Africa-Europe Bioclimatic Collaboration 21

Africa-Europe BioClimatic buildings for XXI century

REPORT ON INDICATORS OF OVERALL BUILDING ENERGY PERFORMANCE

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ABC 21 project

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Executive Summary

ABC 21 project aims to increase the energy performance, the quality of life and sustainability of West-African buildings through the identification, strengthening and effective deployment of affordable bioclimatic designs and local materials under the challenging African climate and urbanization context. Considering that heat is the predominant feature of African climates, particular attention should be given to the issue of cooling of buildings, which is fundamental to achieve comfortable living environments. However, in some parts of Africa, the energy need for heating to satisfy the current comfort expectations of occupants cannot be overlooked.

The purpose of this report is to carry out a critical review on the energy performance indicators available in literature and international standards to identify suitable KPIs which can be used to assess the energy performance of bioclimatic buildings. The main concepts/variables and their operative definitions are reported to provide a basis for effective design work and communication.

The main report findings are summarized as follows:

- a set of definitions about **building energy performance** available in literature and international standards (but not easily accessible and familiar to those outside academia, in spite of their relevance for application) has been provided in order to ensure uniformity and coherence in all analyses and reporting. Below, an example from the list of definitions:
    - **"***energy need for heating or cooling***"** heat to be delivered to or extracted from a *thermally conditioned space* to maintain the intended space temperature conditions during a given period of time (ref. 3.4.13 in EN-ISO 52000-1:2017)
- In literature, a precise definition of bioclimatic architecture is missing. This is often associated with vernacular architecture as it is also designed to achieve the maximum level of indoor comfort by exploiting the surrounding microclimate. Bioclimatic architecture is related with the passive solar design (which deals with energy gained from sunlight), sustainable design (which considers the environmental impact of all processes involved) and is in line with the design principles of Zero Energy Buildings (ZEBs). Considering the definitions reviewed in literature, it is possible to outline the following reference statement: "*Bioclimatism is a concept that integrates the micro-climate and architecture with human thermal comfort. It refers to an architectural design approach which adopts passive strategies and renewable energy systems to achieve comfort in buildings and neighbouring areas.*"
- An analysis of the **climatic context** has been reported to better characterize the energy needs of the buildings in the countries under study.
- 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 analysed to characterize high energy performance buildings, whose very low amount of energy required is mainly covered by energy from renewable sources. A selection of the following indicators will be used to assess and compare the case studies.
    - Energy, Quality of the building fabric
        1. *Energy needs for heating* [kWh/y/m^2]

2. *Energy needs for cooling* [kWh/y/m^2]
3. Optional: *Energy use for lighting* [kWh/y/m^2]
4. Optional: air tightness (ACH at 50 Pa difference or equivalent)

- Energy, users' behaviour and appliances
  1. *Energy needs for Sanitary Hot water* [kWh/y/m^2]
  2. Total *internal gains* [kWh/y/m^2]

- Total primary Energy, (Building fabric + systems)
  1. *Total Primary energy* use [kWh/y/m^2]
  2. Provide values for present national *primary energy factors* – PEF (3 values for each flow of delivered energy: total, renewable, non renewable)
     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/y/m^2]
  2. *Renewable Primary energy* generated on-site and Self consumed [kWh/y/m^2]
  3. *Renewable Primary energy* exported to the grid [kWh/y/m^2]

- *Non Renewable Primary Energy*, or Global *primary energy* balance
  1. *Non Renewable Primary energy use without compensation* for exported energy (kWh/y/m^2)
  2. *Non Renewable Primary energy use with 100% compensation* for exported energy (consumption minus on-site generation in kWh/y/m^2)
  3. *Renewable Primary energy use* considering the 100% renewable scenario [kWh/y/m^2]. 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) (%)

- With reference to bioclimatic buildings, literature reports few studies focusing on specific bioclimatic indicators. Some references address the topic of environmental resources. The computation of the present indicators does not intend to replace the tools that are already used under the scope of bioclimatic procedures, such as bioclimatic charts. They just intend to enrich the procedures by providing an overview of the exploitable resource and of the capacity of the building to exploit those resources. Omar et al. identify four environmental cooling resources: external convection, ventilation, sky radiation and the ground. The authors defined two sets of bioclimatic indicators, one for the quantification of the amount of cooling (heating) energy of a given resource that could be exploited (sheltered) and the other for the assessment of these resources (heat sources) exploitation (sheltering) by the building. These indicators, adapted to air-conditioned buildings, are proposed to be adopted by designers and architects looking for optimal bioclimatic solutions in the early stages of building design to reduce the cooling needs in hot and humid climates.

Abbreviations

Term	Name
nZEB	nearly Zero Energy Building
OBP	Online Browsing Platform
$\mathbf{f_{P,TOT}}$	total primary energy factor
$\mathbf{f_{P,REN}}$	renewable primary energy factor
$\mathbf{f_{P,NREN}}$	non-renewable primary energy factor
EPB	Energy Performance of Building
HDD	Heating Degree Days
CDD	Cooling Degree Days
WWR	Window-to-wall ratio
GA/FA	Ratio of glazing to net Floor Area

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1 Introduction

In recent years, the construction industry has been comprehensively focusing on energy performance of buildings and on achieving higher standards of living comfort. One of the most sophisticated ways to attain both at the same time is (re)achieving building's climate balance by using bioclimatic design [1]. Buildings designed based on bioclimatic architecture are more sustainable, have a healthier indoor environment, are more comfortable and have improved energy efficiency, which ultimately leads to lower energy costs [2].

ABC 21 aims to increase the energy performance, the quality of life and sustainability of West-African buildings through the identification, strengthening and effective deployment of affordable bioclimatic designs and local materials under the challenging African climate and urbanization context.

Considering that heat is the predominant feature of African climates, particular attention should be given to the issue of cooling of buildings, which is fundamental to achieving comfortable living environments. However, in some parts of Africa, the energy need for heating to satisfy the current comfort expectations of occupants cannot be overlooked.

The cooling of buildings can, and should, be achieved by natural means, avoiding the use of extensive mechanical systems. The aim of the passive cooling techniques is to prevent the accumulation of heat gains and provide natural cooling, minimizing the occurrence of overheating. The principles of passive cooling techniques have been successfully used for centuries before the appearance of air conditioning. These traditional techniques, reinforced with contemporary technological knowledge and optimized, can be successfully incorporated in the design and operation of buildings [1].

In this framework, this document provides:

- a set of definitions about **building energy performance** available in literature and international standards to ensure uniformity and coherence in all analyses and reporting;
- a literature review of the concept of **bioclimatic architecture** to clearly identify the design strategies and objectives;
- an analysis of the **climatic context** to better characterize the energy needs of the buildings in the countries under study;
- a set of energy **Key Performance Indicators (KPIs)** to characterize high energy performance buildings, whose very low amount of energy required is mainly covered by energy from renewable sources;
- a literature review of KPIs for bioclimatic buildings.

Quantifying building energy performance through the development and use of KPIs is an essential step in achieving energy saving goals in both new and existing buildings.

In *Task 3.4 – Case studies of European and African Bioclimatic buildings*, a selection of these indicators will be used to assess and compare the case studies. Information regarding the energy use in the buildings will be collected from different sources (e.g. energy performance certificates, electricity bills, dynamic energy simulations etc.).

2 State of the art: bioclimatic architecture in warm climates

Bioclimatic building design is an engineering practice most commonly defined as using **climatic resources** of a particular location with the help of building envelope elements to ensure living comfort, while energy sources are efficiently utilized [2].

Bioclimatic architecture encompasses three directions: energy, human health/wellbeing and sustainability. The term ‘bioclimatic architecture’ refers to an alternative method of constructing buildings in which the local climate conditions are considered (microclimate) and diverse passive technologies are used with the aim of improving energy efficiency [3]. It is recommended to start the bioclimatic design with a regional ‘climate resources’ analysis [2], which uses basic climatic data to determine best suited passive solutions. Tools such as the Olgyay’s or Givoni’s diagram (bioclimatic charts) are used to assess thermal comfort evaluating the adoption of different passive strategies (see *D3.2 - Report on comfort indicators and scenarios* for the complete description).

2.1 Definition of bioclimatic architecture

In literature, a precise definition of bioclimatic architecture is missing. This is often associated with vernacular architecture as it is also designed to achieve the maximum level of indoor comfort by exploiting the surrounding microclimate. Bioclimatic architecture is related with the passive solar design (which deals with energy gained from sunlight), sustainable design (which considers the environmental impact of all processes involved) and is in line with the design principles of Zero Energy Buildings (ZEBs) [4].

The following Table 1 reports an overview of the approaches identified with the concept of bioclimatic architecture, which can be found in literature. They have been classified highlighting the reference climate provided in the different sources.

Table 1: Description of bioclimatic design approaches available in literature

Ref	Bioclimatic Architecture descriptions	Climate
[3]	*1 - Bioclimatic architecture attempts to achieve human thermal comfort by interacting energetically with the exterior climate.* *2 - Vernacular architecture is in a developmental process intended to reclaim the architectural values of protection against the severities of the exterior climate in accordance with the objective of minimal consumption (to near-zero if possible).*	All
[5]	*1 - Bioclimatic design refers to an architectural design approach that utilizes solar energy and other related environmental resources to provide indoor and outdoor human thermal comfort.* *2 - The most important things to be considered in the bioclimatic building design is human thermal comfort. According to ASHRAE 55: “Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment…etc."*	Humid subtropical climate
[6]	*1 - Bioclimatism is a concept that integrates the micro-climate and architecture with human thermal comfort conditions.*	Mainly warm climate

	This definition is based on the following statement: "The comfort zone of a bioclimatic chart is defined as the range of climatic conditions within which the majority of persons would feel thermally comfortable"[7]	
[8]	*1 - The bioclimatic approach is adopted while designing the building using passive cooling strategies.* *2 - The purpose of the bioclimatic approach is to predict the potential of different passive strategies by developing a bioclimatic chart. This includes the comfort zone and the boundaries of passive cooling strategies.*	All
[9]	*1 - Bioclimatic architecture, able to improve indoor thermal comfort and to achieve at the same time good building energy performance.* *2 - Moreover, Rupp and Ghisi [10] have highlighted the role of the chosen method assessing thermal comfort for the determination of energy saving potentiality in commercial buildings located in hot-humid climates.*	Hot-humid climates
[11]	*1 - Bioclimatic design is to obtain a fully passive building, which produce thermal comfort without mechanical system.* *2 - …current standard of living that future occupants expect. In this context, a bioclimatic design intends to: a) protect the indoor environment from outdoor heat sources, b) exploit sources of freshness from outdoor environment, and c) make use of thermal inertia to manage the fluctuation of the outdoor freshness availability.*	Hot-humid climates
[12]	*1 - The term 'bioclimatic' has traditionally related to the relationship between climate and living organisms, or to the study of bioclimatology. In the context of buildings, in general, and housing, in particular, it is concerned with a third factor in the relationship between the living organisms and climate – that is, the form and fabric of the building.* *2 - Early definitions of bioclimatic housing emphasized the overlapping fields of biology, climatology and architecture (Olgyay, 1963).* *3 - Components of bioclimatic design. Current themes centre on a range of issues concerning the relationship between the biological and physical domains, such as:* - *climate types and requirements;* - *adaptive thermal comfort;* - *vernacular and contextual solutions;* - *tools and assessment methods;* - *microclimate: sun path, wind and rain;* - *working with the elements, such as passive and active systems; and development of a responsive form (Price & Myers, 2005).* *4 - The main principle of bioclimatic design for passive and low energy buildings is to provide a comfortable environment by virtue of the passive features of design.* *5 - Research into bioclimatic issues has taken the form of passive low energy architecture research and is carried out worldwide, with a well-developed field, as is evidenced in the passive and low energy architecture (PLEA) conferences.*	Mainly warm climate

[13]	*1 - Bioclimatic architecture is a wide concept which involves the adaptation of the building's design and construction techniques to the surrounding conditions, including the use of natural resources and traditional techniques* *2 - The thermal performance of a bioclimatic building has to show how to solve the thermal discomfort due to the climate without the aid of the mechanical systems.*	Warm temperate subtropical climate
[14]	*Bioclimatic architecture is an integrated architecture, adapted to its physical, socio-economic and cultural environment. It is the kind of architecture that takes into account the analysis of the climate and environmental characteristics where the building is situated, promoting improved comfort and a reduction in energy consumption. Its aim is to maximize interior environmental comfort, (thermal comfort, light, sound, etc.) using only the design elements and architectural forms available.*	All

Considering the above definitions, it is possible to outline the following reference statement:

Bioclimatism is a concept that integrates the micro-climate and architecture with human thermal comfort. It refers to an architectural design approach which adopts passive strategies and renewable energy systems to achieve comfort in buildings and neighbouring areas.

2.2 Climate zoning

This section presents an overview of the current state and the future climate projections in the territories under study in ABC 21 in order to better characterize the buildings energy need. The project focuses mainly on the countries located in Northern and Western Africa, i.e. Morocco, Algeria, Libya, Mauritania, Senegal, Togo. However, other countries, such as Kenya and La Réunion (France) will be taken into account. In Europe, case studies of bioclimatic buildings located in southern countries, such as Italy and Portugal, will be considered.

According to the Köppen climate classification [15] which is shown in Figure 1, North-Western African countries (Morocco, Mauritania, Mali, Algeria, Niger, etc.) can be classified mostly under arid desert hot climate. Parts of Morocco, Algeria and Tunisia lying along the coast nearer to Europe have a Mediterranean climate similar to the south of Italy and Portugal. The central strip is characterized by semi-arid hot climate while the territories in the lower part (Guinea, Ghana, Togo, Nigeria, etc.) show a tropical climate. Literature reports also the future map (Figure 2) related to the period 2071-2100 based on climate change projections from 32 Coupled Model Intercomparison Project phase 5 (CMIP5) models [16].

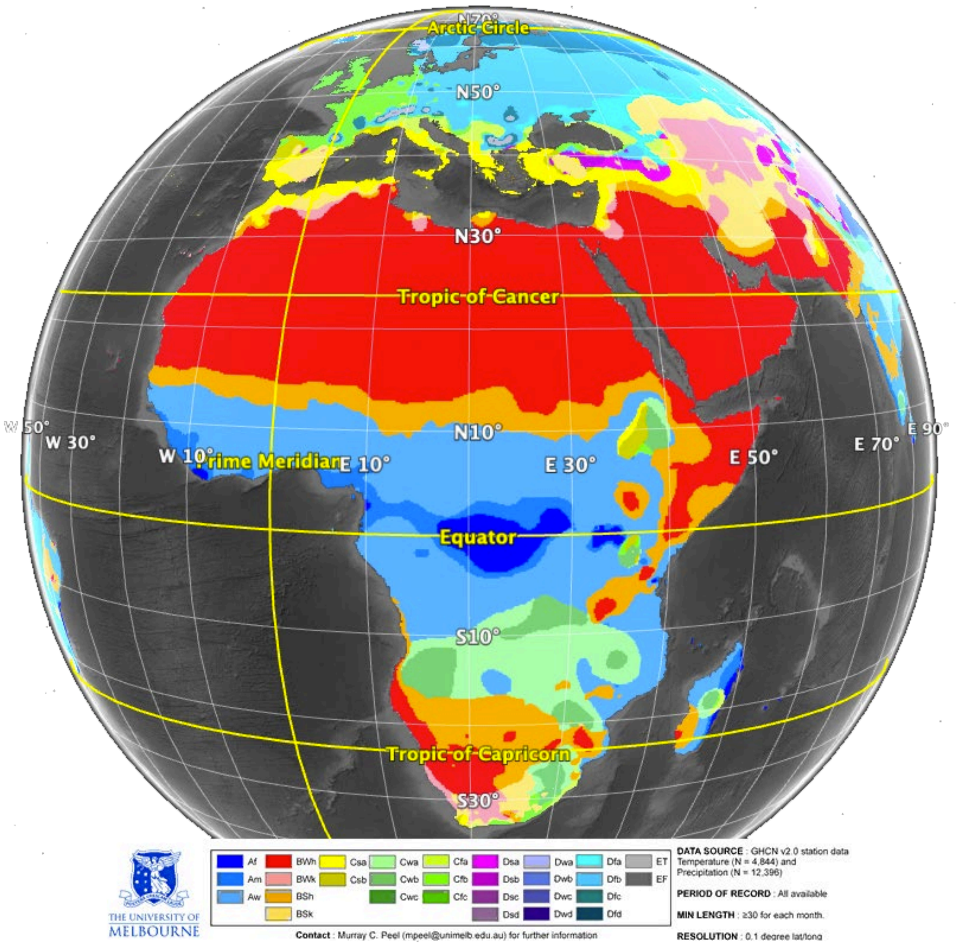


Figure 1: Africa and Europe view of Köppen climate classification

Table 2: Köppen climate classification

Group A: Tropical/megathermal climates	
	Af: Tropical rainforest climate
	Am: Tropical monsoon climate
	Aw: Tropical savanna climate
Group B: Dry (desert and semi-arid) climates	
	BWh: Arid desert hot climate
	BWk: Arid desert cold climate
	BSh: Semi-arid (steppe) hot climate
	BSk: Semi-arid (steppe) cold climate
Group C: Temperate/mesothermal climates	
	Csa: Mediterranean hot summer climates
	Csb: Mediterranean warm/cool summer climates
	Csc: Mediterranean cold summer climates
	Cfa: Humid subtropical climates
	Cfb: Oceanic climate
	Cfc: Subpolar oceanic climate
	Cwa: Dry-winter humid subtropical climate
	Cwb: Dry-winter subtropical highland climate

	Cwc: Dry-winter subpolar oceanic climate
Group D: Continental/microthermal climates	
	Dfa/Dwa/Dsa: Hot summer continental climates
	Dfb/Dwb/Dsb: Warm summer continental or hemiboreal climates
	Dfc/Dwc/Dsc: Subarctic or boreal climates
	Dfd/Dwd/Dsd: Subarctic or boreal climates with severe winters

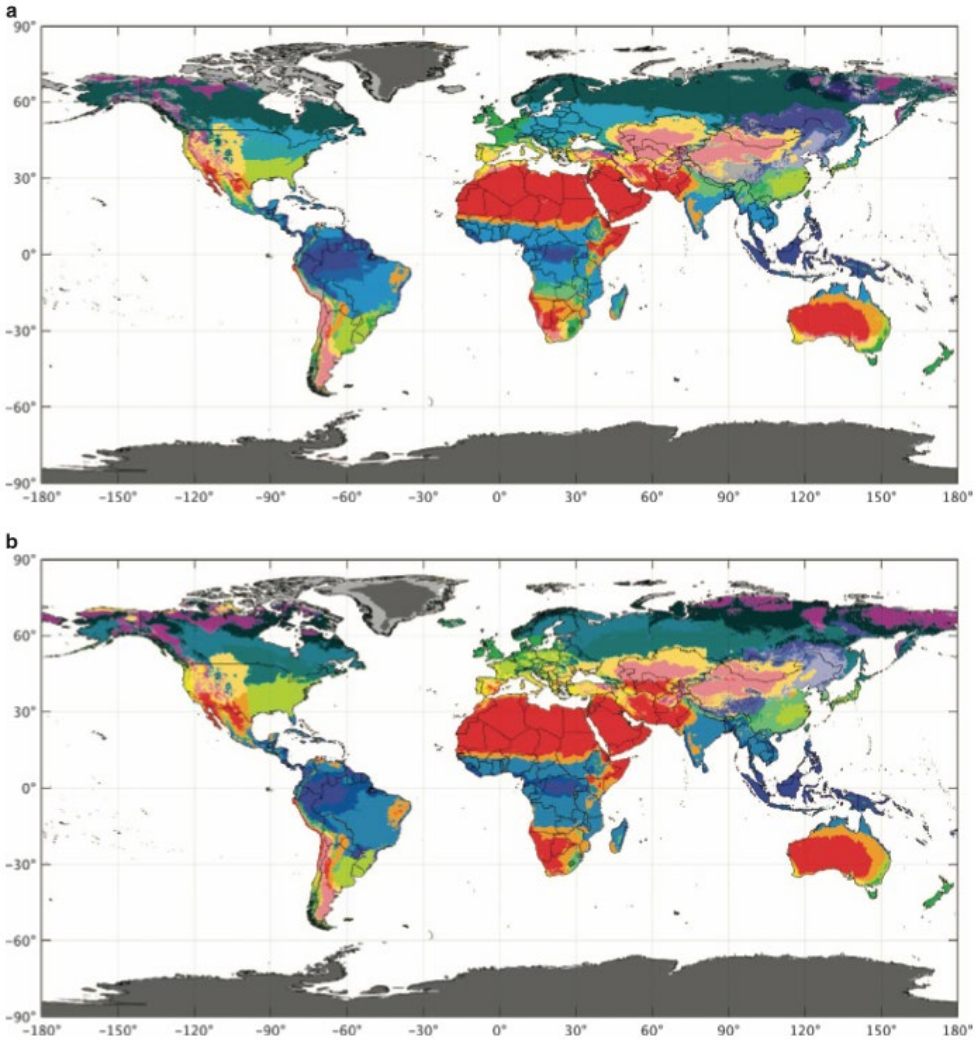


Figure 2: Köppen-Geiger classifications. Part (a) shows the current status and part (b) the future map (2071–2100) [16]

To describe roughly the climatic zones boundaries, we consider the following three parameters, namely:

- air temperature
- solar radiation
- elevation

since they can be considered as the most influential variables for thermal comfort in hot climates [17]. In order to have a general overview of the African and European climatic context, the following maps [18] indicate: the yearly average temperature (Figure 3), the yearly average global horizontal irradiation (Figure 4) and the elevation of terrain surfaces (Figure 5). In *Task 3.2 - Indicators and weather files for future climate, as input for design of buildings and districts* more accurate climatic analyses are being developed.

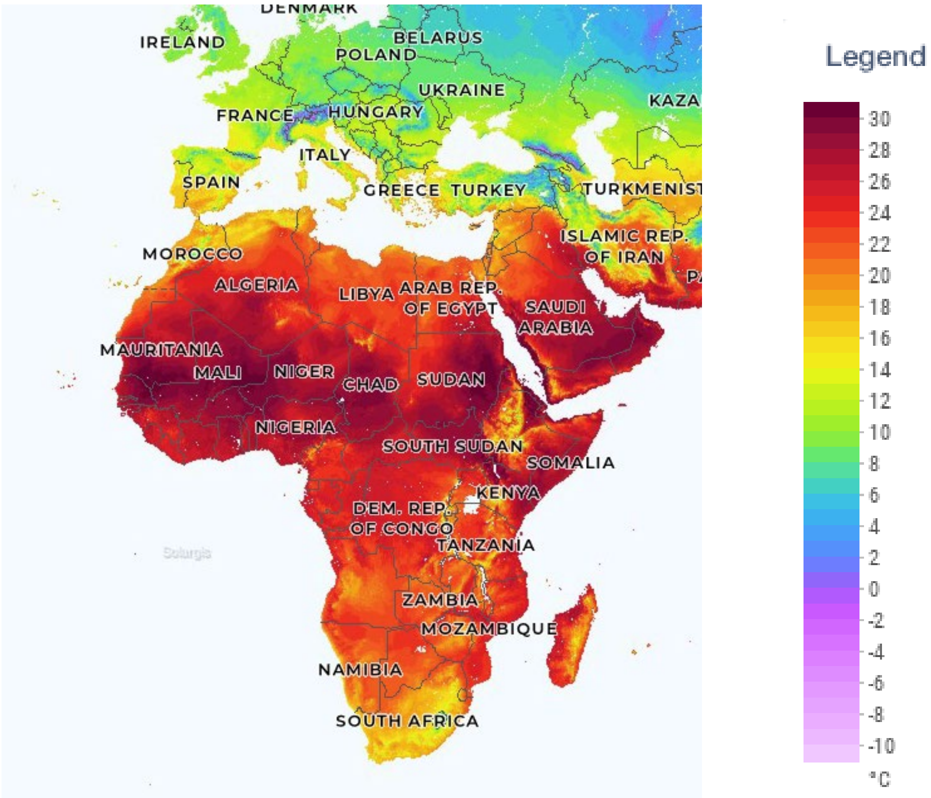


Figure 3: Yearly average air temperature at 2 m above ground. Calculated from outputs of ERA5 model (© 2019 NOAA and NASA)

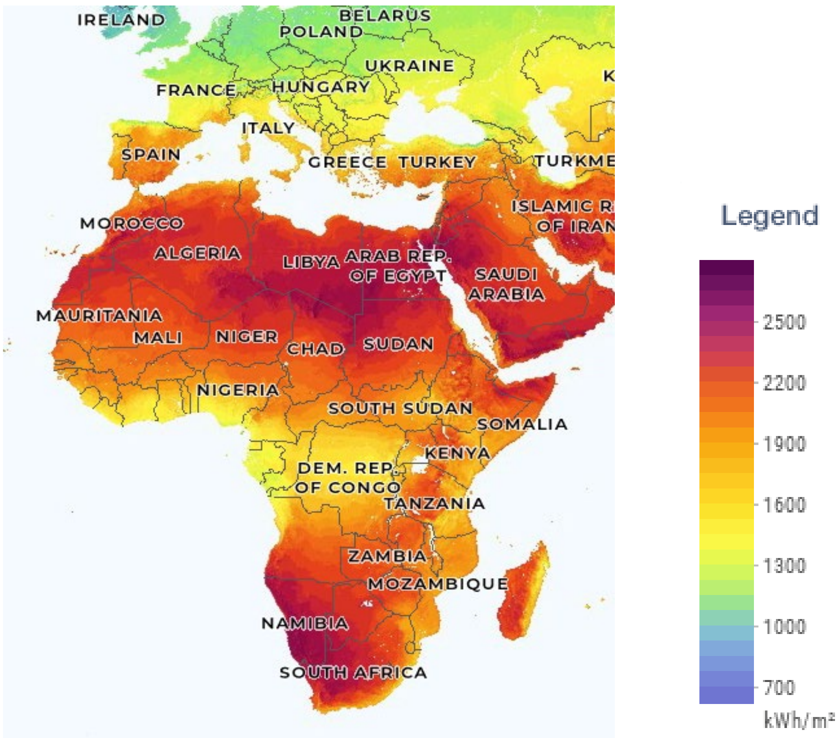


Figure 4: Yearly average global horizontal irradiation (© 2019 Solargis)

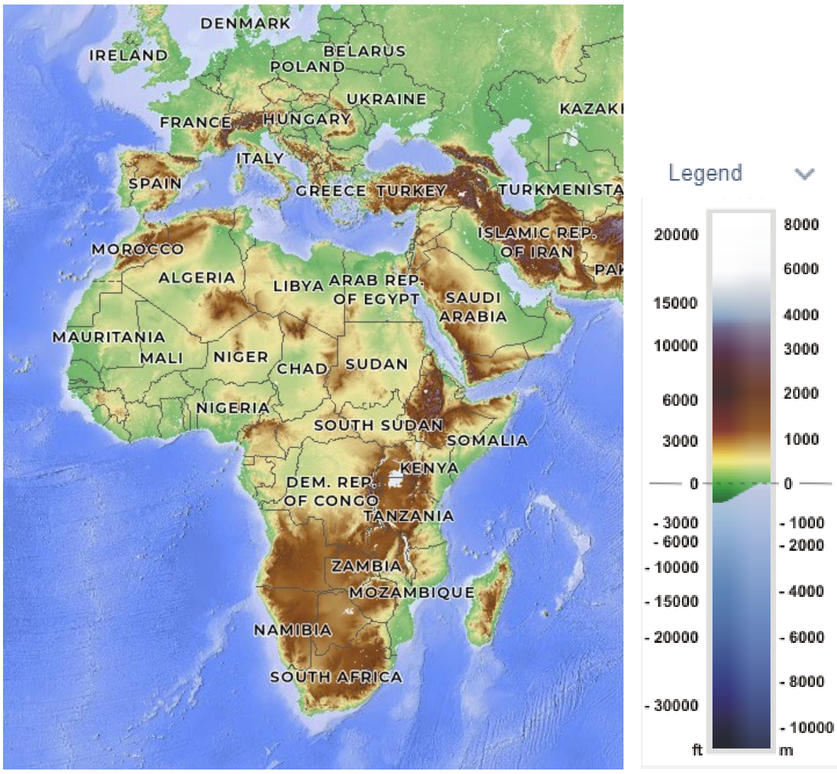


Figure 5: **Elevation of terrain surface above/below sea level, processed and integrated from SRTM-3 data and related data products (© 2019 SRTM)**

As shown in Figure 3, African continent is mainly characterized by an average air temperature value above 20 °C, which highlights the key role of adopting passive cooling strategies in buildings. However, certain territories in North Africa, South Africa and other small regions present colder winters, as shown in Figure 6.

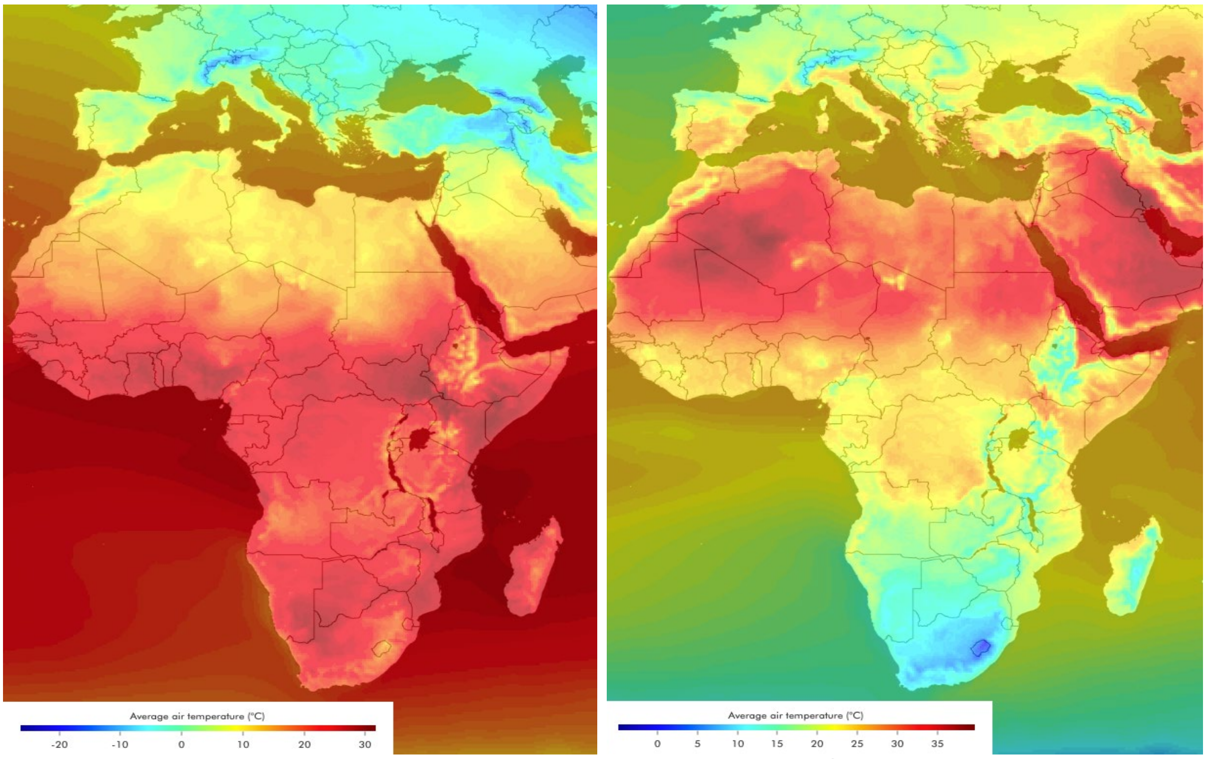


Figure 6: Monthly mean air temperature (January scenario on the left, July scenario on the right) from Past Climate Explorer (Source: ERA5 dataset, 1981-2010)

Countries like Morocco, Algeria, Tunisia and Libya show a temperature difference of 20 °C between the coldest and warmest months [19]. As in southern Europe and unlike other African states, these areas are characterized by a short winter which implies an energy need for heating in buildings [20].

2.3 Bioclimatic design strategies

Bioclimatic architecture allows to increase the comfort of a building in any season or climate by reducing the energy need for heating, cooling, lighting and ventilation, which also leads to a decrease in energy costs [4]. A building can be declared bioclimatic when it exploits the locally climatic resources within its design applying passive measures. Figure 7 shows a schematic illustration of bioclimatic concept.

Although buildings have a strong potential of reducing their energy consumption and greenhouse gas emissions, the main challenge is to achieve this target without compromising thermal comfort needs. Several bioclimatic diagrams are used as tools during the design phase to identify the appropriate passive strategy and achieve comfort levels. The most widely used involve the diagram developed by Victor Olgyay [21], and the diagram by Baruch Givoni [3] (see *D3.2 - Report on comfort indicators and scenarios* for the complete description).

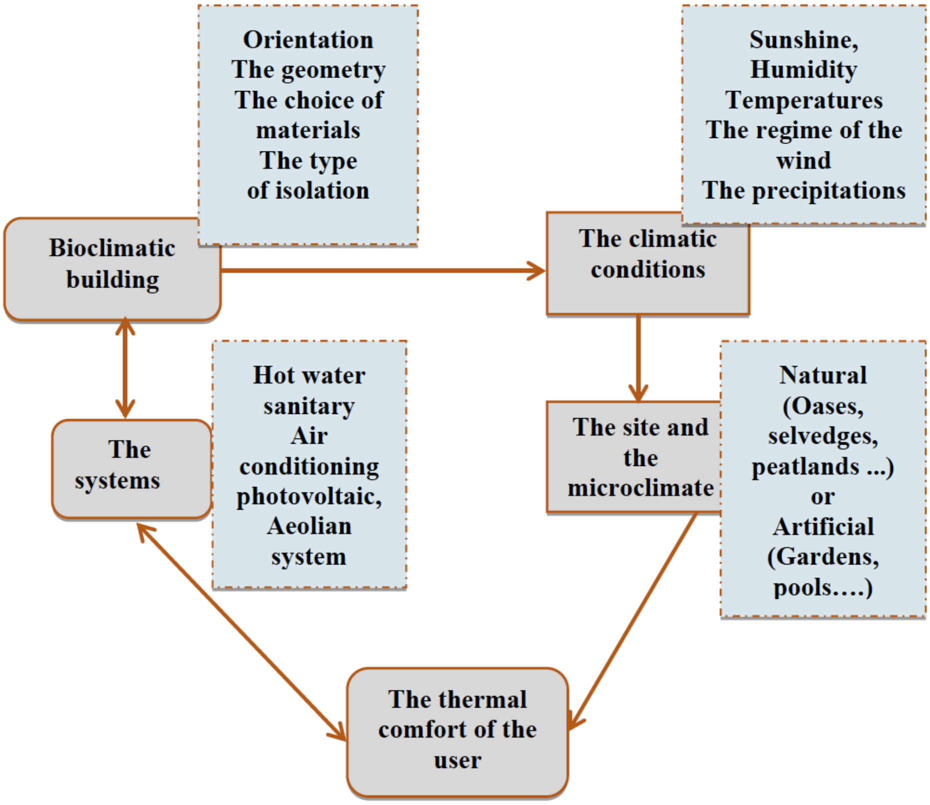


Figure 7: Schematic illustration of bioclimatic concept [22]

Several aspects should be analyzed during the design process, which are associated with the available environmental resources, such as the orientation of the house, the solar protection needs, the required spacing between buildings, the road and promenades' surface, the implementation of trees and green areas to lessen the impact of radiation and preserve fresh air and types of materials to be used. In the variety of climatic contexts, it is possible to achieve a balance between building and climate by applying a series of project strategies – referred as **bioclimatic or passive design strategies**. In Table 3 a possible list of variables to be considered in the design of a bioclimatic building is presented and will be considered in the definition of the assessment criteria in *Task 3.4 – Case studies of European and African bioclimatic buildings*.

Table 3: Study variables in the assessment of bioclimatic buildings [23]

N	Major variable	Sub variables
1	Building envelope and orientation	- Using materials that reduce heat gain and loss - East-West Orientation - Provision of water bodies
2	Energy Source	- Photovoltaic panels - Wind energy
3	Sun Shading Device	- Windows overhang - Operable shading device - Recesses - Internal Shading
4	Passive Design	- Natural Ventilation (size and type and position of windows) - Ceiling height - Natural lighting - Use of court yard - Zoning of internal spaces
5	Indoor Air Quality	- Avoidance of stale air build up - use of ventilation control system - Avoiding noise, avoiding air pollutants - Visual amenity - Green elements in the interior
6	Heating And Cooling	- Green roof - evaporative cooling
7	Landscape	- Effective use of vegetation - Reflective roof - Water bodies - Vertical landscap
8	Thermal mass	- Use of materials with good thermal mass e.g. clay bricks, concrete tiles etc

Considering that heat is the predominant feature of African climates, particular attention should be given to the issue of cooling of buildings, which is fundamental to achieve comfortable living environments. The cooling of buildings can be realized by natural strategies, avoiding the use of extensive mechanical systems. The aim of the passive cooling techniques is to avoid the accumulation of heat gains and provide natural cooling, avoiding the occurrence of overheating. A summary of the passive cooling techniques is reported in [23].

3 Creating a common framework

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.

EU has created via its Directives a legislative infrastructure (mandatory Building performance certificates, cost-optimal methodology, mandatory nearly Zero Energy Buildings, National renovation plans) and support actions (e.g. Framework Research Program, H2020, fiscal and incentives to energy efficiency in many states, etc.). Voluntary labels like Minergie and Passivhaus, in certain cases used by local governments as standards, have favoured innovation and high-quality materials and components. But also limitations have come by a non-uniformity in the definition of overall building performance in terms of energy needs, delivered energy, total or non-renewable primary energy, non-uniformity of nomenclature across countries, which creates a barrier to effective communication and comparability of performances of design approaches and techniques.

In the following we report a selection of the main concepts, definitions, and terminology, mostly taken from European and International standards to create a common framework as a necessary basis for effective design work, and its communication. In addition, to support and simplify the identification of the energy levels in a sound manner, some visual representations are provided. A clear explanation of the four essential energy concepts (energy need, delivered energy, total and non-renewable primary energy) can be also retrieved in a video [24]. These materials have been developed within the European Union's Horizon 2020 project AZEB [25] (Affordable Zero Energy Buildings). The additional representation of the *energy need for cooling* has been realized within ABC 21.

3.1 Nomenclature and definitions about building levels and indexes from EN-ISO 52000-1:2017 [26]

NOTE: all the terms defined in ISO or EN Standards or the EU Directives will be written in *underlined italics* in this text. The following definitions are mainly also available at the ISO Online Browsing Platform (OBP) [27], in English and partly in French, as in the example below:

Terms & Definitions

energy need for heating or cooling	**besoin d'énergie pour le chauffage ou le refroidissement**
heat to be delivered to or extracted from a thermally conditioned space to maintain the intended space temperature conditions during a given period of time	chaleur à fournir ou à extraire d'un espace climatisé pour maintenir les conditions de température voulues dans cet espace pendant une durée donnée
ISO 52000-1:2017(en), 3.4.13	ISO 52000-1:2017(fr), 3.4.13

Available in: EN FR

Figure 8: Example of definition available at the ISO Online Browsing Platform (OBP)

- "*energy need for heating or cooling*" heat to be delivered to or extracted from a *thermally conditioned space* to maintain the intended space temperature conditions during a given period of time (ref. 3.4.13 in EN-ISO 52000-1:2017)
- "*energy need for domestic hot water*" heat to be delivered to the needed amount of domestic hot water to raise its temperature from the cold network temperature to the prefixed delivery temperature at the delivery point without the losses of the domestic hot water system (ref. 3.4.12 in EN-ISO 52000-1:2017)
- *"useful heat gain"* part of internal and solar heat gains that contribute to reducing the *energy need for heating* (ref. 3.6.11 in EN-ISO 52000-1:2017)

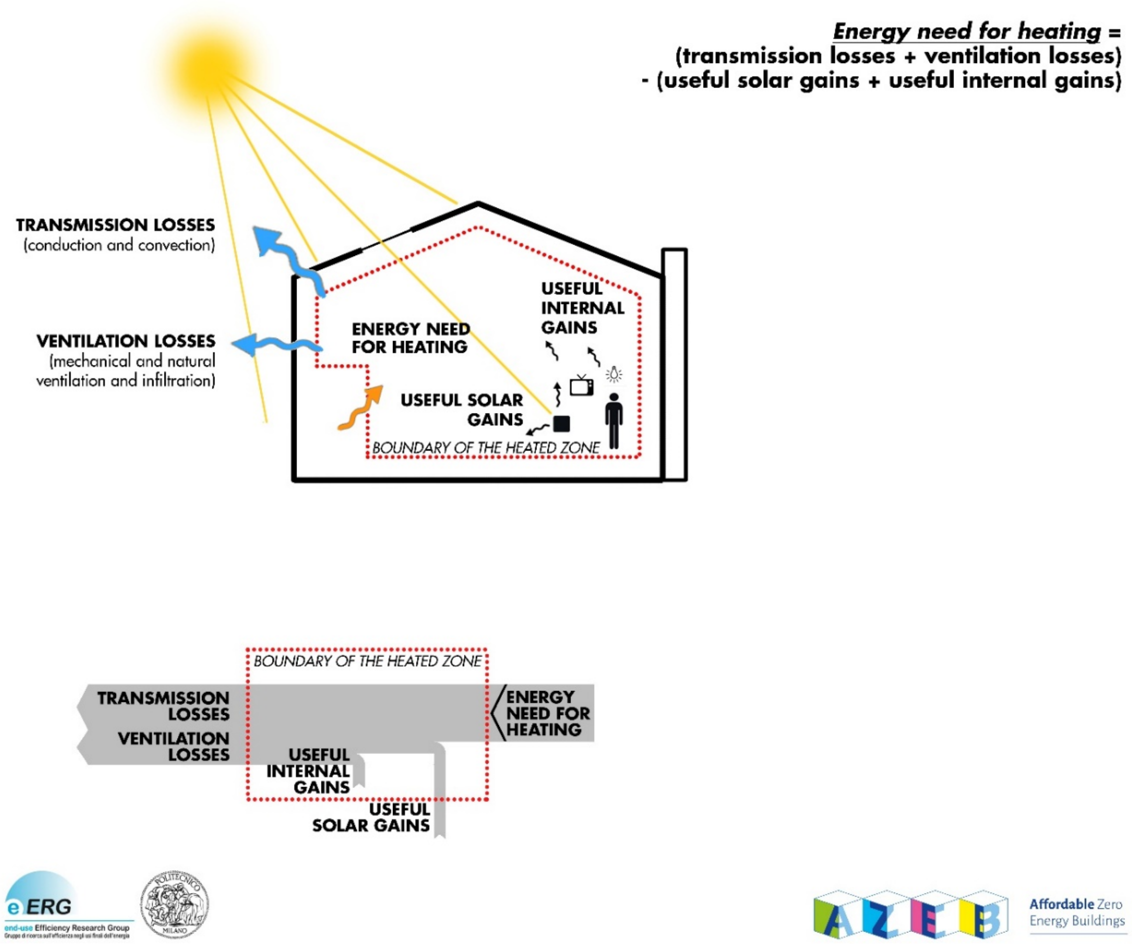


Figure 9: Scheme of energy levels: *energy need for heating*. Source: Erba S., Pagliano L. 2019. AZEB project

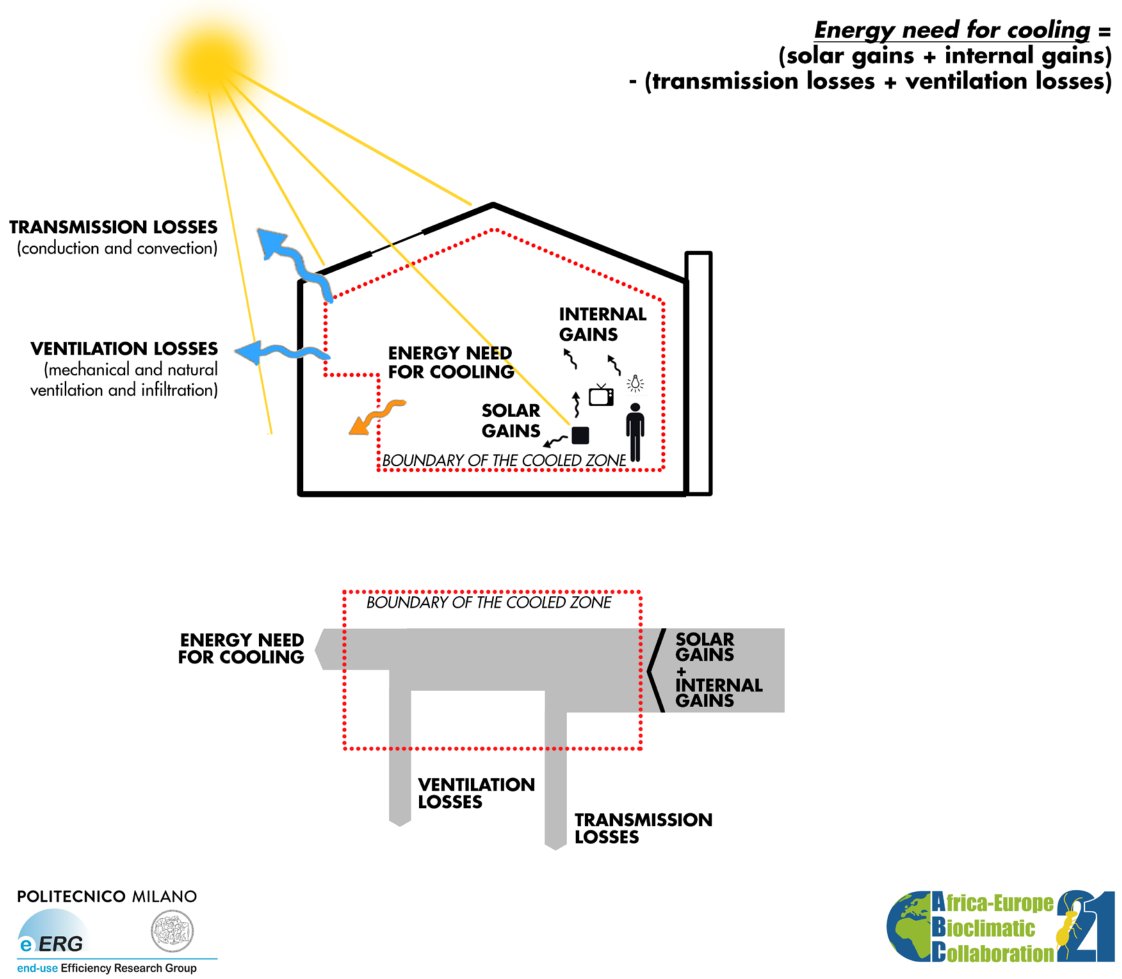


Figure 10: Scheme of energy levels: *energy need for cooling*. Source: Erba S., Pagliano L. 2021. ABC 21 project

- "*energy use for lighting*" electrical energy input to the lighting system (ref. 3.4.16 in EN-ISO 52000-1:2017)
- *"building service"* service provided by technical building systems and by appliances to provide acceptable indoor environment conditions, domestic hot water, illumination levels and other services related to the use of the building (ref. 3.3.3 in EN-ISO 52000-1:2017)
- *"EPB service"* building service included in the assessment of the energy performance (ref. 3.5.13 in EN-ISO 52000-1:2017)
- "*delivered energy*" energy, expressed per energy carrier, supplied to the technical building systems through the assessment boundary, to satisfy the uses taken into account or to produce the exported energy. (Note that *delivered energy* can be calculated for defined energy uses or it can be measured). (ref. 3.4.6 in EN-ISO 52000-1:2017)

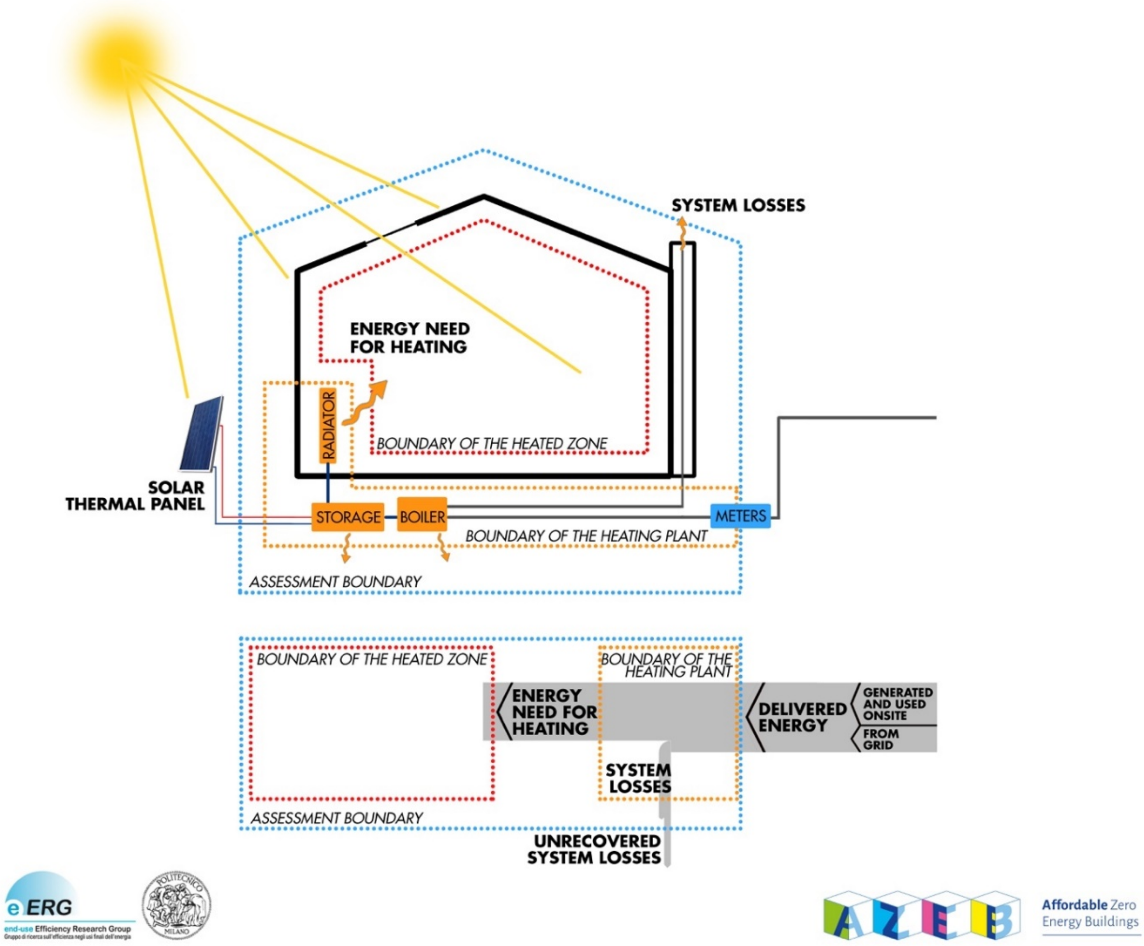
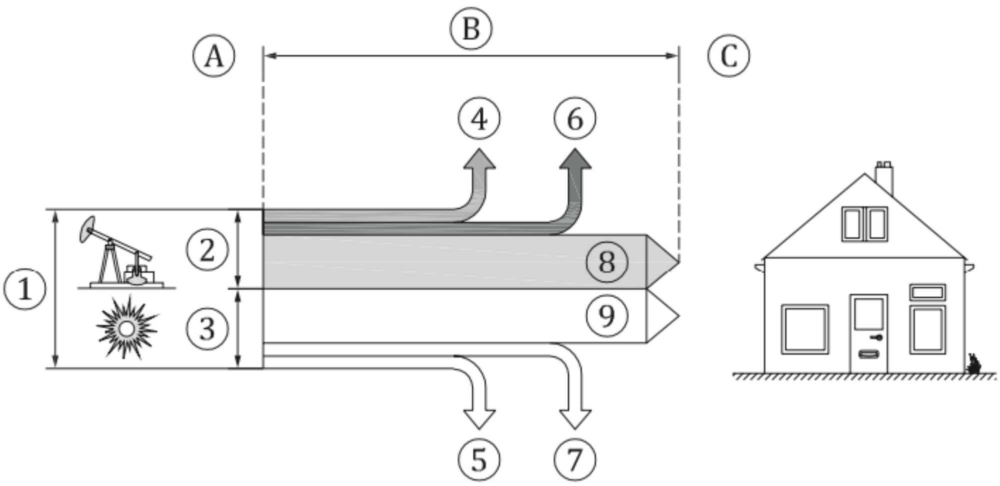


Figure 11: Scheme of energy levels: *delivered energy*, case where the energy service considered is space heating, delivered by a boiler and on-site solar thermal panels. Source: Erba S., Pagliano L. 2019. AZEB project

- "energy *from renewable sources*" "*renewable energy*" energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases (ref. 3.4.11 in EN-ISO 52000-1:2017)
- **"***non-renewable energy***"** energy taken from a source which is depleted by extraction (e.g. fossil fuels**)**. Note 1 to entry: Resource that exists in a finite amount that cannot be replenished on a human time scale. (ref. 3.4.26 in EN-ISO 52000-1:2017)
- **"***primary energy***"** energy that has not been subjected to any conversion or transformation process. (Note that primary energy includes non-renewable energy and renewable energy. If both are taken into account, it can be called *total primary energy*) (ref. 3.4.29 in EN-ISO 52000-1:2017)
- **"***non-renewable primary energy factor***"** non-renewable *primary energy* for a given energy carrier, including the *delivered energy* and the considered energy overheads of delivery to the points of use, divided by the *delivered energy* (ref. 3.5.17 in EN-ISO 52000-1:2017)
- **"***numerical indicator of primary energy use***"** primary energy use per unit of reference floor area**.** Note 1 to entry: Since primary energy use can be expressed in total primary

energy, non-renewable primary energy can be specified in the numerical indicator (e.g., non-renewable primary energy use). (ref. 3.5.18 in EN-ISO 52000-1:2017)

- **"*renewable primary energy factor*"** renewable *primary energy* for a given *distant* or *nearby* energy carrier, including the *delivered energy* and the considered energy overheads[1] of delivery to the points of use, divided by the *delivered energy* (ref. 3.5.21 in EN-ISO 52000-1:2017)
- **"*total primary energy factor*"** sum of renewable and non-renewable *primary energy factors* for a given energy carrier (ref. 3.5.25 in EN-ISO 52000-1:2017)



$$f_{\mathrm{Ptot}} = \frac{1}{8+9} \qquad f_{\mathrm{Pnren}} = \frac{2}{8+9} \qquad f_{\mathrm{Pren}} = \frac{3}{8+9}$$

Key

A	energy source	4	non-renewable infrastructure related energy
B	upstream chain of energy supply	5	renewable infrastructure related energy
C	inside the assessment boundary	6	non-renewable energy to extract, refine, convert and transport
1	total primary energy	7	renewable energy to extract, refine, convert and transport
2	non-renewable primary energy	8	delivered non-renewable energy
3	renewable primary energy	9	delivered renewable energy

Figure 12: schematic representation of the definition of total, non-renewable and renewable primary energy factors, according to ISO 52000-1:2017 [26]

[1] "Energy overhead" stands for the energy used for transporting the generated renewable energy to the building, e.g. the energy losses on the electric grid and energy storage for supplying wind energy from a distant wind farm to the building.

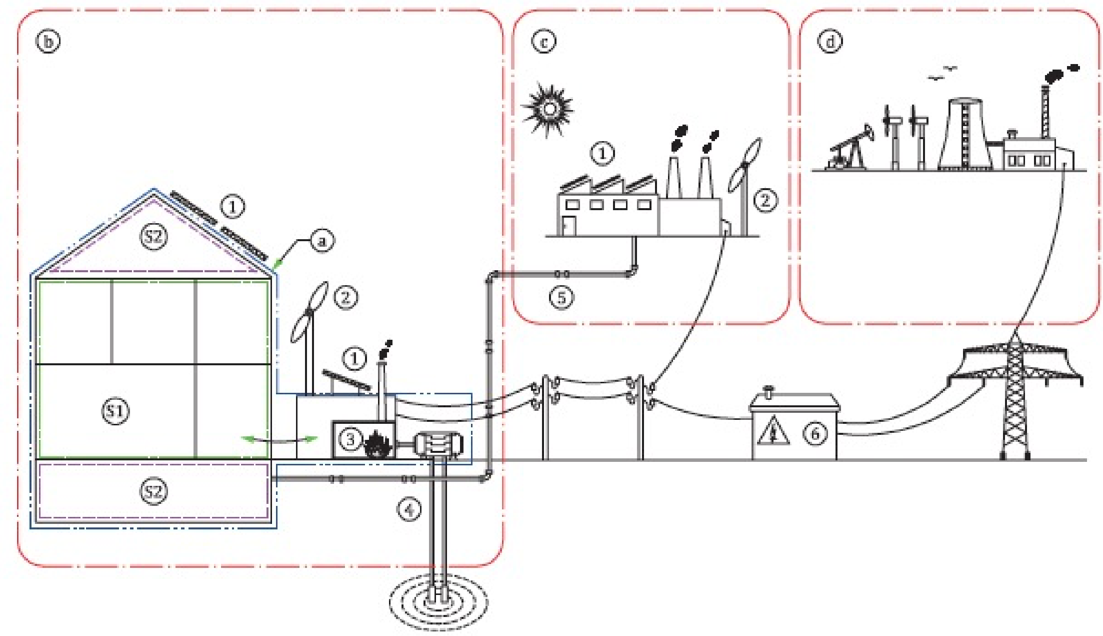
Table 4: Example of primary energy factors chosen by the Italian Legislator [Source: DM 26/6/15, Ann. 1, Art.1.1]. $f_{P,TOT}$ = total primary energy factor, $f_{P,REN}$ = renewable primary energy factor, $f_{P,NREN}$ = non-renewable primary energy factor

Energy carrier	$f_{P,NREN}$	$f_{P,REN}$	$f_{P,TOT}$
Natural gas	1.05	0	1.05
GPL	1.05	0	1.05
Fuel oil	1.07	0	1.07
Coal	1.1	0	1.1
Solid biomass	0.2	0.8	1
Liquid and gaseous biomass	0.4	0.6	1
Electric energy from the grid	1.95	0.47	2.42
District heating	1.5	0	1.5
Municipal solid waste	0.2	0.2	0.4
District cooling	0.5	0	0.5
Thermal energy from solar collectors	0	1	1
Electric energy produced by photovoltaic, small scale wind/hydro electricity (self-consumption)	0	1	1
Electric energy produced by photovoltaic, small scale wind/hydro electricity (export to the grid)	0	1 (only to counterbalance consumption in the same month, NOT in the entire year)	1 (only to counterbalance consumption in the same month, NOT in the entire year)
Thermal energy from the external environment - Free cooling	0	1	1
Thermal energy from the external environment - Heat pump	0	1	1

The *assessment boundary* (which is the one that is crossed by delivered energy and exported energy) is distinct from the on-site, nearby and distant *perimeters*

- *"nearby"* <the building site> on local or district level (e.g., district heating or cooling) (ref. 3.4.24 in EN-ISO 52000-1:2017)
- *"on-site"* the premises and the parcel of land on which the building(s) is located and the building itself. Note that on-site defines a strong link between the energy source (localisation and interaction) and the building (ref. 3.4.27 in EN-ISO 52000-1:2017)
- *"distant"* <to the building site> not *on-site* nor *nearby* (ref. 3.4.7 in EN-ISO 52000-1:2017)

The concept of on-site, nearby and distant is schematically shown in Figure 13.



Key

a	assessment boundary (use energy balance)	1	PV, solar
b	perimeter: on-site	2	wind
c	perimeter: nearby	3	boiler room
d	perimeter: distant	4	heat pump
S1	thermally conditioned space	5	district heating/cooling
S2	space outside thermal envelope	6	substation (low/medium voltage and possible storage)

Figure 13: Example of a scheme representing the concept of perimeters and assessment boundary. Source: EN-ISO 52000-1

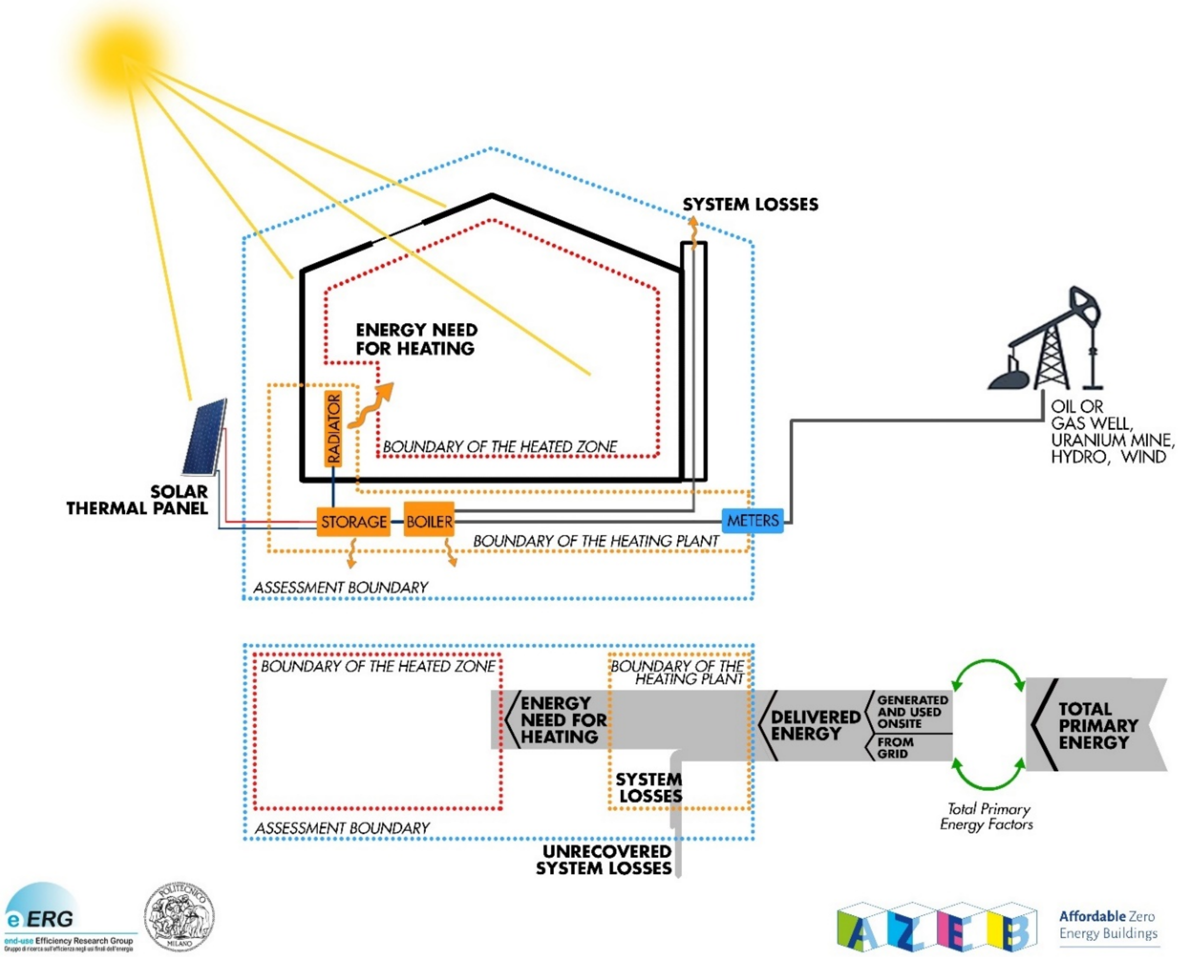


Figure 14: Scheme of energy levels: *total primary energy*, case where the energy service considered is space heating, delivered by a boiler and on-site solar thermal panels. Source: Erba S., Pagliano L. 2019. AZEB project

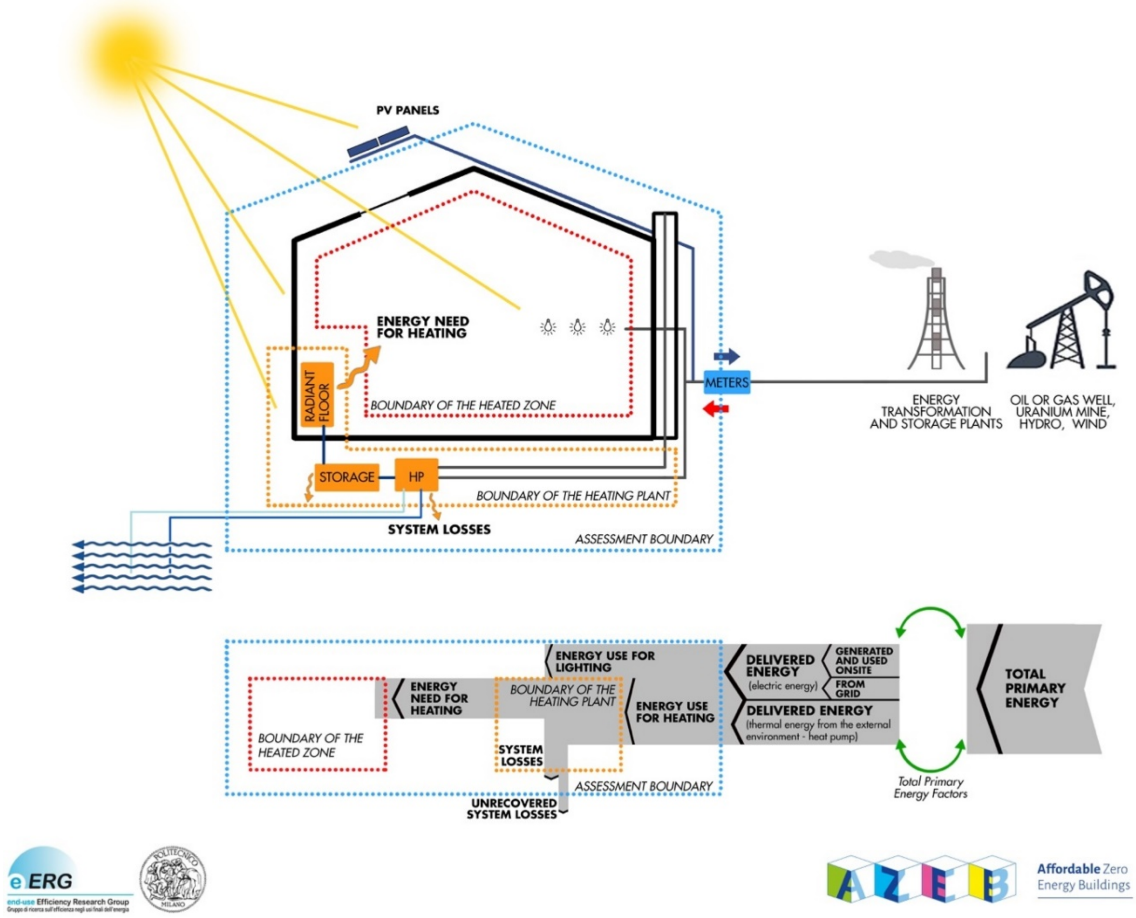


Figure 15: Scheme of energy levels: *total primary energy*, case where the energy service considered is space heating and the energy is delivered by a heat pump and on-site PV panels. Source: Erba S., Pagliano L. 2019. AZEB project

- "*building fabric*" all physical elements of a building, excluding *technical building systems*

  Example: Roofs, walls, floors, doors, gates and internal partitions. It includes elements both inside and outside of the thermal envelope, including the *thermal envelope* itself. The fabric determines the thermal transmission, the thermal envelope airtightness and (nearly all of) the thermal mass of the building (apart from the thermal mass of furniture and technical building systems). The fabric also acts as an indoor barrier to wind and rain. The building fabric is sometimes described as the building as such, i.e., the building without any technical building system. (ref. 3.1.5 in EN-ISO 52000-1:2017)

- **"***thermal envelope area***"** total area of all elements of a building that enclose *thermally conditioned spaces* through which thermal energy is transferred, directly or indirectly, to or from the external environment. Note 1: the thermal envelope area depends on whether internal, overall internal or external dimensions are being used. Note 2: the thermal envelope area does not include the area to adjacent buildings; see ISO 13789:2017 [28]. Note 3: the thermal envelope area may play a role in the ways to express the overall and partial energy performance and energy performance requirements and comparison against benchmarks. [source: ISO 13789:2017 [28], 3.9 — with addition of notes 2 and 3] (ref. 3.1.15 in EN-ISO 52000-1:2017)

- *"technical building system"* means technical equipment for space heating, space cooling, ventilation, domestic hot water, built-in lighting, building automation and control, on-site electricity *generation*, or a combination thereof, including those systems using energy from renewable sources, of a building or building unit; (EPBD 2018 [29] Art.2, definitions)
- **"***thermally conditioned space***"** heated and/or cooled space (ref. 3.1.16 in EN-ISO 52000-1:2017)
- **"***thermally unconditioned space***"** room or enclosure that is not part of a *thermally conditioned space* (ref. 3.1.17 in EN-ISO 52000-1:2017)
- **"***useful floor area***"** <for EPB assessment> area of the floor of a building needed as parameter to quantify specific conditions of use that are expressed per unit of floor area and for the application of the simplifications and the zoning and (re-)allocation rules (ref. 3.1.18 in EN-ISO 52000-1:2017)
- "*degree-days*" ISO 15927-6:2007 [30] (where they are named *accumulated temperature differences)* specifies the definition and method of computation for the heating *degree-days*, which represents an index of climate severity as it affects energy use for space heating. "Calculation or estimation of accumulated temperature differences is based on the concept of a base temperature. The base temperature reflects the point at which buildings begin to need heating to maintain the required internal temperatures. This is the external temperature below which the heating plant is assumed to come into operation."

  When hourly data are available, heating *degree-days* (HDD) shall be calculated according to the following equation:

  HDD = $\sum_{h=1}^{n} \Delta T_h \,(T_b)/24$

  where:

  $\Delta T_h\,(T_b) = (T_b - T_{hm})$ if $T_{hm} < T_b$
  $\Delta T_h(T_b) = 0$ if $T_{hm} > T_b$

  with:

  T_b: base temperature [°C]
  ΔT_h: hourly temperature difference [°C]
  T_{hm}: hourly mean temperature [°C]

  When hourly data are not available, the approximate method given in 4.5 (ref. ISO 15927-6:2007), based on the maximum and minimum temperatures each day, may be used.

  NOTE: since calculating using daily or hourly data, or different choices of a conventional base temperature, brings to different values of HDD, the exact definition of HDD used in every calculation/project should be made explicit. Cooling Degree Days (CDD) are defined in a similar manner. In this case, it is especially important to specify the chosen base temperature since the potential range for the choice is broader.

ABC21 is funded by the
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Additional explanation regarding Degree Days are reported in *D3.4 - Report on availability of weather files and indicators for today and future weather in Africa and EU*.

3.2 Nomenclature and definitions about area and space indicators from ISO 9836:2017 [31]

- The surface areas are expressed in square metres, to two decimal places (ref. 5.1.1.2 in ISO 9836:2017)
- "*covered area*" is the area of ground covered by buildings in their finished state (ref. 5.1.2.1 in ISO 9836:2017)
- "*total floor area*" of a building is the total area of all floor levels. Floor levels may be storeys which are either completely or partially under the ground, storeys above ground, attics, terraces, roof terraces, service floors or storage floors (ref. 5.1.3.1 in ISO 9836:2017)
- "*total floor area*" of each level is obtained from the external dimensions of the enclosing elements, at floor height, above and below ground. These elements include finishes, claddings and parapets (ref. 5.1.3.2 in ISO 9836:2017)
- "*total floor area*" is calculated separately for each floor level. Areas with varying storey height within one floor level (e.g. large halls, auditoria) are also calculated separately (ref. 5.1.3.3 in ISO 9836:2017)
- "*total floor area*" is made up of the net floor area and the area taken up by the structure (ref. 5.1.3.5 in ISO 9836:2017).
- "*intra-muros area*" is the "*total floor area*" less the floor area taken up by the external walls (floor area of the building envelope) (ref. 5.1.4.1 in ISO 9836:2017).
- "*net floor area*" is the area between (within) the enclosing elements (ref. 5.1.5.1 in ISO 9836:2017)
- The "*net floor area*" is determined separately for each floor level. It is calculated from the clear dimensions of the finished building at floor height, excluding skirtings, thresholds, etc.
- Covered floor areas that are not enclosed or only partially enclosed and have no enclosing elements are determined by the vertical projection of the outer limit of the covering components. Areas with varying storey height within one floor level (e.g. large halls and auditoria) are calculated separately. (ref. 5.1.5.2 in ISO 9836:2017)
- Also included in the "*net floor area*" are demountable components such as partitions, pipes and ducts. (ref. 5.1.5.3 in ISO 9836:2017)
- floor "*areas of structural elements*", door and window recesses, and niches to recesses in the elements enclosing the area are not included in the *net floor area* (ref. 5.1.5.4 in ISO 9836:2017)
- The *net floor area* is divided into *usable area*, *services area* and *circulation area*. (ref. 5.1.5.5 in ISO 9836:2017)

- "*area of structural elements"* is the area within the *total floor area* (on a horizontal section at floor level) of the enclosing elements (e.g. external and internal load-bearing walls) and the area of columns, pillars, piers, chimneys, partitions, etc., which cannot be entered. (ref. 5.1.6.1 in ISO 9836:2017)
- "*usable area"* is that part of the net floor which corresponds to the purpose and use of the building. (ref. 5.1.7.1 in ISO 9836:2017)
- "*services area"* is that portion of the *net floor area* with technical installations which service the building or parts of it. (ref. 5.1.8.1 in ISO 9836:2017)
- "*circulation area*" is that portion of the net area used for circulation within the building (e.g. the area of stairwells, corridors, internal ramps, waiting areas, escape balconies, etc.). (ref. 5.1.9.1 in ISO 9836:2017)
- The *net floor areas* of lift shafts and the floor areas of built-in conveying installations for general circulation, e.g. escalators, on each floor level are also included in the category of *circulation area*. (ref. 5.1.9.3 in ISO 9836:2017)
- "*building envelope area"* is obtained from buildings or parts of buildings which are enclosed on all sides and covered, including those parts of the structure which are above the top level of the ground and those below it. (ref. 5.1.10.1 in ISO 9836:2017)

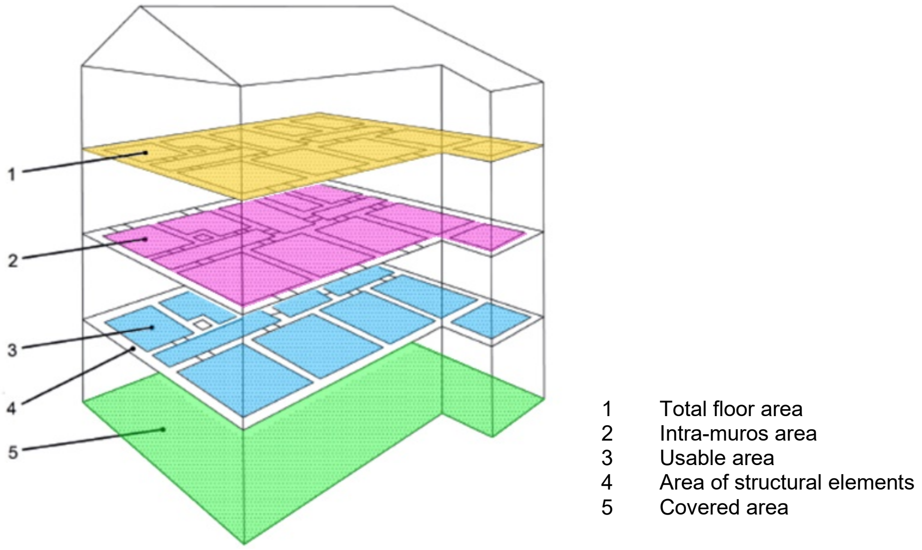

Figure 16: Presentation of principal areas - figure adapted from ISO 9836:2017 [Note: colours have been introduced by the authors of this chapter for higher clarity]

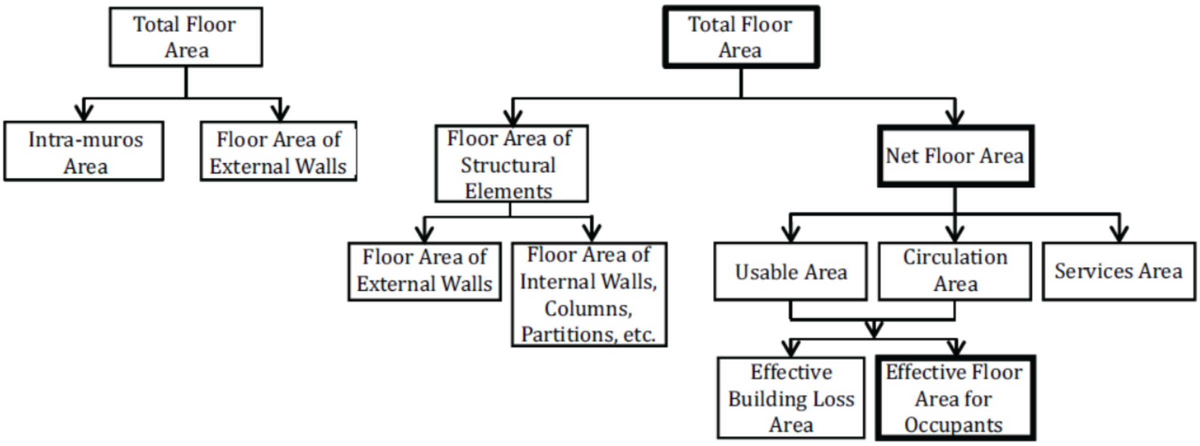

Figure 17: Components of total floor area - scheme from ISO 9836:2017 [31]

4 Energy Key Performance Indicators (KPIs) for bioclimatic buildings

Quantifying building performance with respect to energy use is an essential baseline for assessing any potential savings along with evaluating and validating improvements. In new constructions, this information is useful to the planning, design, construction, and commissioning phases. In existing buildings, quantifying baseline energy performance is necessary when performing fault detection and diagnostics, retro-commissioning, and measurement and verification, along with making retrofit decisions [32].

Literature shows efforts in using the performance-based approach and the **energy Key Performance Indicators (KPIs)** represent the base to quantify and benchmark the energy performance of buildings. They allow the measurement and management of the progress towards the project's goals to guide design development, comparing design solutions and supporting the decision-making process. However, the passive behaviour of a building, is not effortlessly synthetized: conditioned buildings may be easily compared addressing indicators such as the total primary energy use and the non-renewable primary energy use, while buildings with no thermal plant need more sophisticated analyses because in these kind of buildings, it is particularly difficult to assess the effect of passive strategies.

With reference to the definition of bioclimatic architecture reported in section 2.1, we can state that besides meeting the essential requirement to build an advanced building with the nearly-zero energy target, the bioclimatic architecture also aims to guarantee the satisfaction and maintenance of the comfort conditions of the users adopting passive strategies. In ABC 21 project we will take into account both buildings without any mechanical system and buildings equipped with a mechanical system that exploits renewable energy to a very significant extent.

The aim of identifying KPIs is:

- to define a simple set of indicators to be used during the design phase of bioclimatic buildings and easy to check during the construction, commissioning, measurement and verification phase. Adopting a clear and common nomenclature according to standards allows effective communication between different actors (policy makers, professional designers, building energy managers and building owners), with different backgrounds and coming from different countries.
- To consistently analyse and compare the energy performance of the different case studies selected in Task 3.4.

4.1 Sources

To define the list of energy KPIs for ABC 21 different sources have been analysed: EN-ISO standards (Table 5), European projects (Table 6) and scientific literature.

Table 5 Selection of standards relevant to ABC 21 energy KPIs definition

Standard	Title
ISO 52000-1:2017 [26]	Energy performance of buildings - Overarching EPB assessment. General framework and procedures
ISO/TR 52000-2:2017 [33]	Energy performance of buildings - Overarching EPB assessment - Part 2: Explanation and justification of ISO 52000-1
ISO 52016-1:2017 [34]	Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads. Calculation procedures
EN ISO 52003-1:2017 [35]	Energy performance of buildings - Indicators, requirements, ratings and certificates - Part 1: General aspects and application to the overall energy performance
ISO 52018-1:2017 [36]	Energy performance of buildings - Indicators for partial EPB requirements related to thermal energy balance and fabric features - Part 1: Overview of options
ISO 9836:2017 [31]	Performance standards in building - Definition and calculation of area and space indicators

Table 6 List of European projects relevant to ABC 21 energy KPIs definition

Project acronym	Project title	Relevant aspects
AZEB	Affordable Zero Energy Buildings	Definition of indicators and assessment methods for cost effective nZEB
CRAVEzero	Cost Reduction and market Acceleration for Viable nearly zero-Energy buildings	Definition of KPIs for performance-based characterization of nZEB
ExcEED	European Energy Efficient building & district Database	Definition of a collection of tailored Key Performance Indicators (KPIs) that will “transform data into information”
inteGRIDy	integrated Smart GRID Cross-Functional Solutions for Optimized Synergetic Energy Distribution, Utilization & Storage Technologies	Definition of KPIs about the overall energy system performance towards the evaluation of the high-level business objectives defined in the inteGRIDy project

4.2 KPIs for the assessment of nearly Zero Energy Buildings

The energy performance of bioclimatic buildings can be assessed starting from the target of nearly Zero Energy Buildings (nZEBs). According to the European Directive on Energy Performance of Buildings [37], “a ‘nearly zero-energy building’ means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”. Following the ISO 52000-1 (annex H), a set of indicators can be defined to address: the quality of the building fabric, the efficiency of active technical building systems and the use of renewable energy sources.

The performance of the building fabric can be evaluated on the basis of the *energy needs for heating and cooling*. They take into account:

- the quality of the building envelope (e.g., insulation, windows);
- the bioclimatic design (e.g., solar gains, natural lighting);
- the thermal inertia, the zoning; and
- the need to guarantee adequate indoor environmental conditions in order to avoid possible negative effects such as poor indoor air quality (due to lack of ventilation) or hygrothermal problems (such as mold).

In addition, the *energy needs for hot water*, the *energy use for ventilation* and *energy use for lighting* (by electric lighting systems) should be also addressed.

The performance of *technical building systems* (e.g. their efficiency in covering the *energy needs* starting from renewable or non-renewable sources) can be evaluated using the *total primary energy* use.

Total / renewable / non-renewable primary energy is calculated by multiplying each stream of *delivered energy* for the respective *total / renewable / non-renewable primary energy factors.*

The *non-renewable primary energy* use accounts for the part of *total primary energy* not yet covered by renewable sources (either generated *on site* or *nearby* or *distant*).

Non-renewable primary energy use can be additionally calculated with or without *compensation* between energy carriers and with or without compensations for renewable energy exported to the grid.

The *primary energy factors* used in the calculation of primary energy should be always explicitly reported, indicating the renewable and non-renewable part (see Table 4 as an example). In case there is a choice to adopt compensation for exported energy when calculating non-renewable primary energy, the factors for renewable energy delivered TO the assessment boundary of the building or exported FROM the assessment boundary to the grid should also be reported. The latter two factors may be symmetrical (identical) or asymmetrical (different).

The *renewable energy* generation on site can be expressed as a *primary energy* production. In order to evaluate to which extent the energy required is covered by renewable sources, the ratio of *renewable primary energy* over the *total primary energy* use is proposed as an indicator.

It is worth noting that the values of the above mentioned indicators for assessing the building energy performances depend also on the chosen comfort scenario (combination of temperature, air velocity, humidity, etc.), which should be explicitly defined and described. This topic has been addressed in *D3.2 – Report on comfort indicators and scenarios*.

Table 7 reports a complete set of indicators, in line with EN ISO standards, for describing a nearly ZEB. It has been defined within the EU project AZEB (Affordable Zero Energy Buildings), both for policymaking and for design practice [38,39] and consists of:

- Energy needs for heating, cooling and hot water and energy use for ventilation and lighting
- Total primary energy use
- Renewable primary energy use/total primary energy use (which is equivalent to indicating the non-renewable primary energy use defined in EN ISO)
- Indicating explicitly in a table the assumed values of $f_{P,TOT}$, $f_{P,NREN}$ and $f_{P,REN}$ (the latter separately for import to or export from the building if they are different).
- The building services considered should be at least heating, cooling, ventilation, hot water and lighting as stated in EPBD.

A selection of these indicators will be considered in the case studies identified in Task 3.4, on the base of the data available (e.g. energy performance certificates, electricity bills, dynamic energy simulations etc.).

Table 7 KPIs for nearly Zero Energy Buildings [38]

Energy, Quality of the building fabric	Per unit of heated or conditioned floor area
Energy needs for heating (kWh/y/m^2)	
Energy needs for cooling (kWh/y/m^2)	
Optional: *Energy use for lighting* (kWh/y/m^2)	
Optional: air tightness (ACH at 50 Pa difference or equivalent)	
Energy, users' behaviour and appliances	Per unit of heated or conditioned floor area
Energy needs for Sanitary Hot water (kWh/y/m^2)	
Total *internal gains* (kWh/y/m^2)	From lighting, appliances, IT equipment, people
***Total primary Energy*, (Building fabric + systems)**	Per unit of heated or conditioned floor area On Hourly, monthly and yearly base
Total Primary energy use (kWh/y/m^2)	
Provide values for present national *primary energy factors* – PEF (3 values for each flow of delivered energy: total, renewable, non renewable)	Natural gas, heat from district heating, electricity from the grid , PV, other renewables,…

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	Per unit of heated or conditioned floor area On Hourly, monthly and yearly base
Renewable Primary energy generated on-site (kWh/y/m²) *Renewable Primary energy* generated on-site and Self consumed (kWh/y/m²) *Renewable Primary energy* exported to the grid (kWh/y/m²)	
***Non Renewable Primary Energy*, or Global primary energy balance**	Per unit of heated or conditioned floor area On Hourly, monthly and yearly base
Non Renewable Primary energy use without compensation for exported energy (kWh/y/m²)	
Non Renewable Primary energy use with 100% compensation for exported energy (consumption minus on-site generation in kWh/y/m²)	
Renewable Primary energy use considering the 100% renewable scenario (kWh/y/m²). In this case it coincides with *Total Primary energy use*	
Ratio of *renewable primary energy* over the *total primary energy* use (with and without compensation) (%)	
Calculation time step	Please specify whether the calculation time step is an hour, a month or a year

4.3 Bioclimatic indicators

The ultimate achievement of the bioclimatic design is to obtain a fully passive building, which produce thermal comfort without mechanical system. However, the hot and humid climate led to the widespread use of air-conditioning systems and, thus, high electricity consumption [11]. In this context, bioclimatic strategies would take advantage of locally available environmental sources of freshness (air, sky vault or soil) to minimize the cooling energy consumption of the buildings.

Literature reports few studies where the environmental resources are described, and bioclimatic indicators are defined. The computation of the present indicators does not intend to replace the tools that are already used under the scope of bioclimatic procedures, such as bioclimatic charts (see *D3.2 - Report on comfort indicators and scenarios* for details). They just intend to enrich the procedures by providing an overview of the exploitable resource and of the capacity of the building to exploit those resources.

Omar et al. [11] identify four environmental cooling resources: external convection, ventilation, sky radiation and the ground. The authors defined two sets of bioclimatic indicators, one for the quantification of the amount of cooling (heating) energy of a given resource that could be exploited (sheltered) and the other for the assessment of these resources (heat sources) exploitation (sheltering) by the building. These indicators, adapted to air-conditioned buildings, are proposed to be adopted by designers and architects looking for optimal bioclimatic solutions in the early stages of building design to reduce the cooling needs in hot and humid climates.

- The first set of energy potentials depends only on the construction location and the building dimensions. It evaluates, for each environmental resource, the maximum available cooling energy. The related energy potentials are called "**environmental resource indicators**" (Figure 18; Table 8).
- The second set of energy potentials evaluates, for each environmental resource, the actual quantity of cooling energy that is utilized by a building, with a specific set of construction solutions. These are principally conceived to orientate the choice of designer toward pertinent solutions that optimize the exploitation of bioclimatic resources. The related energy potentials are called "**building performance indicators**" (Figure 19; Table 9).
- The third set of three indicators quantifies the capacity of a building to transfer outdoor cooling resources to the indoor environment (Table 10).
    - The **cover rate** relates the exploited cooling energy from a specific resource to the internal heat loads through the envelope Q^{EXP} res.
    - The **exploitation rate** relates the exploited cooling energy from a specific resource to the environmental cooling energy that would be exploitable for that specific resource.
    - The **sheltering rate** represents the capacity of the envelope to act as a barrier facing the external heat sources.

Chesné et al. [40] have defined three resource potentials (Table 8):

- The **solar total potential**, which is defined at each time step like the sum of the direct and diffuse incoming radiation on every walls of the building.
- The **sky total potential**, which is defined like the total net flow exchanged between the sky and the building walls surface. In order to take into account the impact of the radiation exchanged with the sky only, the wall surface temperature is considered at external temperature.
- The **air total potential**, which is defined like the enthalpy flow exchanged between the outside and the inside air at a temperature equal to the cooling set-point, for a given ventilation rate.

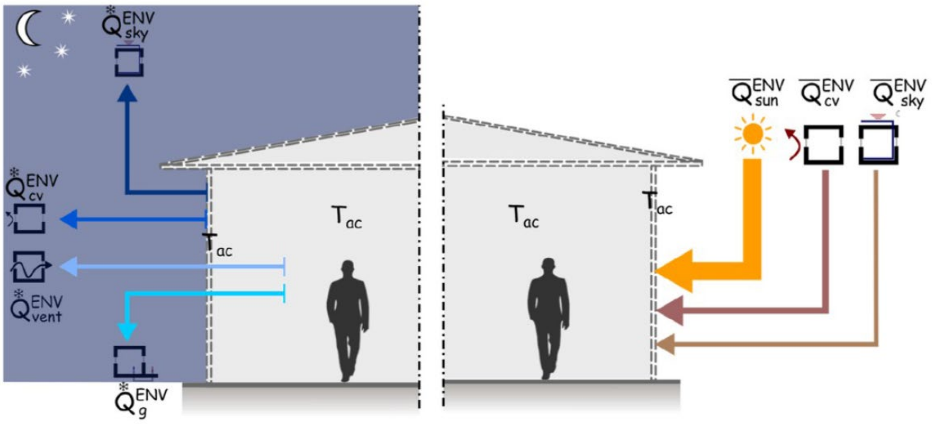

Figure 18 The Environmental Resource Indicators (ERIs)

Table 8 List of Environmental Resource Indicators (ERIs)

Environmental Resource Indicators (ERIs)	Formula	Ref
$\bar{Q}^{ENV}_{sun}$ - environmental heat input potentials from the sun	$\bar{Q}^{ENV}_{sun} = \int_0^{24} \phi_{sun} dt$ Where: ▪ $\phi_{sun} = \Sigma_w(\phi_{diff} + \phi_{dir,w})S_w$ ▪ ϕ_{diff} is the diffuse radiation ▪ $\phi_{dir,w}$ is the direct radiation on each wall and roof ▪ S_w is the surface of each wall and roof.	[11]
Q^{*ENV}_{sky} - environmental cooling potentials from the sky vault	$Q^{*ENV}_{sky} = \int_0^{24} \lvert\phi^{ref}_{sky-}\rvert \cdot I_{night} \cdot dt$ where ▪ I_{night}= 0 when sun radiation is present ▪ I_{night}= 1 when there is no radiation from the sun ▪ $\phi^{ref}_{sky} = S_{rhw} \cdot \sigma \cdot (T^4_{sky} - T^4_{ac})$ ▪ S_{rhw} is the surface of the roof plus half of the walls' surfaces	[11]
Q*cv - environmental cooling potentials from the external convection	$Q^{*ENV}_{cv} = \int_0^{24} \lvert\phi^{ref}_{cv-}\rvert \cdot I_{night} \cdot dt$ where ▪ I_{night}= 0 when sun radiation is present ▪ I_{night}= 1 when there is no radiation from the sun ▪ $\phi^{ref}_{cv} = S_w \cdot h_{cv} \cdot (T_{a,out-}T_{ac})$ ▪ S_w is the surface of each wall and roof. ▪ h_{cv} is the convective heat transfer coefficient $h_{cv} = 5.7 + 3.8v_{wind}$ ▪ T_{ac} is the air conditioning temperature	[11]

	▪ $T_{a,out}$ is the outdoor air temperature	
Q*vent - environmental cooling potentials from the natural ventilation	$Q^{*ENV}_{vent} = \int_0^{24} \lvert \phi^{ref}_{vent-} \rvert \cdot dt$ Where: ▪ $\phi^{ref}_{vent} = cp_a \cdot \rho_a \cdot \dot{V}^{ref} \cdot (T_{a,out-}T_{ac})$ ▪ $\dot{V}^{ref} = min\left[\frac{C_d \cdot S_{wind}}{2\sqrt{2}} \cdot \sqrt{\Delta C_p} \cdot v_{wind}; \frac{10 \cdot V_{bat}}{3600}\right]$ ▪ The ventilation flow $\dot{V}^{ref}$ has a maximum value fixed at 10 ach (air change per hour) ▪ C_d is the discharge coefficient of the window openings (it is assumed 0.6) ▪ ΔC_p is the difference of wind pressure coefficient between the windward and the leeward walls ▪ v_{wind} is the mean wind velocity at roof height (It is estimated as 0.5 on the windward wall and 0.7 on the leeward wall) ▪ $v_{wind} = v_b \cdot c_r(z)$ (local wind velocity from logarithmic law of Von Karman) ▪ v_b corresponds to the measured wind velocity at 10 m above ground level ▪ $c_r(z)$ is the terrain roughness coefficient, which considers the height above ground and the ground roughness of terrain upwind $c_r(z) = \begin{cases} k_r ln\left(\frac{z}{z_0}\right) & z_{min} \leq z \leq z_{max} \\ c_r(z_{min}) & z \leq z_{min} \end{cases}$ $k_r = 0.19\left(\frac{z_0}{0.05}\right)^{0.07}$	[11]
Solar total potential	$\Pi_{TOT\,sun} = \sum_{walls} \left(\phi_{dir_W} + \phi_{dif_W}\right) S_W$	[40]
Sky total potential	$\Pi_{TOT\,sky} = \sum_{walls} F_{\varepsilon\omega\sigma}(T^4_{out} - T^4_{sky}) S_W$	[40]
Air total potential	$\Pi_{TOT\,air} = \dot{m}C_p(T_{cooling} - T_{out})$ With $\dot{m} = \frac{\rho_{air} V_{in} \tau_{ventil}}{3600}$	[40]

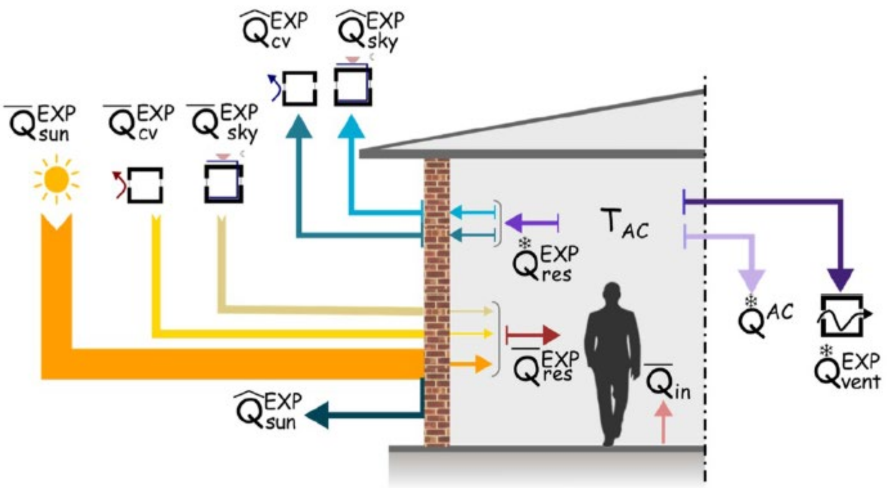

Figure 19 The building performance indicators for the design stage

Table 9 List of the Building Performance Indicators (BPIs) [11]

Building Performance Indicators (BPIs)	Formula
Qexp sky - exploited heat input potentials by the sky	$\bar{Q}_{sky}^{EXP} = \int_0^{24} \phi_{lw+} dt$
Qexp cv - exploited heat input potentials by the surface	$\bar{Q}_{cv}^{EXP} = \int_0^{24} \phi_{cv+} dt$
QSHexp sun - sheltering potentials by the sun	$\hat{Q}_{sun}^{EXP} = (1-\alpha)\overline{Q}_{sun}^{ENV}$
QSHexp sky - sheltering potentials by the sky	$\hat{Q}_{sky}^{EXP} = \int_0^{24} \lvert\phi_{lw-}\rvert dt$
QSHexp cv - sheltering potentials by the surface	$\hat{Q}_{cv}^{EXP} = \int_0^{24} \lvert\phi_{cv-}\rvert dt$
Qexp vent - exploited cooling potential for ventilation	$Q^{*}{}_{vent}^{EXP} = \int_0^{24} \lvert\phi_{inf-} + \phi_{vent-}\rvert dt$
Qexp ac - exploited cooling potential for air conditioning	$Q^{*AC} = \int_0^{24} \lvert\phi_{ac}\rvert dt$
Exploited heat input potential	$\overline{Q}_{res}^{EXP} = \int_0^{24} (\phi_{net_{in+}} + \phi_{tr}) dt$

Table 10 List of performance ratios [11]

Performance ratios	Formula
Cover rate	$\tau^{cov} = \dfrac{Q^{*EXP}}{\overline{Q}_{res}^{EXP}}$
Exploitation rate	$\tau^{EXP} = \dfrac{Q^{*EXP}}{Q^{EXP}}$
Sheltering rate	$\tau^{SHE} = \dfrac{\hat{Q}_{sun}^{EXP} + \hat{Q}_{sky}^{EXP} + \hat{Q}_{cv}^{EXP}}{\left(\overline{Q}_{sun}^{EXP} + \overline{Q}_{sky}^{EXP} + \overline{Q}_{cv}^{EXP}\right)}$

Additional tools and indicators [41] that can be exploited as preliminary indicators in the design phase are proposed below:

Charts:

- Sun charts (related to the building configuration and location)
- Monthly pattern and temperature variation (related to the building location)
- Relative humidity vs. Dry bulb temperature (related to the building location)

Calculations:

- Window-to-wall ratio (WWR)

$$WWR = \frac{Area\ of\ Exterior\ Openings\ (excluding\ mullions\ and\ window\ frames)}{Total\ Wall\ Area\ of\ Exterior\ Facade\ (width\ x\ floor - to - ceiling\ height)}$$

- Ratio of glazing to net floor area (GA/FA)

$$\frac{GA}{FA} = \frac{Glazing\ Area}{net\ Floor\ Area}$$

5 Conclusion

The deliverable aims to provide a framework for ABC 21 project on the energy performance of bioclimatic buildings.

First it clarifies the concept of bioclimatic architecture and shows a description of the African and European climatic context under study in order to give indications about the buildings energy needs.

Then a set of indicators is proposed to quantify the building energy performance, according to the terminology and guidelines provided by EN-ISO standards. Further, the deliverable reports a literature review of bioclimatic indicators available in literature.

The report provides also a list of the reference nomenclature, standards and a description of the energy levels useful to create a common ground for effective communication within the project's Consortium for the development of the analyses and for clear communication of the results to stakeholders and the public.

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