RCP 8.5 is often used in long-term climate change impact studies. In this way, RCP8.5 was the scenario considered in the **ABC21 project to produce the future weather files for the two future climate periods considered (2040-2060 and 2080-2100) and for all the case study sites proposed by the ABC21 project**, see map in Figure 8.

The future climate files developed in ABC 21 are available on the project website and can be accessed via the following link:

https://www.abc21.eu/weather-files-for-future-climate/

Figure 8: Locations for which future weather files have been produced (Google map adapted by ABC 21)

Weather indicators can be useful to predict the impact of climate change in building design in general, and in bioclimatic/passive buildings where a careful rational interaction with the climate is by definition the objective. ABC 21 reviewed the definitions of heating and cooling degree-days as weather indicators (that are usually used for estimation of building energy needs and weather classification) and presented the **bioclimatic indicators** that assess the natural ventilation (NV) cooling potential and the availability of weather indicators data.

In the building energy analysis area, degree-days (DD) are a metric used to express how harsh is the climate during the heating period (**heating degree-days, HDD**) or cooling period (**cooling degree-days, CDD**). The degree-days are defined as the cumulated difference between a base temperature and the outdoor air temperature. There are several methods to calculate the HDD and CDD, such as the mean daily degree-day, the mean daily outdoor air temperature, and the residual cooling degree-days, in general with different base temperatures for HDD and CDD. Even for the same DD method, several base temperatures were already proposed (with large differences between them), indicating that there is no consensus in the scientific community for a universal base temperature for each method. This implies that, in many cases, HDD or CDD values cannot be directly compared, and attention must be given to ensure that comparisons are only made with equal base temperatures.

The development of higher air temperatures and longer heat waves in the future, might lead to higher energy needs for cooling in both commercial and residential buildings, with consequent efforts for adaptation, negative feedback on mitigation efforts and costs, risks of "cooling poverty".

To prevent/contain this increase, building designers are encouraged to use ***bioclimatic*** design and ***passive systems*** through a local-optimized selection and mix among solar shading, external insulation, exposed thermal mass in climates with high day-night temperature excursion, ***comfort ventilation***, ***nocturnal ventilative cooling,*** exchange with the ground, evaporative cooling, radiation to the sky…These strategies have in common their search for synergy with local climate and the use of natural heat sinks as a source of free or low energy cooling.

As for the effects of ventilation, to assess the cooling capacity in a certain climate, **passive cooling indicators** were proposed, such as the **climate cooling potential, the natural ventilation hour,** the **climate potential for natural ventilation,** and **the suitability of air temperature for natural ventilation.**

The **climate cooling potential (CCP)** indicator is the average of the hourly indoor and outdoor temperature differences at night, when those differences are higher than 3º C. This indicator is based on the concept of degree-days and considers that the base temperature corresponds to the comfort building temperature and has a sinusoidal oscillation during the year. The CCP can show the effect of climate change on passive cooling systems, but it has some limitations, such as: ignoring the wind effect on natural ventilation; assuming that ventilation only happens by stack effect and at night.

The **natural ventilation hour (NV hour)** is the number of hours in a year when the outdoor weather is favorable for passive cooling via ventilation. The NV hour checks if the outdoor temperature and air velocity are within certain limits. The NV hour has some drawbacks, such as: not avoiding saturated air from humidity control; ignoring the vertical difference in wind speed; and not separating passive cooling for day and night.

The **climatic potential for NV (CPNV)** is similar to the NV hour, but it defines comfort differently. The CPNV allows natural ventilation if the outdoor temperature and humidity are within certain ranges, and it does not consider how wind affects indoor air speed during natural ventilation. The CPNV counts both daytime natural ventilation (when occupied) and night cooling (when unoccupied), with different lower limits for each.

The **suitability of air temperature for NV (SNV)** indicator assumes that NV can be used when the outdoor temperature is between 10º C and 26º C. This range is split into two parts: between 10º C and 16º C, outdoor air can improve indoor air quality; between 16º C and 26º C, ventilation can remove heat and increase or maintain thermal comfort. This indicator is simpler than the others and easy to apply. However, it does not consider night cooling, humidity limitations or wind effect.

A free tool is available from the Center for the Built Environment (https://clima.cbe.berkeley.edu/). Given a weather data file, it visualizes the hours when outdoor air temperature is within a chosen interval suitable for natural ventilation and allows excluding hours when dew point temperature of the outdoor air is below the temperature of cooling surfaces, e.g. the temperature of a radiant floor.

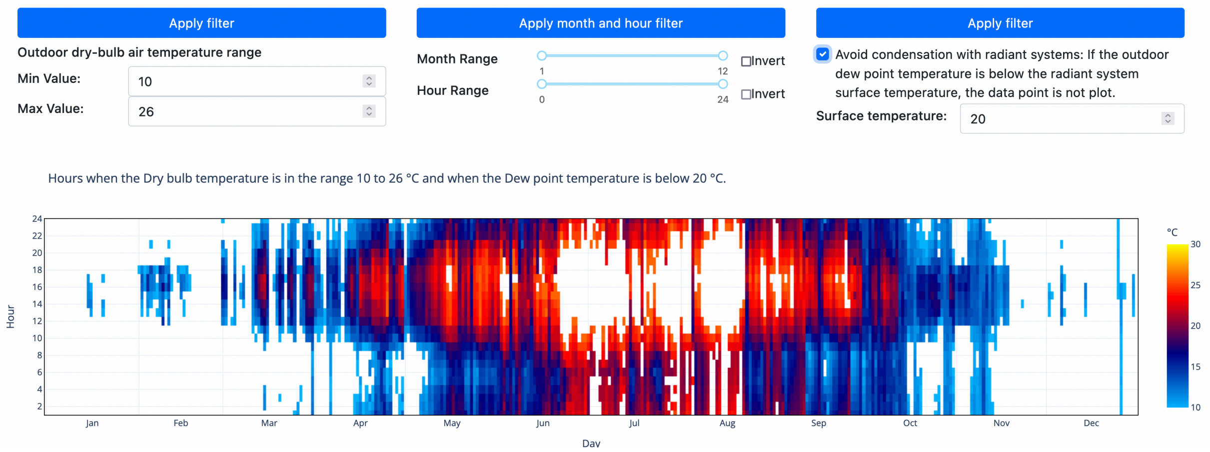


Figure 9: visualisation of the hours in principle suitable for natural ventilation (in case heat needs to be exported out of the building, e.g due to internal or solar gains), excluding hours when condensation might happen on radiant surfaces. Case of Milano (https://clima.cbe.berkeley.edu/).

4.3 Measurements

The literature analysis has highlighted the limited availability of measured physical data as well as occupant's feedback in buildings in Africa, and, to a lower extent, in Europe. In particular, this has been underlined in the ASHRAE Global Thermal comfort Database II, which offers a total of about 2 000 data collected in African buildings, compared e.g., to more than 31 000 data from the European ones. The African field studies available in the ASHRAE database are from Nigeria and Tunisia.

Consequently, the ABC 21 project has put efforts not only in collecting existing data but also in generating new ones by realizing measurement campaigns and post occupancy evaluations (where possible) in a subset of the case studies. In these buildings we monitored for some weeks/months the main variables influencing indoor thermal comfort (air temperature, mean radiant temperature, air velocity and, to a minor extent, relative humidity). We note that **air velocity** is an essential element of comfort in bioclimatic buildings, where comfort ventilation and nocturnal ventilative cooling are among the main passive strategies. **Hot sphere anemometers** have been used since they are sensitive to air velocity from all directions and are more robust compared to the more common hot wire anemometers. Also, some weather stations have been installed through a collaboration with the TAHMO, the **Trans-African Hydro-Meteorological Observatory** which is developing a vast network of weather stations across Africa which are **particularly robust** versus harsh climate, insects' intrusion, … and able to communicate data via radio to a central server.

The procedure to conduct thermal comfort assessments in bioclimatic buildings should include:

1. Standardised Objective methods based on physical measurements.
2. Standardised Subjective methods based on occupants' surveys to investigate their satisfaction with the indoor environment.

Measurements campaign of physical parameters

Three distinct levels of monitoring activities are suggested by the ABC21 project, (the measurements should last at least 2 to 3 months during the hottest period) in relation to the availability of resources:

- The first level is a basic monitoring level with sensors capable of measuring the **air temperature** and **relative humidity** (RH) in selected spaces inside the building. Outdoor conditions are limited to air temperature and RH measured with the same kind of sensors 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** must measure at least global horizontal solar irradiance, wind speed and wind direction, air temperature, and relative humidity.
- The third one is a more detailed monitoring with, in addition to level 2, the measurement of all indoor thermal environment parameters (i.e., the **air temperature**, the **air velocity**, the **operative temperature** - via the **black globe temperature** and air velocity - and the **relative humidity**), in parallel with interviews of occupants.

Following the standard EN ISO 7726, specific recommendations regarding the most appropriate position of the sensors, the time span and installation tips were drawn up.

Occupants' surveys

To collect a comprehensive set of information from the occupants of the buildings it is recommended to use here-and-now surveys and general long-term satisfaction surveys.

Spot (here-and-now) ***surveys*** are short questionnaires with the objective to receive feedback from the occupant **right at the moment** when the survey is answered. These types of questionnaires are correlated **with simultaneous measurements of the indoor environmental variables**, (i.e. the air temperature, the air velocity, the operative temperature - via the black globe temperature and air velocity - and the relative humidity). 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). Spot questionnaires have been developed according to the standard ISO 10551, which describes the various judgements which are recommended for an assessment of comfort or stress based on subjective data.

It is also important to include questions for collecting information about the **activities performed** and the **garments worn,** to assess the corresponding metabolic rate and the insulation values of garments, respectively. Finally, it is recommended to collect information about the **status of the controls** (e.g., if the door is open or closed, if the windows are open or close, fans are active or not, ...).

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.

The ***general satisfaction surveys*** have the objective of tracking the general evaluation of the indoor environment by the occupant over a relatively long-time frame. Simultaneous measurements of physical parameters are not required. They should be conducted in the same year as measurement and done by a substantial number of occupants. The survey must be conducted at least one year after the building is fully occupied and, if possible, two times a year in different seasons (e.g. hot season/cold season)

5. Examples of African and European bioclimatic buildings

To provide **inspiring examples of European and African Bioclimatic buildings**, 24 case studies were selected and analyzed in ABC 21. They were selected for their ability to exemplify the goals:

- **Bioclimatic design**
- **Passive strategies,**
- **Energy efficient active systems,**
- **Daylighting,**
- **Suitability to specific local climate conditions (e.g., stark rains),**
- **Use of local materials, with low embedded energy and sustainable production,**
- **Post Occupancy Evaluation (POE) available or potentially possible.**

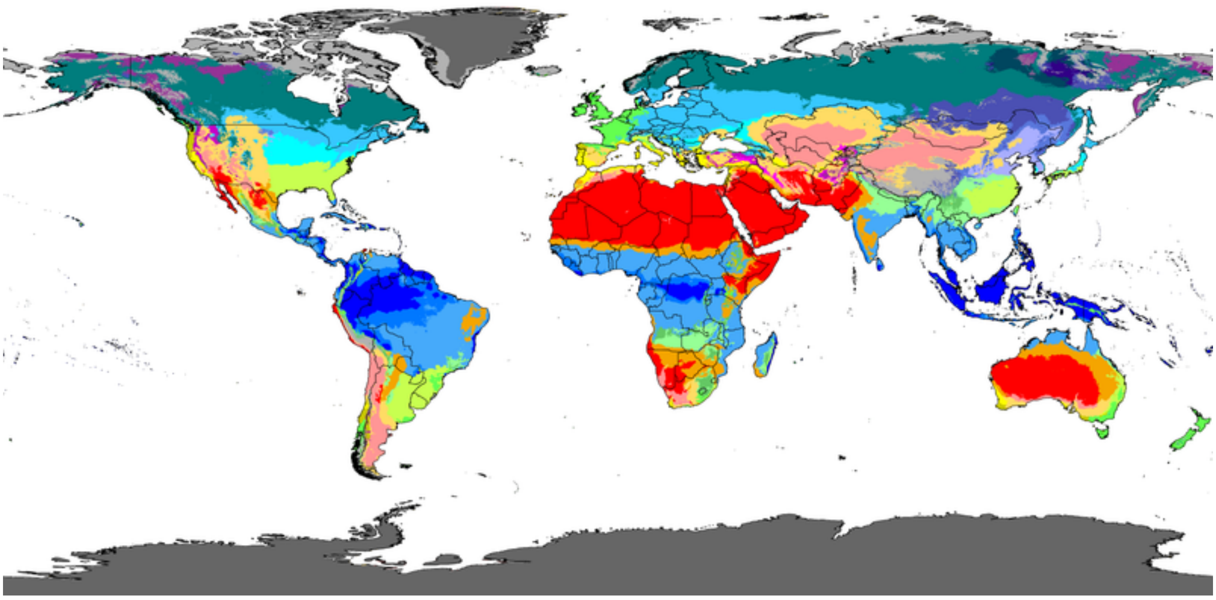
For each case study, a description of environmental data, passive solutions used, POE and user feedback was complied, using a clear-cut reporting format based on the common language and indicators presented in chapter 5.

Initially, a collection of measured data from previous measurement and assessment campaigns or – in a selection of cases – with measurement and assessment performed within ABC 21 was planned. During the research, it emerged that there is very little information available on indoor comfort in buildings in Africa and not much on bioclimatic buildings in Europe either. To support the uptake of bioclimatic buildings by policymaking, building industry and private and public clients, there is a strong need to provide objective data on their performance. Therefore, the project also conducted a **monitoring campaign** in a subset of the case studies (for methodology see chapter 4.3).

In the following pages, all 24 case studies are listed with their summary description. For detailed information, see https://www.abc21.eu/publications/ . On the ABC21 project website, an online map allows locating the case studies and to have access to the description of each building.

Table 3: Köppen classification symbols. Source : Wikipedia

1st	2nd	3rd
A (Tropical)	f (Rainforest) m (Monsoon) w (Savanna, dry winter) s (Savanna, dry summer)	
B (Dry)	W (Arid Desert) S (Semi-Arid or steppe)	h (Hot) k (Cold)
C (Temperate)	w (Dry winter) f (No dry season) s (Dry summer)	a (Hot summer) b (Warm summer) c (Cold summer)
D (Continental)	w (Dry winter) f (No dry season) s (Dry summer)	a (Hot summer) b (Warm summer) c (Cold summer) d (Very cold winter)
E (Polar)		T (Tundra) F (Ice cap)

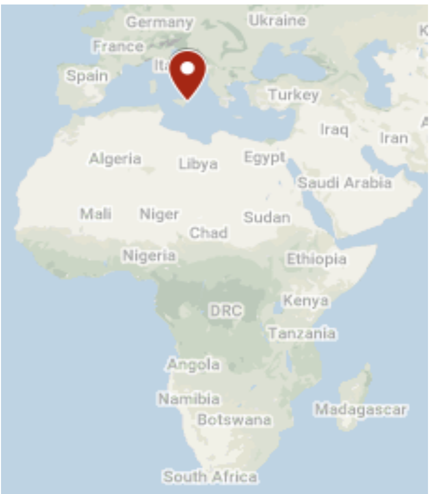


Legend of the Köppen–Geiger climate classification [view | edit]

A	B	C			D			E
Af Am	BWh BWk	Csa	Cwa	Cfa	Dsa Dsb	Dwa Dwb	Dfa Dfb	ET
Aw As	BSh BSk	Csb Csc	Cwb Cwc	Cfb Cfc	Dsc Dsd	Dwc Dwd	Dfc Dfd	EF

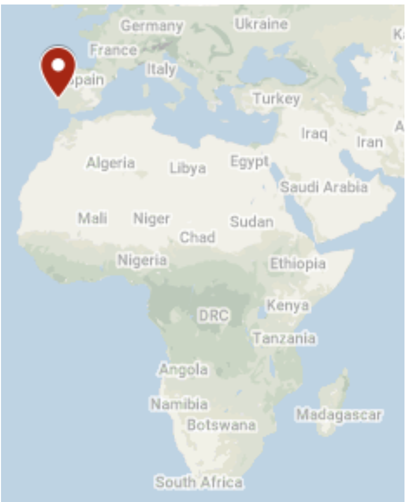
Figure 10: By Beck, H.E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. *Present and future Köppen-Geiger climate classification maps at 1-km resolution*;. Nature Scientific Data. DOI:10.1038/sdata.2018.214., CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=74795121

CASE STUDY 1-01: BOTTICELLI PROJECT | ITALY



Architect / designer	Eng. Carmelo Sapienza of Sapienza & Partners technical firm
Location	37.60422167605705, 15.045983886279847
City	Mascalucia
Country	Italy
Building Type	Residential
Climate zone (Köppen–Geiger classification)	Csa: Temperate, Dry and Hot summer
Description	Botticelli project is a single-story home, composed by a living room (including the kitchen), three bedrooms, a study room and two bathrooms. 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).
Main bioclimatic strategies	Comfort ventilation (by cross ventilation), Nocturnal ventilative cooling, Earth-to-Air Heat Exchangers, Reversible heat pump, High thermal mass (multilayer wall), Exterior insulation finishing system, Motorized solar shading system, PV system, Solar thermal collectors, High soil permeability, Rainwater collection & water reuse.

CASE STUDY 1-02: CML KINDERGARTEN| PORTUGAL

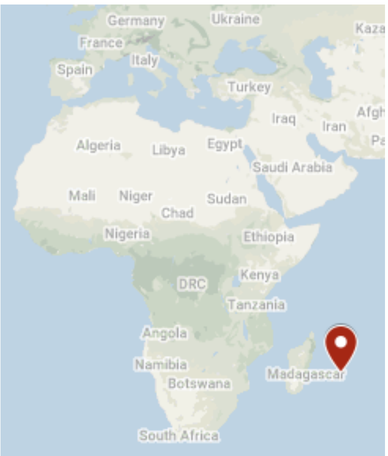


Architect / designer	Appleton & Domingos, Arquitetos
Location	38.74359816203614, -9.131250349942396
City	Lisbon
Country	Portugal
Building Type	Educational
Climate zone	Csa: Temperate, Dry and Hot summer
Description	The CML kindergarten, constructed in 2013, is a small two-story building with a total area of 680 m^2 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.
Main bioclimatic strategies	Natural (stack) ventilation, high exposed thermal mass, daylighting with skylights, passive and active solar shading, acoustic insulation, solar thermal energy.

CASE STUDY 1-03: IZUBA ENERGIES BUILDING | FRANCE

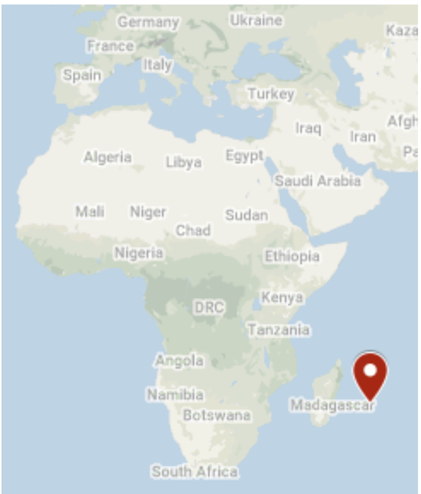
Architect / designer	RIGASSI et Associés Architectes
Location	43.56050216309316, 3.7915132981980086
City	Fabrègues
Country	France
Building Type	Offices
Climate zone (Köppen–Geiger classification)	Csa: Temperate, Dry and Hot summer
Description	Izuba Energies Building is an office building located in France, more precisely near Montpellier, in the Fabrègues Ecoparc. The building construction is based on a bioclimatic architectural conception, using 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** - see https://fulfill-sufficiency.eu/ for a definition -, efficiency, and renewable energies). This includes, *inter alia*,: hygrothermal comfort, low impact components, user behaviour, waste management, indoor air quality, etc.
Main bioclimatic strategies	Nocturnal ventilative cooling, Thermal inertia, High level of insulation of the walls and the roof, Wood timber structure, Fixed and mobile solar protection, Geothermal heat pump, Floor cooling, Fan coil, Natural daylighting, PV system, Use of local materials (mudbrick wall, straw), Mediterranean plants.

CASE STUDY 1-04: NIAMA | LA REUNION



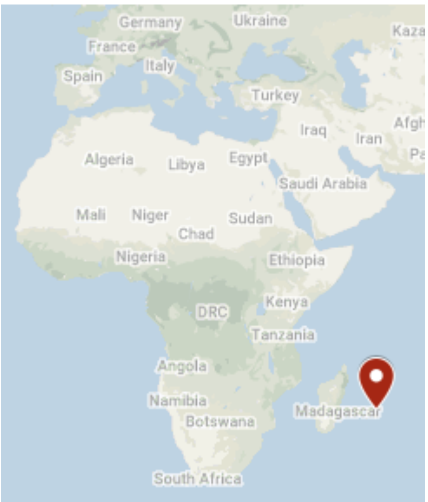
Architect / designer	Co-Architectes
Location	-21.337417747378176, 55.46382756587495
City	Saint-Pierre
Country	La Reunion, France
Building Type	Residential
Climate zone	Aw: Tropical, Savanna, dry winter
Description	Located in the eco-neighbourhood of 'Ravine Blanche,' in Saint-Pierre, La Réunion, 'Niama' 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 RTAADOM). 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 to enhance thermal comfort while reducing energy consumption.
Main bioclimatic strategies	Cross ventilation, Louvered shutters, high porosity of the facades, fixed vertical and horizontal solar shading, sun and rain protected exterior veranda, low solar absorptivity materials, highly efficient ceiling fans, domestic hot water, native plants.

CASE STUDY 1-05: ENERPOS | LA REUNION



Architect / designer	Thierry Faessel-Bohe
Location	-21.34080841368781, 55.491067294562335
City	Saint-Pierre
Country	La Reunion, France
Building Type	Educational
Climate zone	Aw: Tropical, Savanna, dry winter
Description	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 and one of the few in a tropical climate. 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.
Main bioclimatic strategies	Cross natural ventilation (exterior & indoor glass louvers), Fixed solar shading (horizontal wooden strips), Ventilated double roof, Insulation of exterior walls and roof, BIPV roof, daylighting.

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



Architect / designer	Olivier Brabant
Location	-20.902046923902343, 55.485358557421655
City	Saint-Denis
Country	La Reunion, France
Building Type	Educational
Climate zone	Af: Tropical, Rainforest
Description	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 also function as shading devices.
Main bioclimatic strategies	Cross ventilation, comfort ventilation, side louvers, low pressure shaft, passive solar protection with large overhangs, wooden structure, walls and roof insulation, native plants, PV car parks.

CASE STUDY 1-07: MAISON DES ENERGIES | SENEGAL

Architect / designer	Mathieu Hardy
Location	15.3726727929116, -13.12709036192232
City	Matam
Country	Senegal
Building Type	Residential & Offices
Climate zone (Köppen–Geiger classification)	BWh: Dry, Arid Desert, Hot
Description	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. This house was designed in such a way as to be able to respect key principles of bioclimatic architecture, such as the use of natural ventilation. In addition, its Nubian-vaulted technical concept does not require the use of increasingly rare timber beams or imported metal sheets, with benefits to Africa's economic and environmental problems, while offering comfort to its users.
Main bioclimatic strategies	Cross ventilation (shutter doors and louvered shutter systems with adjustable slats), Traditional structure in adobe banco, locally used Mud Bricks, Ceiling fans, Vegetation, "Voute Nubienne" Concept.

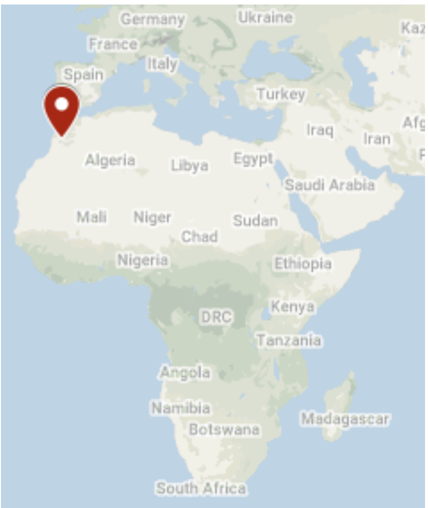
CASE STUDY 1-08: UNON OFFICE BUILDING | KENYA

Architect / designer	Beglin Woods Architects
Location	-1.2326008075647548, 36.81796828684429
City	Nairobi
Country	Kenya
Building Type	Offices
Climate zone (Köppen–Geiger classification)	Cfb: Temperate climate, no dry season, warm summer
Description	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 walkways. 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 its 1 200 occupants thanks to 6 000 square meters of solar panels with a total peak power of 550 kWp.
Main bioclimatic strategies	Natural ventilation via stack effect, high thermal capacity walls (stones), high quality solar glass, PV farms on the rooftop of the building, atrium with vegetation, natural daylighting, collection of rainwater, indigenous trees, waste management.

CASE STUDY 1-09: VILLAS DES CHERCHEURS | MOROCCO

Architect / designer	Elie Mouyal
Location	32.214157096376795, -7.935813503615992
City	Ben Guerir
Country	Morocco
Building Type	Residential
Climate zone (Köppen–Geiger classification)	BSh: Semi-arid, Hot
Description	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. The buildings walls are constructed with solid stone locally extracted. External walls and roof are insulated with hempcrete panels. Other bioclimatic concepts are applied.
Main bioclimatic strategies	Traditional Moroccan medina architecture, locally extracted stone, natural ventilation, wind-tower coupled with a pebble foundation, high thermal mass, insulated walls, and roof (hempcrete material).

CASE STUDY 1-10: DAR NASSIM PROJECT | MOROCCO



Architect / designer	Al Omrane Holding
Location	31.6497350, -8.0615803
City	Marrakech
Country	Morocco
Building Type	Residential
Climate zone (Köppen–Geiger classification)	BSh: Semi-arid, Hot
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 conducted 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 conduct an extension by adding a solar hammam and a dining room as well as a bedroom. 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.
Main bioclimatic strategies	Natural ventilation strategy, Nocturnal ventilative cooling, ground coupling on thermal load, Double-glazed windows, Mobile solar shadings, Insulation of walls (air gap) and roof (extruded polystyrene), Solar water heater, PV panels on the roof, high-efficiency LED lighting, Advanced home automation system

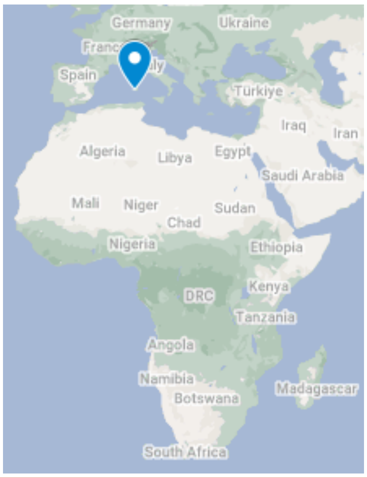
CASE STUDY 1-11: DAR AMYS VILLA | MOROCCO

Architect / designer	Mohamed El Anbassi
Location	31.61685854559842, -8.033311845423265
City	Marrakech
Country	Morocco
Building Type	Residential
Climate zone (Köppen–Geiger classification)	BSh: Semi-arid, Hot
Description	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 on-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.
Main bioclimatic strategies	Overhangs, thermal insulation of the roof and external walls, Earth-to-Air Heat Exchanger (EAHE), water &waste management, solar water heater

CASE STUDY 1-12: SALAM CARDIAC SURGERY CENTRE | SUDAN

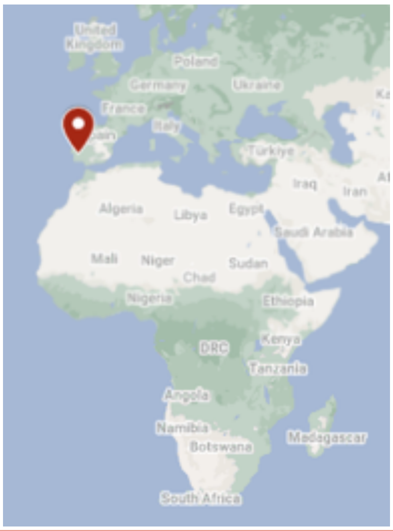
Architect / designer	Studio Tamassociati
Location	15.509919818764784, 32.66305412641556
City	Khartoum
Country	Sudan
Building Type	Health Facility
Climate zone	BWh: Dry, Arid Desert, Hot
Description	The Salam Cardiac Surgery Center is located in Soba Hill, 18 km from the city of Khartoum, in Sudan. It 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. The design of the SALAM cardiac surgery centre followed three main guiding principles: the idea of a “hollow” space and a pavilion-based system, the choice of the best possible technology given the context as well as the search for an ethical language for this type of architecture.
Main bioclimatic strategies	Mixed modes of ventilation and space conditioning (cross ventilation & air conditioning), Shaded waiting areas and paths, Bamboo sun baffle, insulated wall (2 layers of bricks separated by an insulating air cavity), Ventilated metal roof, Series of tunnels (labyrinth like structure) to filter the large quantities of dust and sand in the air, solar collectors, PV-farm, shrubs, and trees.

CASE STUDY 2-01: PATIO HOUSE | ITALY



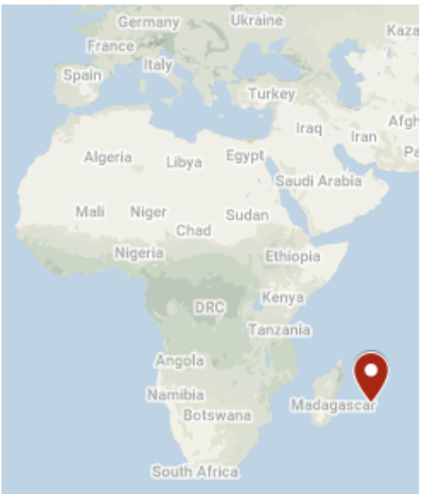
Architect / designer	Michele Ricci, Giovanna Nardini
Location	39.217703, 8.374674
City	Portoscuso (Carbonia Iglesias), Sardinia
Country	Italy
Building Type	Residential
Climate zone (Köppen–Geiger classification)	Csa: Temperate, Dry and Hot summer
Description	The project stems from the desire to create a sustainable and innovative building, in energy class A+ suitable for the Sardinian Mediterranean climate, made with natural materials: 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 in 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.
Main bioclimatic strategies	Comfort ventilation and nocturnal ventilative cooling High level of insulation (walls with straw bales) Inner courtyard (to be shaded, presently too warm) Efficient (but to be completed) solar protection – porch and pergolas

CASE STUDY 2-02: RUINHA HOUSE | PORTUGAL



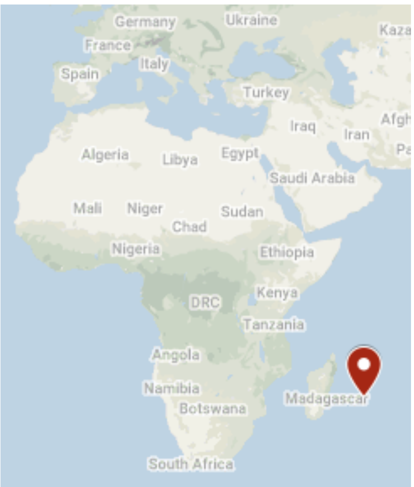
Architect / designer	Tânia Teixeira/CRU
Location	38.64812, -8.21353
City	Montemor-o-Novo
Country	Portugal
Building Type	Residential
Climate zone (Köppen–Geiger classification)	Cwa: Temperate, Dry winter, Hot summer
Description	Ruinha House Project is a self-built refurbishment located in Montemor-o- Novo city centre. Rammed earth walls around 200 years old meet the ones built when refurbishing the house. The same material, earth, is separated by two centuries of history. The house with around 100 m^2 is located in a very old and narrow street, Ruinha, which means literally small street. It is one of the oldest streets of the outer city wall, characterized by ground floor houses with big chimneys that are characteristic of Alentejo. The renovation maintained the facade with its prominent chimney.
Main bioclimatic strategies	Cross natural ventilation High thermal mass of the walls and roofs Garden Use of local materials (Rammed earth, called Pisé in French)

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



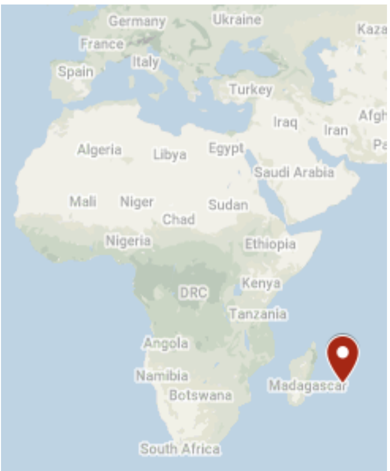
Architect / designer	Antoine Perrau Architectures
Location	-21.296017233539235, 55.46026013458472
City	Saint-Pierre
Country	La Reunion, France
Building Type	Educational
Climate zone (Köppen–Geiger classification)	Aw: Tropical, Savanna, dry winter
Description	The school is composed of 12 classrooms (5 nursery classrooms and 7 elementary classrooms). It was designed according to two differentiated zones: 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 pillars downstream.
Main bioclimatic strategies	Cross natural ventilation, ceiling fans, large unit roof umbrella, reflective and specific sun protection, gardens, insulated roofs, green roof, management of rainwater

CASE STUDY 2-04: ESIROI BUILDING | LA REUNION



Architect / designer	LAB Réunion
Location	-21.340, 55.491
City	Saint-Pierre
Country	La Reunion, France
Building Type	Educational
Climate zone	Aw: Tropical, Savanna, dry winter
Description	The new building of the ESIROI (Ecole Supérieure d'Ingénieurs Réunion Océan Indien) is now located on the Terre Sainte university campus, in Saint Pierre on Reunion Island. One wing of the building also accommodates an extension of the IUT (University and Technological Institute) located on the same campus. 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,
Main bioclimatic strategies	Work on thermal zoning and optimal orientation of the building, cross natural ventilation, use of tensioned canvas, low inertia materials, dense vegetation, effective solar protection, PV

CASE STUDY 2-05: MALACCA FLORES | LA REUNION



Architect / designer	Antoine Perrau Architectures, 2APMR
Location	-20.938292512241063, 55.29568172939064
City	Le Port
Country	La Reunion, France
Building Type	Residential
Climate zone (Köppen–Geiger classification)	Aw: Tropical, Savanna, dry winter
Description	Delivered in late 2011 in Port city in the Reunion Island, the housing projects Malacca and Flores are designed as an urban complex and form the entrance of the development zone Mail de l'Ocean, which aims to open the city to the port. This is a 9-storey block with mixed functions: 138 social housing units divided into 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 addition to the concepts of diversity and energy savings, the project is finely adapted to the climatic constraints.
Main bioclimatic strategies	Narrow buildings, naturally cross ventilated housing units equipped with louvered windows, detached covered corridors, covered verandas, and effective sun shading systems (caps, vertical blades), underground car park allowing the building to be surrounded by green spaces, green roofs, detached over-roofs with PV and solar thermal panels.

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

Architect / designer	Kéré Architecture
Location	12.218139628590144, -2.378258705093982
City	Koudougou
Country	Burkina Faso
Building Type	Educational
Climate zone (Köppen–Geiger classification)	BSh: Dry, Semi-Arid, Hot
Description	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 earth walls, poured and cast in-situ into large formworks.
Main bioclimatic strategies	Comfort ventilation, high thermal mass, optimized solar protection, use of local materials (clay walls, eucalyptus wood branches), vegetable garden, natural daylighting, flood management

CASE STUDY 2-07: LYCEE SCHORGE | BURKINA FASO

Architect / designer	Kéré Architecture
Location	12.216743389817205, -2.3780847033262478
City	Koudougou
Country	Burkina Faso
Building Type	Educational
Climate zone (Köppen–Geiger classification)	BSh: Dry, Semi-Arid, Hot
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.
Main bioclimatic strategies	Natural cross-ventilation and stack effect with louvered shutters and ventilation chimneys, high thermal mass of the walls, large roof overhangs, "screens" made of eucalyptus branches, massive undulating ceiling that enhances natural daylighting, use of locally sourced laterite stone and eucalyptus wood.

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

Architect / designer	KHOZE Architecture / Elementerre
Location	13.744376437735298, -15.76656745830613
City	Nioro
Country	Senegal
Building Type	Others
Climate zone (Köppen–Geiger classification)	BSh: Dry, Semi-Arid, Hot
Description	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) or with ceiling fans.
Main bioclimatic strategies	Comfort ventilation (natural cross ventilation) Evaporative coolers in some spaces Detached overhanging roofs Vegetated patios Use of compressed earth blocks

CASE STUDY 2-09: LYCEE JEAN MERMOZ | SENEGAL

Architect / designer	Terre Neuve
Location	14.718193231710131, -17.484476683878636
City	Dakar
Country	Senegal
Building Type	Educational
Climate zone (Köppen–Geiger classification)	BSh: Dry, Semi-Arid, Hot
Description	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.
Main bioclimatic strategies	Exterior covered walkways, ventilated cavity walls, awnings, and roofing with high thermal inertia, interior islands with trees and shade.

CASE STUDY 2-10: MAISON DES YVELINES | SENEGAL

Architect / designer	Mathieu Hardi AL-MIZAN. Architecture
Location	15.593247890123722, -13.311984869213356
City	Ourossogui
Country	Senegal
Building Type	Residential & Offices
Climate zone (Köppen–Geiger classification)	BWh: Dry, Arid Desert, Hot
Description	The 'Maison des Yvelines' is a mixed-used 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, which are locally available and provide thermal inertia.
Main bioclimatic strategies	Cross natural ventilation High thermal mass of the walls and roofs Inner courtyards offering ventilated and shaded spaces Use of local materials (mud bricks)

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

Architect / designer	Architetti Senza Frontiere Italia
Location	15.291778, -15.936056
City	Mbakadou
Country	Senegal
Building Type	Educational
Climate zone (Köppen–Geiger classification)	BSh: Dry, Semi-Arid, Hot
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 ventilation; 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 ventilation for comfort ventilation High thermal mass of the walls and roofs Use of local materials (mudbricks and typha) Large roof overhangs Cassava garden, shrubs, and trees

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

Architect / designer	Renzo Piano Building Workshop & Studio Tam associati
Location	0.08378874306047031, 32.45785942464613
City	Entebbe
Country	Uganda
Building Type	Health Facility
Climate zone (Köppen–Geiger classification)	Af: Tropical, Rainforest
Description	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." according to the assumption that: "Beauty is not just an aesthetic choice; it is part of treatment. 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.
Main bioclimatic strategies	High thermal mass of the load-bearing walls, Roof canopy structure, Garden with more than 350 trees, Natural light, Use of local materials (raw earth), 3 600 m^2 of photovoltaic panels.

6. Enhancing skills in designing bioclimatic buildings

6.1 Technical guidelines and tools for future-proof passive design in warm climates

During the last century, the perception of availability of an infinite and cheap source of energy thanks to the improvements of technologies for the use of fossil fuels was one of the elements that **separated the design of buildings from consideration of their surrounding environment**. Since the realization of the first building using the new technology of mechanical production of chilled water (in 1906 it was completed the Larking office building in Buffalo, designed by Franck Lloyd Wright), in the previous decades invented and used for industrial applications, and other technological developments in lighting and glazing, construction practice has gradually and steadily moved away from a careful consideration of local climate and resources.

Having abandoned the design of buildings adapted to the local climate and context, buildings are now mostly only able to meet comfort expectations by using large amounts of energy. Whenever heating or cooling active systems fail or are turned off due to poor maintenance or high energy costs, buildings can maintain the indoor environment within the comfort band only for a few hours, and they can afterward **rapidly drift outside of minimal safety conditions**.

This poor performance can be lethal during the ever more frequent heatwaves. And the availability of large amounts of cheap fossil energy revealed itself as a short anomaly in human history, due to the obvious limits to resource and land use and to "environmental space" where to discharge the generated waste.

Meanwhile, Europe and Africa are facing challenges in the building construction and housing sector. Europe is struggling with an aging building stock, whose rapid and radical transformation is needed to meet the goals of reducing energy use and protecting the climate. Various forms of climate disruption and prolonged heat waves are affecting the planet. These effects are significant in the South of Europe and severe in Africa. Retrofits and improved designs of both buildings and cities across the European and African continents are needed to ensure the comfort and health of citizens. New buildings should be designed following **concepts that will make them robust against expected climatic changes during their lifetime, the next 50 to 100 years**. African countries are facing an acute housing shortage, with the continent's population projected to double by 2050, and the fastest urbanization rate in the world.

In such a condition, there is a growing need for comfortable and affordable building space with high environmental performance. There is renewed interest in bioclimatic principles and use of bio- or geo-sourced local building materials in both Continents.

Bioclimatic architecture in hot regions, according to B. Givoni, a master of this type of architecture, (in his book "Passive and low energy cooling of buildings") involves architectural design and choice of materials aiming at providing comfort while minimizing the demand for energy used.

To achieve these aims, different architectural features need to be properly designed:

- the layout of the building and its orientation,

- the number, size, location, and details of its windows;
- the shading devices,
- the thermal resistance and heat capacity of its envelope.

The proper use of the above means results in a minimization of the **diurnal indoor average temperature**, which remains anyway higher than the average diurnal outdoor temperature.

Givoni also provides a definition for ***passive cooling systems***, which are capable of transferring heat from the building to the available natural heat sinks, thus **lowering the indoor average temperature below the outdoor level**.

Proper architectural *bioclimatic design* in a region with hot climate can be thus considered as a precondition for the application of *passive cooling systems*, such as:

- comfort ventilation,
- nocturnal ventilative cooling,
- radiant cooling to the sky,
- direct evaporative cooling,
- indirect evaporative cooling,
- soil cooling,
- cooling of outdoor spaces.

Several guidelines and studies have been developed to support bioclimatic design over the last decades. And the physical principles regarding heat transfer, interaction of radiation with materials, daylighting, energy involved in phase changes... and their application to the design of effective building envelopes remain obviously all valid (though underutilized in most contemporary architecture).

There are, however, **important changes that ask for an update of that knowledge and application.**

Namely the **development and refinement of our knowledge about thermal comfort**, which has been translated in the last few years into **updated comfort models** and incorporated in International Standards (such as ASHRAE 55:2020 and EN 16798:2017), thus providing both renewed dignity to elements of bioclimatic approach (such as the **role of air velocity in the provision of summer thermal comfort**) which had been largely excluded from practice, and better analytical basis for their incorporation into design.

The offer of **software tools** for thermal simulation with captivating graphical interfaces is growing, but **some lack precision in the terminology and clear identification of the key variables** according to the physical definitions given in the International Standards (as e.g. EN-ISO 52 000), thus obscuring the interpretation of results. Furthermore, these models need hourly weather files as an input ad those are relatively rare in Africa and often based on overly old statistical weather data which bear little resemblance with the present weather in Europe. Reliable, **publicly certified weather files for future climatic situation** at 2050 and 2080 are missing in both continents.

At the same time new modelling tools have become available for incorporating the new findings on comfort into the design workflow. **Several advanced, yet simple to use, tools allow now to rapidly evaluate comfort conditions resulting from early design choices, e.g., according to the new "adaptive comfort model" or "elevated air speed model,"** to graphically describe the climate of the place, to optimize the shape of shading elements, etc. (see e.g. https://cbe.berkeley.edu/resources/tools/).

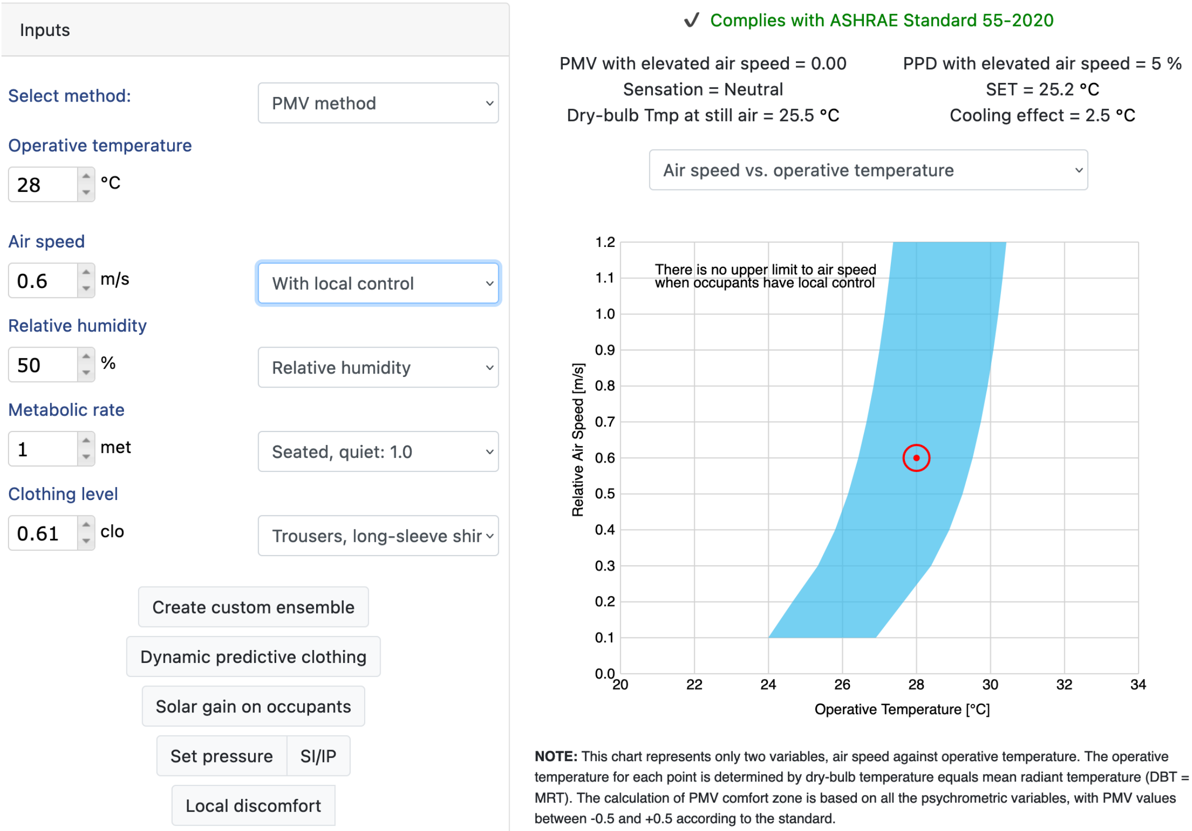


Figure 11: A free online tool for evaluating comfort according to ASHRAE Standard 55:2020 and EN 16798:2017. https://cbe.berkeley.edu/research/cbe-thermal-comfort-tool/

A few of the more complex dynamic simulation tools now also incorporate the new comfort models and allow for better energy and comfort conscious detailed design, when needed. **The update of all those tools to the most recent comfort models is needed**.

Simple technologies with a long history such as **ceiling fans have evolved** with air foil blades **with sophisticated aerodynamic design**, rather than flat ones, and efficient motors whose velocity can be remotely adjusted in close steps or continuously, attaining the noise of a whisper, high stability, and extremely low energy use (besides **nice aesthetics**). They seem to be an accomplishment of the vision of Edward Mazria, "*a future of low-impact buildings is not only necessary but also elegantly achievable*". **A design tool** for selecting size, number, and position of ceiling fans to achieve a desired air velocity level and distribution in a space has been created by the Center for Built Environment and is freely available (Figure 12).

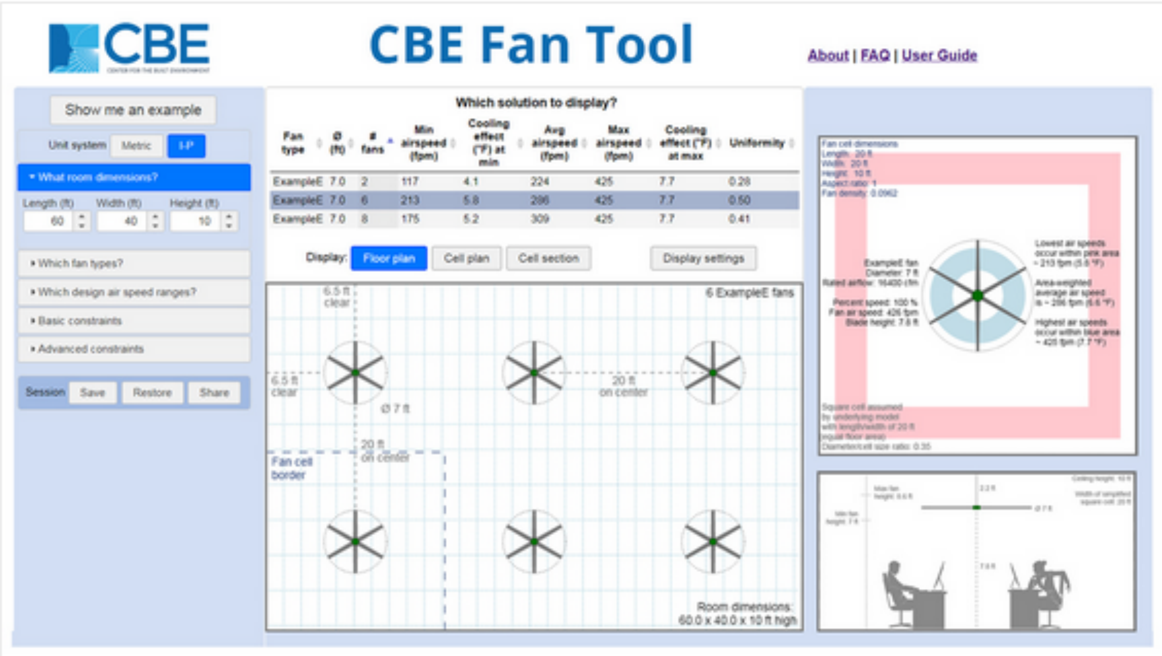


Figure 12: Advanced Ceiling Fan Design tool by CBE. Facilitating appropriate specification and layout of fans based on key design parameters (https://cbe.berkeley.edu/research/advanced-ceiling-fan-design-tool/).

Some traditional construction materials built using local resources, such as **raw earth, benefit now of better compression methods** which ensure the resulting bricks have high resistance to compression even without the addition of cement, which makes them more reliably usable even as structural elements for low rise buildings and fully recyclable at end of life.

New materials have emerged able to radiate energy mainly in the transparency window of the atmosphere, hence **able at daytime to transfer more energy to the sky than the receive by the sun**. Radiative cooling, traditionally used at night-time, is now possible under the sun, with surfaces which can remain cooler than ambient air, while fully exposed to the energy flow from the sun. As it is possible for the Sahara ant, able with its thin and particularly shaped air to radiate to the sky and keep cool under the sun. We elected this astounding animal as our symbol in the ABC 21 project since it sheds light to an important avenue for passively cooling our buildings and cities.

We need now to acknowledge that even succeeding to mitigate climate change, the gases we disposed of in the atmosphere will continue to produce a raise in average temperature and in extreme weather conditions. The design of the envelopes (both new and retrofitted) needs now more than ever to fully incorporate bioclimatic strategies and passive cooling systems, to be able to both protect occupants form harsher conditions and use as little energy as possible. In doing so designers need to have available a description of the local weather for the period of life of the building, which might (and should) extend for a century or more. Hence, we **need reliable, publicly certified, weather file coherent to the future climat**e. On the contrary, we are generally designing now (especially during the decisive early design phase) on the base of weather files or indicators produced as a statistical summary of past decades, greatly inadequate to represent the future.

Urban density will likely increase, as it is necessary to a certain extent to provide housing and services to a growing population and its concentration in urban areas, without requiring too much land and infrastructures and energy for mobility. Even though what is the **preferable density and corresponding height of the buildings** is still a matter of research, it is likely we will still see for some time the construction of "tall" buildings. They were generally not a specific subject of previous guidelines, even though they offer specific opportunities and challenges for the application of bioclimatic and passive principles.

The **guidelines** developed within the ABC21 project represent an effort to respond to the changes described above and **offer an updated view of the future of bioclimatic architecture** (which might be *the* architecture in a climate-compatible future of humanity) under the new boundary conditions of XXI century, while taking advantage of accumulated wisdom and the work of the pioneers of XX century. More work is needed, but we hope this collaboration between Africa and Europe offers the basis for taking steps in the right direction.

6.2 Training tools to design buildings characterized by low energy use.

ABC 21 project developed a set of materials and tools to support the design of bioclimatic buildings. In detail, the **open-access handbook "Sustainable Building Design for Africa"** targeted to consultants and designers (engineers and architects) and other stakeholders (public authorities, financers, real estate managers, etc.), was prepared on the basis of the publication "*Sustainable building design for tropical climates - Principles and Applications for African Countries"*[19], also integrating relevant information from "*Energy and Resource Efficient Urban Neighborhood Design Principles in Tropical Countries - A Practitioner's Guidebook*"[20]. The result is a **comprehensive and updated new publication with design concepts** that can be applied to all African countries. It covers:

- An introduction on energy efficiency and sustainability in buildings
- Climate and building design
- Climate responsive building design
- Energy efficient building design
- Design at community scale
- Renewable energy technologies
- Net zero buildings and communities

Figure 13: Cover page of the open-access handbook "Sustainable Building Design for Africa" (ABC 21).

The second activity consisted in the improvement and adaptation of a **Building Energy Simulation (BES) tool**, already developed by POLIMI and UN-Habitat for the East African Community.

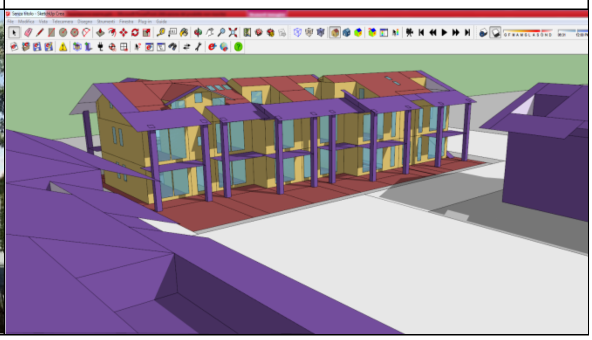
ARCHITECTURAL MODEL	ENERGY SIMULATION MODEL
	

Figure 14: Examples of an architectural rendering and an energy simulation model (ABC 21) realised with the updated interface.

Finally, a **MOOC (Massive On-line Open Course),** summarizing the main contents of the handbook has been developed and made available. The MOOC represents an update of the existing version prepared by POLIMI for the East African Community.

More in detail, the list of lectures of the MOOC and the indication of new contents (underlined) is provided hereafter.

ABC21 is funded by the EU's
H2020 programme

[1] The global warming issue: the impact of the building sector
[2] Integrated design concept and Economics of green buildings
[3] Climatic map of Africa: Climate A
[4] Climatic map of Africa: Climate B
[5] Climatic map of Africa: Climate C
[6] The building's energy balance
[7] Basic concepts of heat transfer
[8] Standard and adaptive approach for thermal comfort
[9] Fundamentals of visual comfort
[10] Site planning and Building design
[11] Roof and walls design by climatic zone (mass, insulation, solar protection)
[12] Embodied energy of materials and life cycle of buildings
[13] Solar geometry and polar diagrams
[14] Solar radiation
[15] Solar shading
[16] Air movements inside and around buildings
[17] Cross ventilation and Stack effect: concept and opening sizing method
[18] Technologies/techniques for enhancing natural ventilation
[19] Natural cooling: concept and sizing method
[20] Glass, light and heat - type of glazing
[21] Window sizing procedure and Tips for window design
[22] Systems to enhance natural lighting
[23] Recommendations by climatic zone
[24] Efficient energy conversion technologies
[25] HVAC types and features
[26] Solar PV and Solar Thermal
[27] Wind Energy, Biomass and Hydro Power

6.3 Webinars

The project organized a **series of webinars covering various topics related to bioclimatic design and sustainable building practices**. These webinars generated engaging discussions, with attendees asking insightful questions and contributing valuable insights.

To reach a wider African audience, one webinar specifically focused on policies was conducted in French. This strategic decision aimed to bridge the language gap and foster increased participation from stakeholders in Africa. The discussions during the webinars provided valuable inputs that were utilized in the project's ongoing work, ensuring that the project benefited from diverse perspectives and experiences.

The following webinars were conducted as part of the ABC 21 project:

- **Webinar 1: Energy & comfort indicators** (organised ad lead by eERG-POLIMI):

  https://youtu.be/DDuiDITT77Y

- **Webinar 2: Local materials & techniques towards the future** (organised ad lead by AUI):

  https://youtu.be/VqHtBdjYo5I

- **Webinar 3: Future Weather Indicators** (organised ad lead by FC.ID)**:**

  https://youtu.be/HNVSBGkdV9c

- **Webinar 4: Successful & promising policies approaches** (organised ad lead by eERG-POLIMI):

  https://youtu.be/6-RzzQbBS2k

- **Webinar 5: Bioclimatic case studies** (organised ad lead by UR):

  https://youtu.be/rXIzvSs9GdI

- **Webinar 6: Net-zero carbon architecture as a solution to Africa housing challenge** (organised ad lead by UN-Habitat):

  https://youtu.be/Erm7fzyWUDY

These webinars served as platforms for knowledge exchange, facilitating discussions on key aspects of bioclimatic design and sharing practical insights and experiences. **All relevant data and recording were added to ABC 21 website:** https://www.abc21.eu/webinars/. The recordings of these webinars will continue to contribute to the dissemination of knowledge beyond the project itself, hopefully leaving a lasting impact on the broader community interested in sustainable building practices.

6.4 International Conference on Bioclimatic Materials and Buildings (ICBMB)

During highly active three days, from May 3rd to May 5th, scientists, politicians, representatives of the building industry, architects, and other experts from Africa and Europe were gathered at the **International Conference on Bioclimatic Materials and Buildings (ICBMB)** in Al Akhawayn University in Ifrane, Morocco. Detailed presentations and discussions around the following four main topics were conducted:

- **Policies** for highly energy efficient buildings, adopting bioclimatic approach
- Analysis of bioclimatic **materials, construction practices & design**
- **Indicators & weather files**, as input for the design of buildings and districts
- Bioclimatic buildings and districts: **Case studies.**

At the opening session, representatives of the Ministry of Habitat of Morocco, the EU Directorate General for Energy and the UN-Habitat, and the Scientific Coordinator of the ABC21 project, presented analysis about social housing needs, construction practices and urbanization development, housing demand, and supply situation. They highlighted the importance of effective policies to promote highly comfortable buildings with minimal ***energy needs for heating and cooling*** by adopting bioclimatic designs and bio- or geo-based materials.

The main points discussed among scientists, architects and engineers were related to the future of the education of the architecture studies and trainings and they pointed at the real need creating or **better combining engineering and architecture training programs** dealing with bioclimatic buildings. Deep discussions were conducted about the performance indicators and guidelines for XXI century bioclimatic buildings and districts. Indicators and weather files for future climate as input for the design of buildings and districts were also presented. Furthermore, several presentations about **innovative materials** and designs attracted a lot of attention from the attendees of the conference. Finally, the session about **case studies** showcased successful case studies with designs responding to esthetical requirement, comfort, and ***low energy needs for cooling and heating***.

In addition to inspiring talks and ground-breaking research, the conference provided many opportunities for effective **networking**.

This event has revealed several opportunities related to bioclimatic materials and designs in terms of new education programs in engineering architecture, energy efficiency in buildings, and lowering carbon footprint of the construction sector. After the conclusion of ABC 21 project, part of the project team is planning to carry this momentum into future endeavors. In 2024, we are planning to organize the second edition of the International Conference on Bioclimatic Materials and Buildings and to contribute to a launch event of a Building Breakthrough Agenda in collaboration with the **Global Alliance for Building and Construction of UN**.

The conference was attended by more than 100 participants from Africa and Europe, we received around 50 abstracts and around 30 recorded presentations on related subjects, and we are still receiving articles for review before publication in the Materials Today journal. The best oral presentations were awarded with a prize.

More information on the **ICBMB** can be found in the following link:

https://www.abc21.eu/icbmb-2023-ifrane

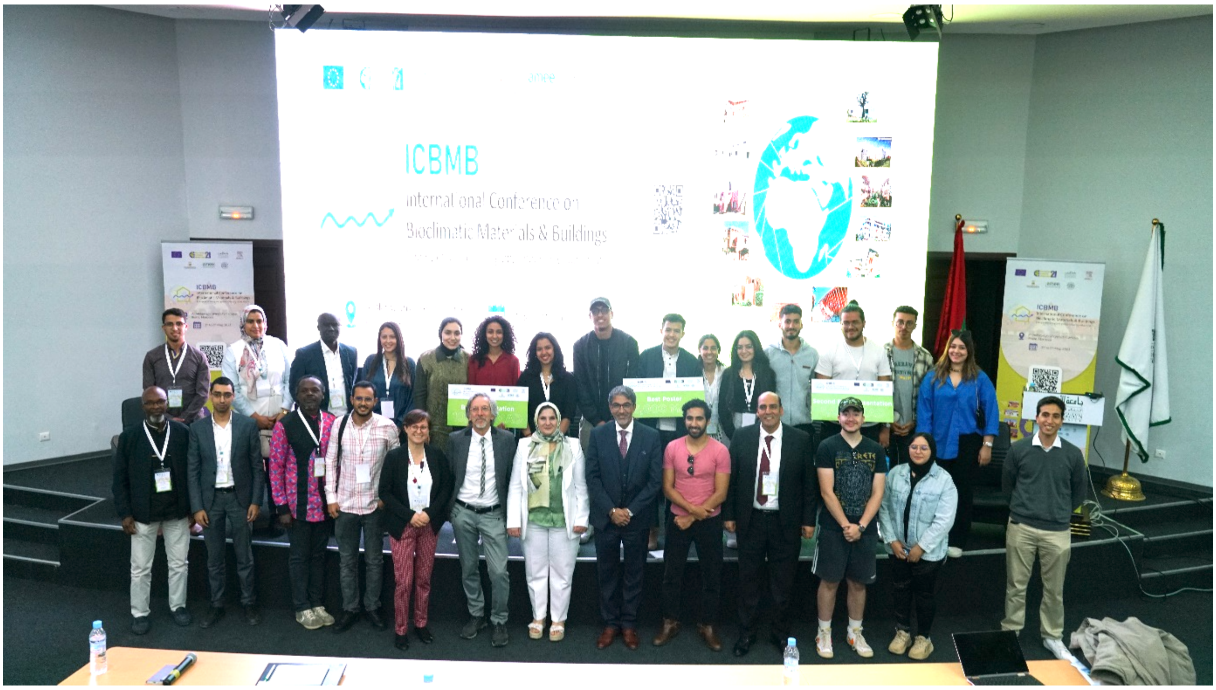


Figure 15: Impression from the ICBMB (ABC 21)

7. Lessons learned and summary of design principles for future bioclimatic buildings, per climate type

EUROPE | Csa. Temperate, Dry and Hot summer (Portugal, Italy, France)

Five case studies have been selected for Europe within ABC 21: three of them are residential houses, one is an educational building, and one is an office building.

				
RUINHA HOUSE	**CML KINDERGARTEN**	**PATIO HOUSE**	**BOTTICELLI PROJECT**	**IZUBA ENERGIES BUILDING**
Montenor-o-Novo, PT	Lisbon, PT	Sardinia,IT	Sicilia, IT	Montpellier, FR
RESIDENTIAL	**EDUCATIONAL**	**RESIDENTIAL**	**RESIDENTIAL**	**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 Kindergarten, 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 the 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 an indirect evaporative cooling system (water is sprayed on the rammed earth walls) that proved to be efficient.

ABC21 is funded by the EU's H2020 programme

High thermal mass:

Four of the case studies use thermal mass with a high level of external insulation.

Only the CML Kindergarten uses 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 ventilated, are using 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: 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 and in the living room of the Ruinha house only.

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

Lessons learned

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 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 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 where 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 large scale (e.g. for the problem of urban sprawl).

Recommendations for Csa: Temperate, Dry and Hot summer

Vegetation:

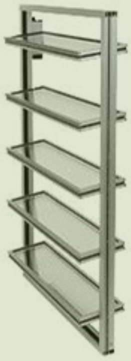
We recommend shading the surroundings of the buildings with native trees and to avoid mineral surfaces around the building. Car parking, if needed, must be located underneath the building to free spaces for vegetation around the building.

Comfort ventilation: Natural cross ventilation highly recommended

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 (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

Ceiling fans:

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”.

ABC21 is funded by the EU's
H2020 programme

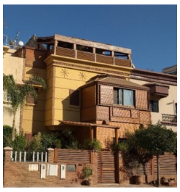
AFRICA | BSh: Dry, Semi-Arid, Hot (Morocco, Burkina)

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

VILLA DES CHERCHEURS

Ben Guerir, MA

RESIDENTIAL



DAR NASSIM PROJECT

Marrakech, MA

RESIDENTIAL

DAR AMYS VILLA

Marrakech, MA

RESIDENTIAL

LYCEE SCHORGE

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

<u>Comfort ventilation:</u>

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 designed for naturally cross ventilation. The "screens" that wrap around the modules 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.

<u>Evaporative cooling:</u>

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

<u>High thermal mass:</u>

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 in other projects too, 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 sourced 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.

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

Lessons learned

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 big umbrellas 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 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

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 do not 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 do not have the control on it.

High thermal mass:

All the case studies have high thermal mass.

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 learned

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 is 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 big umbrellas should 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 should 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 installing 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.

(La Réunion, Uganda, Senegal)| Tropical Rainforest climate – Af & Tropical Savanna with dry winter- Aw

Eight case studies have been selected within the ABC21 project for the Aw & Af climate-types: Two of them are social housing residential buildings. Five of them are educational buildings. One is a hospital in Uganda.

NIAMA

Saint-Pierre, RU

SOCIAL HOUSING

FLORES MALACA

Le Port, RU

SOCIAL HOUSING

ENERPOS

Saint-Pierre, RU

EDUCATIONAL

ESIROI

Saint-Pierre, RU

EDUCATIONAL

MOUFIA THEATER

Saint-Denis, RU

EDUCATIONAL

AIME CEZAIRE 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 Cézaire School, Flores Malaca, 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 Malaca 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

Comfort ventilation:

All the case studies (except some classrooms 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. The airflow design of ESIROI has been tested in a wind tunnel testing facility in Paris.

The hospital does not use natural ventilation as it is fully air conditioned.

Evaporative cooling:

Generally 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.

Use of local / geo- and bio-sourced materials

The case studies of La Reunion usually do not use bio-sourced materials due to the limited availability 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° 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 heat exchanger.

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, most of the buildings (with exception of Niama, Aimé Cézaire and Mermoz) have large BIPV roofs that allows to produce at least 30% of their total electricity use.

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 seven times more electricity thanks to PV panels.

The ESIROI Building is a nearly zero energy building (the building ses only electricity and 96% of the electric energy use 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 not actually imply zero CO_2 emissions unless "***energy needs for heating and cooling***" have 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 and mixed-mode buildings

We recommend installing 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 relatively 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 learned

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 Cezaire School because of the lack of solar shading.

For the Malaca 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.

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 roofs that act as big umbrellas should be promoted, as well as the design of outdoor corridors / buffer spaces. It is recommended to use light materials (e.g. timber) for shadings.

Dark colored 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.

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

Ceiling fans and mixed-mode buildings: We recommend installing 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 for 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.

8. Website and social media

As part of this project, a comprehensive dissemination strategy was planned and implemented to reach a diverse and relevant audience, like policy makers, market actors, the educational and public sector, development agencies and internal financing institutes. The communication activities conducted were articles in journals, policy briefs, events and conferences, workshops and webinars, and press releases.

A central platform for disseminating project-related information was created through the **ABC 21 project website.** This website served, and will serve in the future, as a comprehensive resource, providing **details about the project, research findings, news updates, publications, and upcoming events.** Regular updates and maintenance ensured that the website contained up-to-date and relevant content for the target audience. The ABC 21 website served as a hub for stakeholders to access project materials, stay informed, and engage with the project's progress.

https://www.abc21.eu/

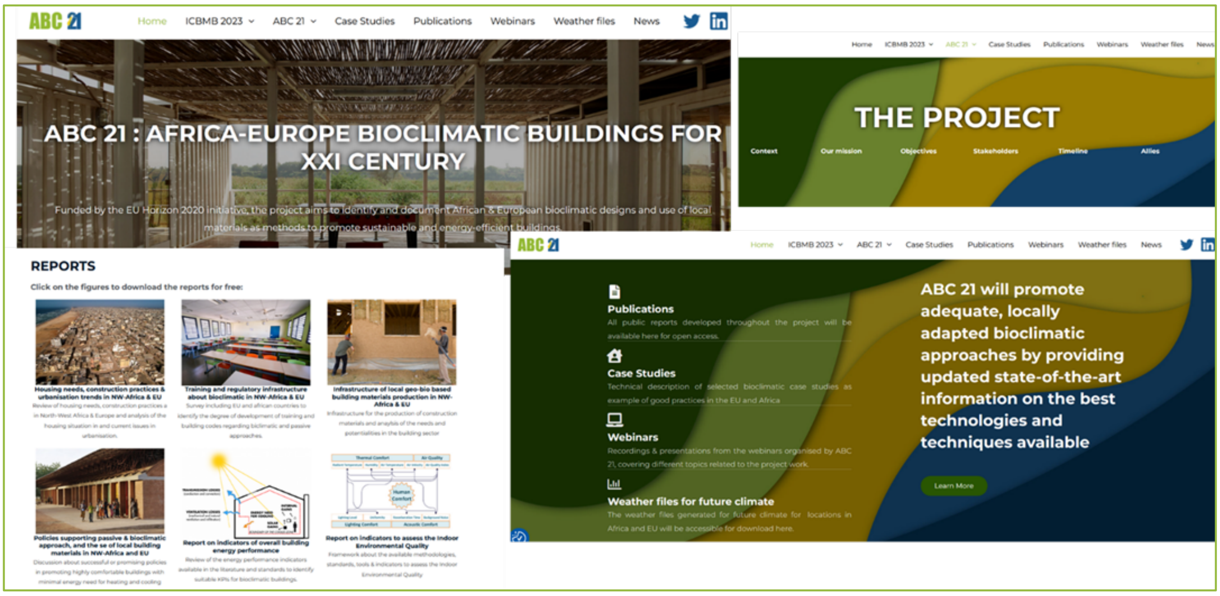


Figure 16: Screenshots of the ABC21 website (ABC 21)

To ensure personalized and targeted communication, direct invitations, newsletters, and formal emails were sent to the project's contact network. In addition, prominent websites, and platforms such as **BuildUp, Construction 21, UN-Habitat,** and **Global ABC** were utilized to extend the project's visibility. The ABC 21 conference was featured on these platforms' event calendars, allowing individuals interested in sustainable construction practices and bioclimatic materials to discover and engage with the project.

Social media played a crucial role in the dissemination strategy, with the project actively using LinkedIn and Twitter to connect with a broader audience. Regular updates, speaker announcements, and program highlights were shared through these channels, fostering discussions, and facilitating the spread of conference information.

https://www.linkedin.com/company/abc21-africa-europe-bioclimatic-collaboration/
https://twitter.com/ABC21_h2020

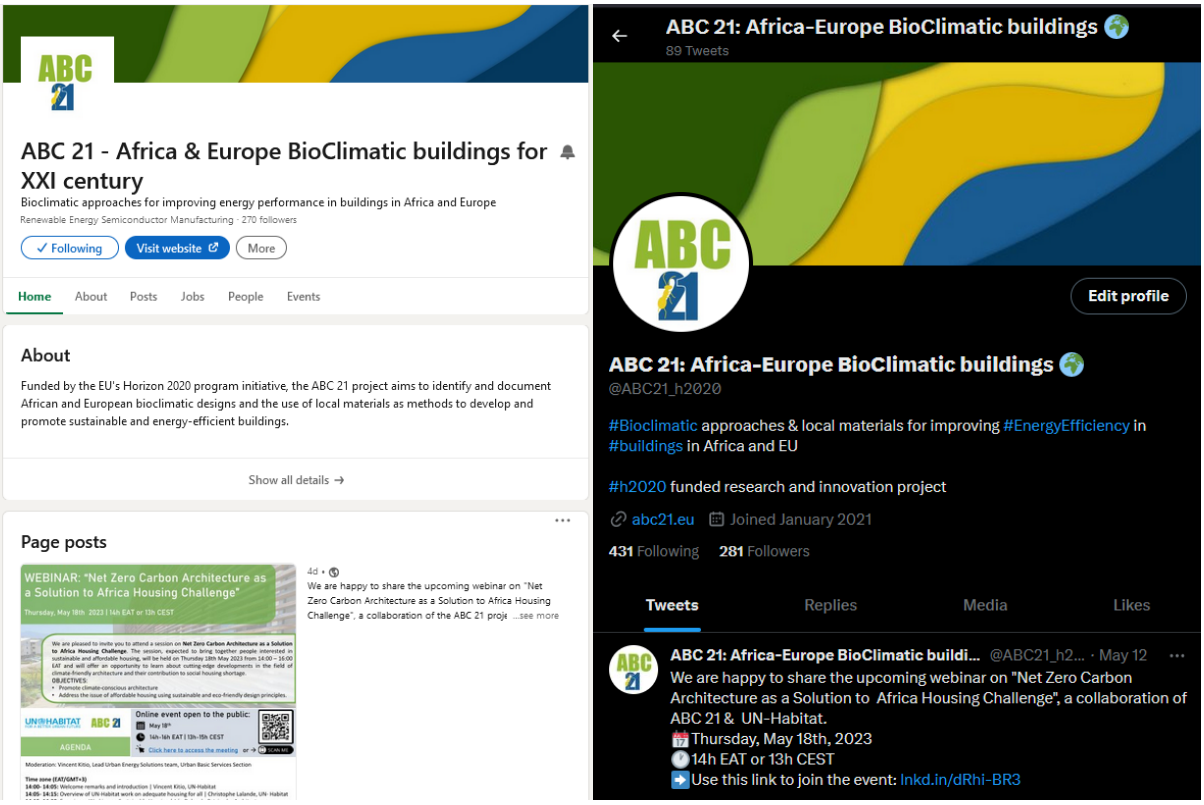


Figure 17: Exemples of social media posts (ABC 21)

Various communication materials, such as **flyers, digital content, and newsletters**, were created to effectively convey project updates and engage the target audience. Additionally, **webinars, events, and conferences** were organized to provide platforms for knowledge exchange and collaboration. Noteworthy events included the **eceee Summer Study 2022, Urban Resilience and One Health Conference, EU COP26 Side Event, and COP26 – French pavilion session**, among others.

Figure 18: ABC 21 project flyer (ABC 21)

The **ICBMB (International Conference of Bioclimatic Materials and Buildings)** served as a significant milestone for the project, featuring renowned speakers who presented on **bioclimatic design and passive systems, geo- end bio-based materials characterization and manufacturing, and case studies**. The conference presentations and posters are freely available through the conference website, facilitating the dissemination of valuable knowledge.

https://www.abc21.eu/icbmb-2023-ifrane/

Figure 19: Start page of ICBMB website (ABC 21)

Figure 20: Impressions from the ICBMB (ABC 21)

Despite the challenges posed by the COVID-19 pandemic, the project successfully adapted to the circumstances by migrating to the online sphere. This shift to virtual spaces enabled broader audience engagement and participation, ensuring that individuals who could not attend in-person events still had the opportunity to benefit from the project's dissemination and exchange activities.

In conclusion, the dissemination strategy employed by the ABC 21 project incorporated various channels and platforms to effectively reach its target audience. The project leveraged personalized communication, prominent websites, social media platforms, a project website, and diverse communication materials to share updates, engage stakeholders, and facilitate knowledge exchange.

Figure 21: ABC 21 logos (ABC 21)

Publications

ABC 21 published various **reports, papers, and other information**. All of them can be found on the project website under https://www.abc21.eu/publications

The most important publications are:

- **Housing needs, construction practices & uurbanization trends in NW-Africa & EU:** Review of housing needs, construction practices in North-West Africa & Europe and analysis of the housing situation in and current issues in uurbanization
- **Training and regulatory infrastructure about bioclimatic architecture in NW-Africa & EU:** Survey including EU and African countries to identify the degree of development of training and building codes regarding bioclimatic and passive approaches.
- **Infrastructure of local geo-bio-based building materials' production in NW-Africa & EU:** Infrastructure to produce construction materials and analysis of the needs and potentialities in the building sector.
- **Policies supporting passive & bioclimatic approach, and the use of local building materials in NW-Africa and EU:** Discussion about successful or promising policies in promoting highly comfortable buildings with minimal "energy needs for heating and cooling".
- **Indicators of overall building energy performance:** Review of the energy performance indicators available in the literature and standards to identify suitable KPIs for bioclimatic buildings.
- **Indicators to assess the indoor environmental quality:** Framework about the available methodologies, standards, tools & indicators to assess the Indoor Environmental Quality, including **thermal comfort**.
- **Energy flexibility indicators, with focus on warm climate conditions:** Describes the concept of time-flexible energy demand in buildings though a critical review of the main methodologies, definitions, and indicators.
- **Availability of weather files & indicators for today/future weather in Africa and EU:** Reviews and discusses methodologies for weather indicators, weather datasets, and production of future weather files.
- **Available methods and tools for the generation of future weather files:** Availability & reliability of weather files to represent current and future weather conditions on which to base the design of buildings.
- **Effect of future weather on the performance of one of the case studies:** Analysis of the effect of future weather on the performance of a case study in different climates, focusing on when, where, and how passive design strategies are influenced by climate change.
- **Materials and construction practices (local and/or adapted to local conditions):** This report investigates the potential of different bio- and geo-sourced materials as construction materials in Europe and Africa.
- **24 case studies of European and African bioclimatic buildings:** Review of 24 fully documented case studies of bioclimatic buildings located in EU & Africa, with data collected from technical experts.

- **Report on updated training tools for building energy simulation (BES):** It lists support materials and tools developed or updated within the ABC 21 project, to design new buildings characterized by low energy consumption.
- **Final report on updated technical guidelines and tools**: The guidelines represent an effort to respond to the challenges of climate change, increasing population, aging buildings in EU, and offer an updated view of the future of bioclimatic architecture under the new boundary conditions of XXI century. They take advantage of accumulated wisdom, the work of the pioneers of XX century, and the availability of new or improved materials.

You can also go to Cordis **https://cordis.europa.eu/project/id/894712/results** the official EU research results site, to gain access to the ABC 21 publications.

Various papers have been published on peer reviewed academic journals and in conference proceedings:

- A study of a passive heating design employing a Trombe wall with PCM: A numerical investigation of the semi-oceanic climate in Morocco
- ASHRAE Likelihood of Dissatisfaction: A new right-here and right-now thermal comfort index for assessing the Likelihood of dissatisfaction according to the ASHRAE adaptive comfort model
- Assessment of graphene oxide clay wall performance as an efficient active heating system
- Effect of reinforced recycled sawdust-fibers additive on the performance of ecological compressed earth bricks
- Improving rheological and mechanical properties of non-plastic clay soil from Bensmim region (Morocco) using bentonite additions
- Machine learning forecasting of thermal, mechanical and physicochemical properties of unfired clay bricks with plastic waste additives
- Rheological and physico-mechanical investigations on the destabilization of unfired clay bricks with almond husk additive by salt
- Simulation of an energy-efficient cool roof with cellulose-based daytime radiative cooling material
- Thermal Study of Clay Bricks Reinforced by Dry-Grass Fibers
- Thermophysical and Mechanical Assessment of Unfired Clay Bricks with Dry Grass Fibrous Filler
- Traditional and modern building materials and practices adapted to natural resources: a way to meet the resilience approach

- Utilization of recycled almond wastes as additives in unfired clay bricks
- Viscoelastic Measurements of Clay Suspensions and their Relationship to Strength of Unfired Clay Bricks with Almond Husk Additive
- Heat transfer characterization with alternative heating element layout in electric ‘Injera’ baking technology

Figures

Endnotes

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2 *For definition of terms, according to Givoni, please consult the "*Final Report On Updated Technical Guidelines And Tools" on https://www.abc21.eu/publications/, and the book of B. Givoni „Passive and low energy cooling of buildings" *Please note that we format in* bold, italic, underlined *all the terms corresponding to physical variables, comfort indicators or design strategies*

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*16 For definition of terms, according to Givoni, please consult "*Final Report On Updated Technical Guidelines And Tools" on https://www.abc21.eu/publications, and the book of B. Givoni „Passive and low energy cooling of buildings" *Please note that we format in* bold, italic, underlined *all the terms corresponding to physical variables, comfort indicators or design strategies*

17 Online Browsing Platform (OBP) at https://www.iso.org/obp/ui

18 Erba, Silvia, e Alessandra Barbieri. «Retrofitting Buildings into Thermal Batteries for Demand-Side Flexibility and Thermal Safety during Power Outages in Winter». Energies *15, fasc. 12 (16 giugno 2022): 4405. https://doi.org/10.3390/en15124405.*

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