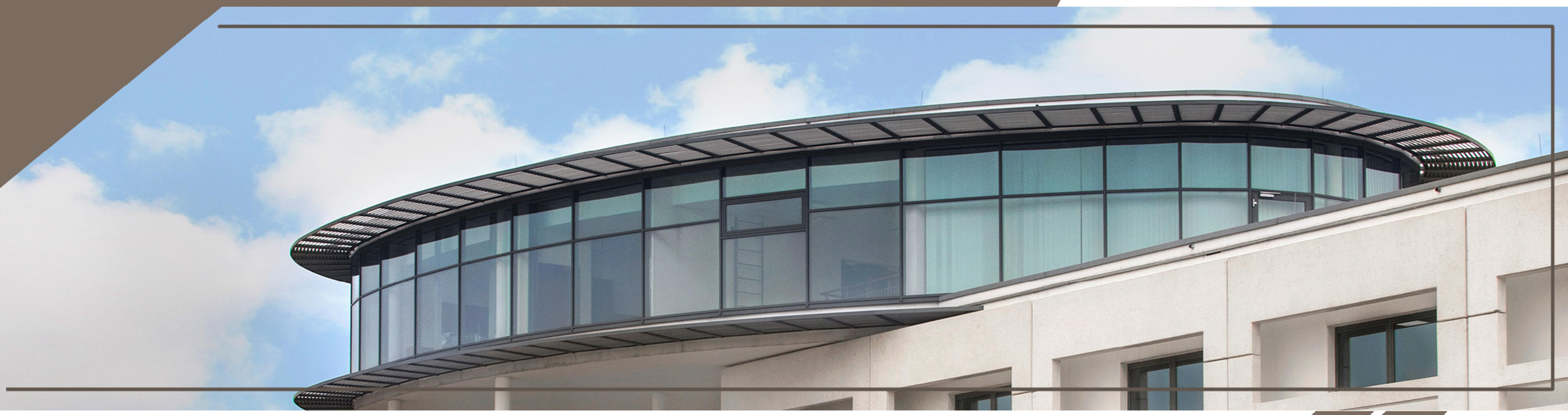
COURSE HANDBOOK



ENERGY EFFICIENT BUILDING DESIGN

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FROM THE AMERICAN PEOPLE

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Energy Efficient Building Design

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CONTENTS

1. INTRODUCTION TO BUILDING PHYSICS

What this module is about

The module is intended to give a general idea about building physics, focusing on the application of basic rules of thermodynamics in building science. Simple rules to calculate and understand the energy flow are explained.

Learning outcomes

At the end of this module, the participant is able to:

- Develop a better understanding on the properties of the building envelope and its thermal balance,
- Understand the rules of thermal flow exchange and its application in building
- designDevelop a higher sensibility on physical properties of materials
- Identify and choose appropriate materials and components energy efficient buildings

1.1. APPLICATION OF THERMODYNAMICS IN BUILDING SCIENCE

BUILDING PHYSICS

Building physics is about the application of specific principles of physics to the built environment. It has been developed in order to improve building design bringing a fundamental understanding of physics. The aim is for an ever-improving interaction and relationship of built environment with the local climate.

Building physics has become a basic design discipline, dealing with the building performance as to physical principles of thermodynamics, fluidodynamics, science of materials, acoustics, optics and lighting.

In this handbook, a particular focus will be given on basic references of thermodynamics, lighting and fluidodynamics, in order to give a glimpse of main solutions for sustainable building.

THE THERMAL AND MOISTURE PERFORMANCE OF THE BUILDING ENVELOPE

Buildings interact with the surrounding environment exchanging substances and energy, in terms of matter and heat. Building Physics considers as "thermal envelope" the entirety of the structures that separate the conditioned part of the building from the non-conditioned space and from the outside. It includes walls, windows, doors and gates, roofs and foundations.

- The many functions of the building envelope can be separated into three categories:
- Support structural and wind loads, depending on construction and materials
- Control the flow exchange of energy and matter, functioning as a barrier or a filter
- Finish the building meeting the prefixed aestetic criteria

This distinction has a big relevance when it comes to calculate and assess the energy gains or losses. Concepts such as insulation and airtightness become fundamental: E.g. 30 to 50% of the energy consumption for air conditioning in buildings comes from air leakages through roofs, walls and openings. Non-controlled heat flux within the external walls creates moisture accumulation and mould formation on the inner surfaces, possibly leading to structural deterioration with time. Therefore thermal and humidity control are critical points for the thermal envelope. Designers (architects and engineers) must plan the enclosure along with the building use, in order to dimension the conditioning system and the thermal envelope, wrapping the defined border with insulation and barriers. Connections between opaque and transparent elements, as well as junctures in general, should be precisely designed and taken care of, since such points become the most sensitive parts of the outer skin.

1.2. ENERGY BALANCE OF BUILDINGS

EQUATION OF THE ENERGY BALANCE

Defining the boundaries of the climatized space, its thermal envelope, is the first step to understand the concept of energy balance. It considers external and internal heat gains/losses of the conditioned building volume during its use.

» External thermal gains

Include the solar gain and the heat gain by conduction through walls, roofs and windows.

» Internal thermal gains

These are generated within the thermal envelope. They are given by the general occupancy and from inner sources of heat, such as occupants and equipment (instruments, appliances and electrically powered objects).

Heat transfer occurs by transmission, air exchange and solar radiation. While in colder climates the goal of calculating the loads is to design the appropriate heating system, in warmer areas the target should be the definition of the cooling demand. Protecting the building from unwanted and uncomfortable energy losses/gains is a major task for a sustainable building design professional. In any case, the knowlwledge and application of the rules of thermodynamics is fundamental to achieve energy savings and economic advantages in the future.

The general equation that regulates the total energy balance of a building is the sum of all the heat transfers, from both inside and outside the built space, both active and passive. All the parameters of the following equation will be analized singularly and separately, showing where the decisions of buildings designers can make important differences.

The equation is relating to a constant heat flow, taking as an assumption fixed temperatures and conditions. It is a simplified equation, which differs from the periodic heat flow calculation. The same assumptions will be taken for the following equations in this chapter.

$$Qi + Qs \pm Qc \pm Qv \pm Qm - Qe = 0$$

Qi is internal heat gains, created by human activity inside the building and from the emissions of devices and facilities.

Qs is solar heat gain, and considers the irradiation through windows and transparent components.

Qc is thermal flux which passes through the envelope via conduction and superficial convection

Qv is losses and gains due to ventilation.

Qm is mechanical control and represents the deliberate induction or subtraction of heat in/from the inner space. In this case, the heat flow is controllable by the user and planned by the designer, so that Qm can be intended as the final goal of the equation, according to the result from the balance of the other factors. In such case, the resulting energy, in W, would correspond to the system performance.

Qe is thermal loss due to evaporation from the building envelope. Its estimation, however, is a particularly difficult and unprecise task, as many variables are difficult to calculate with enough accuracy. Therefore it is often ignored in the general equation.

The main purpose of the thermal balance is to design the room/air conditioning system. While parameters such as Qc and Qs can be improved with what will be after described as passive measures (see 3.2), Qm is the sector dedicated to the active measures (see 3.3) and Qs and Qi can be achieved with a mixture of the two. Major goal is to design the building so that the thermal flux is slown down and minimized. Heat transfer occurs from warmer bodies or surfaces to colder ones, by transission of kinetic energy between particles. Insulating the building is not only important in winter or cold climates to slow down the thermal losses from the inside, but it can also have a remarkable effect in avoiding the heat penetration from the outside in warm season/climates, contributing to a general energy saving.

IDENTIFICATION OF DIFFERENT HEAT GAINS AND COOLING LOAD: TERMS, SI UNITS, MAGNITUDES

» Qi, internal heat gains

Human bodies, with their actions, produce heat, vapour and perspirations, which contribute increasing the inner temperature by a certain rate, depending on the use of the building and on the number of occupants (see 2.1). Lighting fixtures emit light and heat as well. The wattage of each lamp and ballast determines the amount of heat emitted. LED light sources have a minor consumption compared to traditional incandescent and halogen lamps, hence they emit less heat.

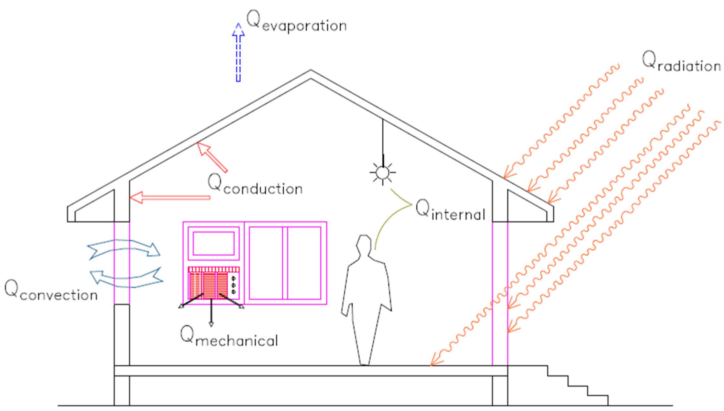


Figure 1.1: Schematic figure showing the different contribution to the general thermal balance of a building – *Source: mnre.gov.in/solar-energy/chapter 4*

Controlling the internal heat sources has an important part in the thermal balance. Designers in general (architects and engineers) have some ways to minimze such gains.

- A thoughtful, comprehensive and innovative lighting design, including high-performance LED lighting. Simulation programs are useful to reach the goal of comfort without wasting enery and money. The objective is to meet requirements (which vary for each type of use) with the least expenditure.
- A correct occupancy plan, helping to shape and dimension the floor area depending on the number of occupants. For every building use, a particular area per person is foreseen, and that value must be taken into account. The exact number of occupants is important to dimension the cooling system as well (heat gain 100 W/person, sitting).

Table 1.1: Wattage of common household facilities – *Source: mnre.gov.in/solar-energy/chapter 4*

Equipment	Load (W)
Radio	15
Television	250
Refrigerator	120
Coffee machine	400
Vacuum cleaner	800
Washing mashine	2,500
Dishwasher	3,050
Water heater	3,500

» ***Qs, solar heat gains***

$$Qs = A * I * G * Sc \ (W)$$

A is the total area of the transparent components

I is the global solar radiation, in W/m², incident on the plane of the window. It is a given data, which depends on the orientation of the building, on the solar angle and on the inclination of the window

G includes the g value of the glass, namely the solar heat gain factor (also SF), representing the ratio of heat flux of the incident radiation transmitted through the glass (see chapter 1.3). It also comprehends the diminuition factor Fc, which considers the contribution of shading systems (reducing the amount of incident light).

Sc is the shading coefficient of the glass layer. It expresses (in values from 0 to 1, the amount of light which is actually transmitted through the window.

The maximum solar radiation on the earth's surface is about 1,000 W/m^2 for clear sky condition. The annual total horizontal irradiation can vary according to the position, from circa 400 kWh/m^2a near the poles, up to 2,500 kWh/m^2a in the Sahara desert.

In the aforementioned formula, the building professional has an important role in choosing the right fenestration, and placing it in the best way. Orientation and position in the envelope play a fundamental part in the overall solar heat gains and so does the window type. The g value is a factor indicating the solar energy transmission of the glass. It is normally given by the glass manufacturer and it belongs to the standard product characteristics. If not available, the designer has the right to request it from the window or glass manufacturer. The lower the value, the less infrared radiation is let in and the more heat gains can be avoided. Especially for modern glazing technology, low heat gain is achieved without compromising the light transmission. For more details see 3.2. and 3.2.

» ***Qc, heat gains by conduction and convection***

This part of the general equation is totally focused on the performance of the thermal envelope, and it is crucial for the designers as it involves materials and project choices.

$$Qc = (\Sigma_i A_i U_i + \Sigma_i l_i \Psi_i) \Delta T \ (W)$$

Ai is the complexive area of each component in the thermal envelope
Ui is the thermal transmittance of each component
Li is the total length of every thermal bridge

Ψi is the heat transmission through every single thermal bridge

This part of the equation can be actively controlled by the building professionals:

- Choosing materials and components (both opaque and transparent) with low U-values. The smaller the values, the lower the heat gain is
- Minimising the heat transfers through thermal bridging (see chapter 3.2)

» *U-value or thermal transmittance*

The transmittance, or U-value, represents the heat flow per unit of area in a building component, considering the temperature difference between the inner and the outer side of 1 K. Mathematically, it consists of the reciprocal of the sum of the resistances R that characterize the different materials in the building component. The calculation of the thermal resistance R is described in the next paragraph.

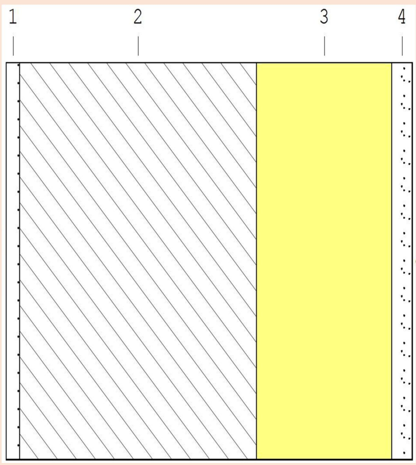
The following formula is used to calculate the thermal transmittance of **opaque elements**.

$$U\ (W/m^2K) = \frac{1}{R_{se} + R1 + R2 + \ldots R_{si}}$$

A low U value indicates small heat gains. External and internal resistances. Rse (0.04 m²K/W) and Rsi (0.14 m²K/W) are the resistances of the superficial air layers to be found on the two surfaces of the thermal envelope. Controlling the U-value of the thermal envelope means being able to manage the building's behaviour in response to external conditions.

Example: U-value calculation

Find the thermal transmittance for the visualized wall. Each material is listed in the table below, along with its thickness and conductivity λ. Resistance R is given by the thickness divided per the conductivity, as further explained.



Window type	*Uw*
Single-glazed window	5
Double-glazed window/air filled	2.7
Double-glazed window/argon filled / high performance	1.9

Layer	*Material*	*Thickness (mm)*	*λ (W/mK)*
1	Plaster	10	0.700
2	Light concrete brick	255	0.420
3	Rock wool	100	0.035
4	Plaster	15	0.700
	Overall	350	

The U-value of the whole component can be calculated using the following formula:

$$U\ (\mathrm{W/m^2K}) = \frac{1}{0.14 + \frac{0.01}{0.7} + \frac{0.225}{0.42} + \frac{0.1}{0.035} + \frac{0.015}{0.7} + 0.04} = 0.277\ \mathrm{W/m^2K}$$

For **transparent elements**, like windows, more factors have to be taken into account, causing the formula to be different:

$$U_W\ (W/m^2K\ ) = \frac{(A_g \cdot U_g + A_f \cdot U_f + I_g \cdot \Psi_g)}{(A_g + A_f)}$$

Where:

A_g is the area of the glass

U_g is the thermal transmittance of the glass

A_f is the area of the frame

U_f is the transmittance of the frame

I_g is the length of the internal edge of the frame

Ψ_g is the linear heat transfer coefficient of the window's edge

Nowadays, double and even triple glazing with gas-insulated spacers offer a better performance compared to windows frames, as accurately made as they might be. Thus, in terms of U-value, larger windows have a better performance than smaller ones, because of the glass-to-frame ratio.

» *Thermal bridges: Linear transmittance*

Geometrical and material discontinuities, as well ad junctions and connections between different elements in the thermal envelope, if not well treated, cause the particular phenomenon called thermal bridge, consisting of an increased enegy flux on that particular point. A simplified formula allows finding the amount of energy crossing the façade.

$$\Psi\ (W/mK)\ = L^{2D} - \Sigma U_i\ x\ L_i$$

Where:

Ψ is the linear thermal transmittance of the thermal bridge.

L^{2D} is the two-dimentional length of the thermal bridge

U_i is the transmittance of each material along the thermal bridge

L_i is the thickness of each material

» *Thermal resistance*

The resistance R (m•K/W) describes the ability of a certain material or aggregation of materials to resist the heat flow. It is calculated by the fraction of the thikness (usually expressed in metres), divided by the material's conductivity

$$R = \frac{s}{\lambda}$$

The R-value is therefore inversely proportional to the conductivity: the lower the λ is, the stronger the material's resistance will be. In the same way, it is directly proportional to the thickness: the thicker, the more resistant. Knowing this basic, and yet fundamental relationship, the designer is provided with one of the most important instruments for an efficient building envelope. Their choice can then vary according to the aesthetics, or to economic and environmental instances, reaching the same results with different strategies.

Some components or material packages are often given by the manufacturers with their R-value, instead of the λ, usually because of their discontinuity and variety of inner compositions. The thermal resistance can also be found for elements with a fixed and standardised thickness. The R-value is also normally useful to calculate the contribution of other incoherent components, such as cavities within the elements' layers. Airshafts, for instance, are always given with the correspondant thermal resistance instead of the simple conductivity.

» *Thermal conductivity*

The thermal conductivity λ, in some cases referred to as k (W/ m•K), is a physical property describing the transport of energy (in the form of heat) through a body, as the result of a temperature difference. λ is a material-related value, independent from any dimension or interaction in the building components. The heat transfer occurs at a lower rate in elements with a low thermal conductivity.

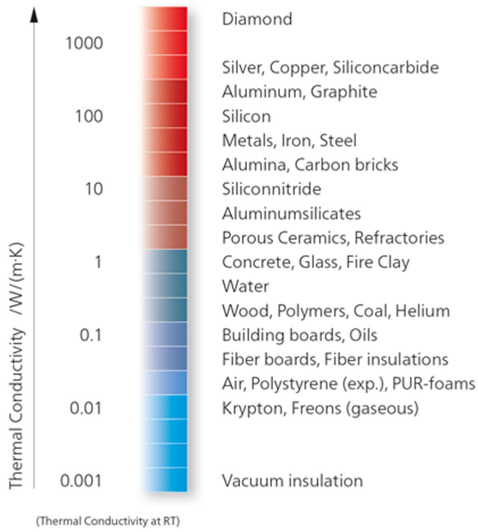


Figure 1.2: Graphic scale of thermal conductivities for generc materials – *Source: www.netzsch-thermal-analysis.com*

According to the second law of thermodynamics, heat always flows in the direction of the lower temperature. Knowledge of the thermal conductivity of main building materials is crucial for building professionals in order to understand the thermodynamic behaviour of every component. This way, they can effectively intervene in the design process to enhance the thermal performance. λ-values are almost always provided from the manufacturers (especially for insulation or thermally-relevant materials). If not, in some cases they should be required, particularly when it comes to calculate the whole performance of the thermal envelope. For standard elements, the typical values can easily be found on the internet.

Table 1.2: thermal conductivities of some common materials – *Source: www.engineeringtoolbox.com*

Material	*λ-value*	*Material*	*λ-value*
Air, atmosphere (gas)	0.024	Gypsum board	0.17
Aluminum	205	Iron	80
Aluminum Brass	121	Krypton (gas, i.e. for windows)	0.0088
Argon (gas, i.e. for windows)	0.016	Leather, dry	0.14
Asbestos-cement board	0.744	Limestone	1. 26 – 1.33
Asbestos-cement	2.07	Marble	2. 08 – 2.94
Bitumen	0.17	Mineral wool insulation materials	0. 035 – 0.045
Brass	109	Paper	0.05
Brickwork, common (building brick)	0. 6 – 1.0	Plaster light	0.2
Brickwork, dense	1.6	Polycarbonate	0.19
Brick, insulating	0. 15 – 0.4	Polyethylene low density, PEL	0.33
Cast iron	58	Polystyrene, expanded styrofoam	0.03
Clay, dry to moist	0. 15 – 1.8	Polystyrol	0.043
Concrete, lightweight	0. 1 – 0.3	Polyurethane foam	0.03
Concrete, medium	0.4 – 0.7	PVC	0.19
Concrete, dense (structures)	1. 0 – 2.0	Sand, moist	0.25 - 2
Copper	401	Sandstone	1.7

Material	λ-value	Material	λ-value
Cork board	0.043	Sheep wool	0.039
Cotton	0.04	Silica aerogel	0.02
Earth, dry	1.5	Soil, clay	1.1
Feathers	0.034	Timber, general	0. 14 – 0.17
Felt insulation	0.04	Vacuum	0
Fiberglass	0.04	Water	0.58
Foam glass	0.045	Xenon (gas)	0.0051
Glass	1.05		
Gravel	0.7		
Ground or soil, moist area	1. 0 – 1.4		
Ground or soil, dry area	0.5		

» *Qv, ventilation heat gains*

The convection heat flow depends on the ventilation rate. The air exchange can be unwanted, i.e. due to infiltration in the building, or intentional, via passive or active means, as explained in Module 3.

The equation to find the ventilation heat flow rate is

$$Qv = 1300 * V * \Delta T \ (W)$$

Where:

1,300 is the volumetric specific heat of air in J/m³ °C

V is the ventilation rate in m^3/s

ΔT is the temperature difference in °C

The first issue to be dealt with in this case is to avoid unintentional ventilation losses, particularly when it comes to protecting the climate-controlled space after achieving the ideal operational temperature. To do so, the thermal envelope must be as airtight as possible.

Table 1.3: Standard number of air changes per hour for rooms - *Source: sustainabilityworkshop.autodesk.com*

Spaces	Air changes per hour
Assembly hall / Auditorium	3-6
Bedrooms / Living rooms	3-6
Bathroom / Toilets	6-12
Cafes / Restaurants	12-15
Cinemas / Theaters	6-9
Classrooms	3-6
Factories	3-6
Garages	12-15
Hospital wards	3-6
Kitchens (common)	6-9
Kitchens (domestic)	3-6
Laboratories	3-6
Offices	3-6

1.3. GLOSSARY OF BUILDING PHYSICS

ESSENTIAL ELEMENTS OF THERMODYNAMICS

Of the utmost importance for achieving sustainability in buildings is the application of basic thermodynamics on building elements. Thermal and humidity comfort is the primary objective to be reached when planning a sustainable building. What follows is a simplified list of some relevant physical properties every building professional should know. Such parameters help understand how materials and components behave in relationship with one another and with the outer climate.

» Specific heat

Dealt with in periodic, not constant heat flow. The specific heat consists of the heat necessary to raise the temperature of a given mass of material by 1°C. The lower the specific heat of a certain material, the less heat will be required to raise its temperature. Hence, materials with a higher specific heat generally perform better in slowing down the process of heat transfer throught the building envelope. The unit is J/kg K.

» Thermal capacity

Thermal capacity or volumetric heat capacity is the property to store energy in form of heat per unit of volume. It is the result of specific heat x density of material (J/ m³ K).

Materials with a higher thermal capacity can store more heat per each degree of temperature increase. Such elements have the ability to store energy, which often (but not always) helps to slow the heat transfer. This process can be more convenient in climates with high temperature differences between day and night.

Table 1.4: Density, specific heat and thermal capacity in different building elements – *Source: www.gridgit.com*

Material	*Density (kg/m³)*	*Specific heat (J/kg K)*	*Thermal capacity (J/m³ K)*
Water	1,000	4,186	4,186
Concrete	2,240	920	2,060
Brick	1,700	920	1,360
Sandstone	2,000	900	1,800
Earth wall (adobe)	1,550	837	1,300
Rammed earth	2,000	837	1,673
Compressed earth blocks	2,080	837	1,740

» Thermal lag

Dealt with in periodic heat flow. Construction with a high thermal mass possesses the capacity of delay the heat transfer from one side to the other. This property is called thermal lag or time lag, and it is indicated in hours. It consists of the time needed for the peak temperature on the outer surface to be registered on the inner side. As the above-mentioned property, higher thermal lag can help contrasting the drastic temperature changes in some regions. More on the subject can be read in 3.2.

» Solar heat gain coefficient of glass (g-value)

The g-value measures the amount of heat introduced through the window via sunlight in comparison with the reflected and part of the absorbed portion. It expresses the ratio of the sum of directly transmitted solar radiation and the amount of absorbed radiation entering the space through a window due to the external solar radiation. Hence, it is expressed by a value between 0 and 1, the lower the value, the lower the heat gain.

» *Relative humidity and dew point*

The relative humidity measures the density of water vapour in the air compared to the vapour density in saturated air with equal temperature and pressure. It comes as a percentage.

RH = (actual water vapour density / saturation water vapour density) x 100

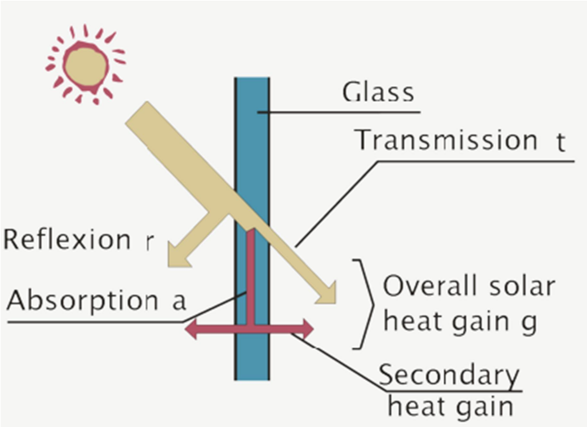


Figure 1.3: Distribution of solar heat flow incident on a glass surface – *Source: EULEB, European high quality low energy buildings, online database*

At lower temperatures, the air loses its ability to carry vapour, and so its relative humidity rises, reaching the so-called dew point, at which the moisture starts to condense (compare psychrometric charts, chapter 2.1 comfort). When it happens on the surface of a wall, or within two layers of the thermal envelope, it can cause mould formation that would eventually damage the materials. Such phenomena can occur everywhere, and therefore it is important to test the airtightness of buildings and to apply vapour barriers in the thermal envelope. Especially in tropical climates, where outer air humidity can rise up to 90%, particular attention should be paid to the superficial condensation between climatized and non-climatized space.

FURTHER READING

1. *Manual of tropical housing and building, part one: Climatic design* • O.H. Koenigsberger, et al.; Longman Group Ltd, London 1973
2. *Building science for building enclosures* • J.F. Straube, E.F.P. Burnett; Building Science Press, Westford, 2005
3. *Aktivhaus, The reference work, from Passivhaus to Energy-Plus house,* • M. Hegger, et al., 2016

2. DESIGN STRATEGY, TASK, CLIMATE AND BOUNDARY CONDITIONS

What this module is about

The module explains the demand of the building sector and the potential of energy efficient building to contribute to a reduction of global warming. Requirements for energy efficiency are defined as well as boundary conditions of climate and comfort. A short overview analyzes the integrated design process for energy efficient buildings.

Learning outcomes

At the end of this module, the participant is able to

- Distinguish between traditional, standard and best practice buildings as relating to energy efficiency
- Identify appropriate methodology and tools as well as professions for integrated design process of energy efficient buildings
- Identify climatic factors and boundary conditions that influence design of energy efficient buildings
- Define design task by requirements of comfort, energy and costs

2.1. OBJECTIVES OF ENERGY EFFICIENT BUILDING DESIGN

EFFECT OF BUILDING ENERGY CONSUMPTION ON GLOBAL WARMING

It is now widely understood that the climate on earth is rapidly changing, and that human activities contribute in large part to this change.

» ***Greenhouse gas emission***

Greenhouse gas emission has been proven to directly affect the warming process that our planet is undergoing, and combustion of fossil fuels is allegedly one of the major causes. Among all human activities, energy consumption for heating and cooling in buildings has been stated to contribute for as much as 30% of the overall energy consumption worldwide, and up to 40% for greenhouse gases emissions. It appears clearly that important measures have to be taken in this sector, confirmed during the 2015 Paris climate change conference. The Paris Agreement, which calls for zero net gas emissions caused by human activities to be reached during the second half of the 21st century, negotiated by 195 countries was adopted by consensus on December 2015. From the below greenhouse emissions from buildings in developing countries will considerably increase over the next decade, as their economies grow and purchasing power of the population increases. But business cannot continue as usual and it is of the utmost importance for these countries as well to participate in the implementation of measures of the Paris climate change conference.

The Paris Agreement defines “long-term goal” of limiting global temperature increase well below 2 degrees Celsius, while urging efforts to limit the increase to 1.5 degrees. The Paris Agreement articulates two long-term goals with regards to emissions of green house gases:

- Mitigation: First, a peaking of emissions as soon as possible (with a recognition that it will take longer for developing countries);

- Then, a goal of net greenhouse gas neutrality (expressed as “a balance between anthropogenic emissions by sources and removals by sinks”) in the second half of this century.

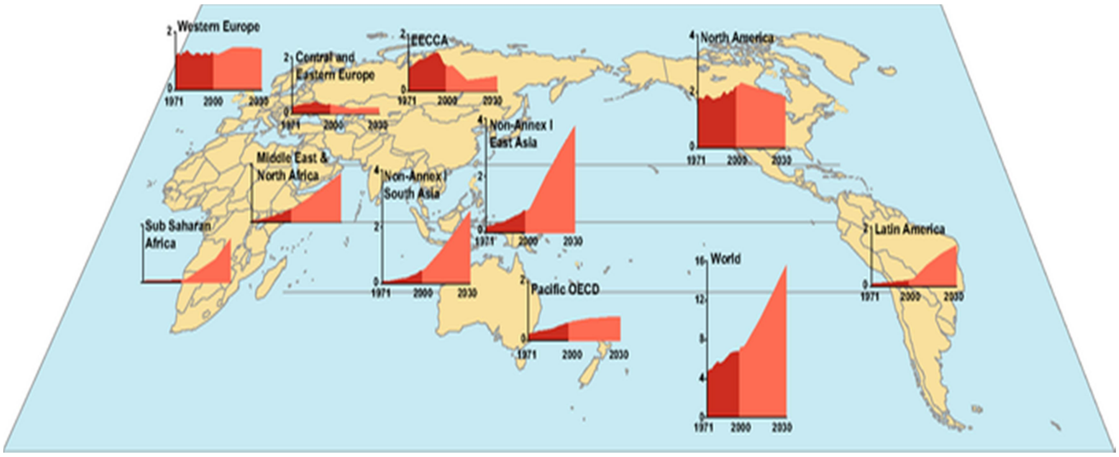


Figure 2.1: CO_2 emissions from buildings (including those through electricity). Projections in light red – *Source: Buildings and climate change summary for decision-makers, UNEP DTIE, 2009*

The general commitment is to limit the temperature increase to 1.5°C, which will necessitate reaching zero emissions sometime between 2030 and 2050, according to United Nations Environmental Programme (UNEP).

» *CO_2 footprint of buildings*

Sustainable buildings can reduce CO_2 emissions significantly by various measures, acting in different directions, such as:

- Optimizing the system performances for heating, cooling and supplementary needs
- Including day-lighting and using the state-of-the-art artificial lighting solutions available
- Using eco-friendly materials, even recycled, as much as possible, and select local sources and suppliers
- Using potable water in a responsible and thoughtful way, adapting the building to manage and re-utilize rainwater.
- Using renewable energy according to the latest requirements and certification systems
- Implementing waste management
- Providing efficient public transportation and pedestrian routes
- Achieving a compact urban/settlement form and retrofitting brownfield sites
- Reducing energy demand in buildings.
- Considerations of social and financial factors related to energy efficiency and global warming.

STANDARDS, REQUIREMENTS, LABELS

The Paris Agreement and the outcomes of the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP21) cover all the crucial areas identified as essential for combating climate change:

1. Mitigation – reducing emissions fast enough to achieve the temperature goal
2. A transparency system and global stock taking – accounting for climate action
3. Adaptation – strengthening ability of countries to deal with climate impacts
4. Loss and damage – strengthening ability to recover from climate impacts
5. Support – including finance, for nations to build clean, resilient futures.

As well as setting a long-term direction, countries will peak their emissions as soon as possible and continue to submit national climate action plans that detail their future objectives to address climate change.

This builds on the momentum of the unprecedented effort which has so far seen 188 countries including Nigeria contribute climate action plans to the new agreement, which aims to dramatically slow the pace of global greenhouse gas (GHG) emissions. The new agreement also establishes the principle that future national plans will be no less ambitious than existing ones, which means these 188 climate action plans provide a firm floor and foundation for higher ambition. Countries will submit updated climate plans – called nationally determined contributions (NDCs) – every five years, thereby steadily increasing their ambition in the long-term.

» Building regulations for energy efficiency

Because of the significant influence of the building sector on CO_2 emissions and climate change, national regulations will improve the energy efficiency in line with the international Paris Agreement. The existing regulations in Nigeria will be adapted and the methodology of existing international regulations for energy efficient buildings may be considered. For example, "the Building Energy Efficiency Guideline (BEEG) was commissioned by the Federal Ministry of Power, Works and Housing (Housing) in collaboration with the Nigerian Energy Support Programme (NESP). It aims to give practical advice to professionals in Nigeria on how to design, construct and operate more energy efficient buildings. The guideline also aims to educate the general public about energy efficiency measures and provides clients with information that help them choose energy efficient buildings. The guideline arises in response to the need to inform and create awareness on:

- What the state of energy consumption in the building sector and the potential for improvement is.
- Why energy efficiency is important and what energy efficiency goals should be set for Nigeria.
- How energy efficiency can be implemented in the building sector in Nigeria.

The EU's main legislation when it comes to reducing the energy consumption of buildings under the 2010 Energy Performance of Buildings Directive:

- Energy performance certificates are to be included in all advertisements for the sale or rental of buildings
- EU countries must establish inspection schemes for heating and air conditioning systems or put in place measures with equivalent effect

- All new buildings must be nearly zero energy buildings by 31 December 2020 (public buildings by 31 December 2018)
- EU countries must set minimum energy performance requirements for new buildings, for the major renovation of buildings and for the replacement or retrofit of building elements (heating and cooling systems, roofs, walls, etc.)
- EU countries have to draw up lists of national financial measures to improve the energy efficiency of buildings under the 2012 Energy Efficiency Directive:
- EU countries make energy efficient renovations to at least 3% of buildings owned and occupied by central government
- EU governments should only purchase buildings which are highly energy efficient
- EU countries must draw-up long-term national building renovation strategies which can be included in their National Energy Efficiency Action Plans.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), e.g., offer several standards for energy efficient buildings and a "Key to Energy Efficiency in Buildings". Usually energy efficient standards or directives define **maximum total energy consumption** per m^2 or m^3 and year in relation to the specific climate zones and building types (residential, non-residential etc.). BEEG considered climatic zones of Nigeria and covered both residential and commercial buildings. The total energy includes all consumers, i.e. cooling, heating, ventilation, and lighting and is defined in terms of final or primary energy (see chapter 4.1). As alternative to the primary energy consumption the CO_2 emission can be applied.

REQUIREMENTS FOR COMFORT

Beside the boundary conditions of climate zones and building types the requirements for indoor **human comfort** and well-being have to be taken into account, as they have a significant influence on energy demand. The following categories of comfort have a direct influence:

- Thermal comfort (ISO 7730, ISO 10551, ANSI/ASHRAE 55)
- Lighting, visual comfort [4] (ANSI/IESNA RP-1-04, EN 12464, ISO 8995-1)
- Air quality (ISO 16814).

The BEEG for Nigeria captures this more succinctly.

» *Certifications and labels*

After the energy crisis in the second half of the 20th century had brought new awareness and concern over environmental issues, many new aspects were to be considered as experts started to think about sustainability as a whole, putting social and economic aspects together. Environmental, economic and social conditions became so the three pillars of sustainability.

In this scenario, the first certification systems started to emerge, with the aim to set acceptable budget and consumption limits and to test building performances. Matching the new criteria of sustainability would also mean to improve the general quality in buildings. New forms of labels were created, in order to state their good quality and to serve as example. Among the many different local organizations, some systems began to spread consistently, and gained a broader and more international recognition. While various national laws may, in different ways, set compulsory requirements for some parts of the building process, labels and certifications are still always voluntary, at least for the private sector. However, they are now increasing considerably as synonyms of high quality and prestige. Certification systems can differ considerably, according to which of the "three pillars" they consider the most.

BEEG Nigeria summarizes these rating systems in a chart highlighting the areas they cover as well as the advantages and disadvantages.

PASSIVHAUS

PASSIV HAUS INSTITUT

Passivhaus (Passive house) is a German energy label, broadly used in Germany and taken as a reference in many European countries. It sets energy consumption standards for residential (but not only) buildings, with strong requirements depending on the state of the building (either existing buildings or new projects). The approach is quite simple and effective, since it calculates requirements on the overall consumption (in kWh/m^2a). The Passivhaus standard was created in Darmstadt, Germany in 1991 and at first was developed for residential buildings, but it soon became popular also for commercial, industrial and public projects.

A building is defined as "Passivhaus" when the inner thermal comfort can be achieved mainly by passive means. Active means for heating and cooling are reduced to a minimum so that a primary energy consumption of 15 kWh/m^2a is not exceeded. The Passivhaus concept was initially conceived for cold climates, but it has been extended to warm and humid climates. The Passivhaus, an airtight and well insulated building with mechanical ventilation and heat recovery, is energy efficient in cold as well as in tropical climates.

BREEAM

breeam

The Building Research Establishment's Environmental Assessment Method (BREEAM), conceived in the UK by the British Building Research Establishment (BRE) between 1980 and 1990, was the first certificate of its kind. Therefore, it can be regarded as prototype for the first generation of environmental certificates. Many other more recent systems have been based on the same contents and schemes. In the UK, BREEAM has had an ever-growing influence on the building sector, starting out as national parameter for office and residential buildings and becoming an international system, used now in many different countries worldwide and constantly updated. The intention of its curators is to give it a flexibility, which allows every possible kind of building to be, assessed even those who are not following the predefined types of use.

For residential projects, BREEAM has spread considerably in the UK, increasingly sustained from the institutions that started to set new requirements of sustainability following its guidelines, thus causing the number of new certified buildings to grow consistently. As of now, in fact, with more than 40,000 registered projects worldwide and 15,000 certificates, it is the certification with the largest number of projects reached thus far. While the BREEAM

International scheme has now 14 certified buildings and some more projects to come in Europe and USA.

In the assessment, the building is considered in the whole context including the availability of public transport in the neighborhood and the ecological impact of its construction, so that its location can have a strong influence on the evaluation. In order to obtain BREEAM certification, various criteria of the projects are assessed to earn credits. A minimum fulfillment of at least 30% of the available credits is required to earn the BREEAM certification. These criteria are:

1. Management strategies
2. Primary energy consumption and CO_2 reduction
3. Health and well-being: Both indoor and outdoor quality
4. Transport: CO_2 production concerning material transport
5. Water consumption
6. Materials used in the project´s life cycle, along with their environmental impact
7. Waste production and management
8. Land use and ecology of the site
9. Emissions of polluting elements, along which sound and light
10. Additional credits for particularly remarkable means of innovation included in the project.

Table 2.1: BREEAM Rating according to the percentage of *fulfillment* – *Source: www.engineersjournal.ie*

BREEAM rating	*% score*
Outstanding	85%
Excellent	70%
Very good	55%
Good	45%
Pass	30%
Unclassified	<30%

Buildings are subsequently awarded certification based on a scale from pass to outstanding. Those buildings that do not earn enough credits are termed as "unclassified".

DGNB

DGNB

The German Agency for Sustainable Buildings (Deutsche Gesellschaft für Nachhaltiges Bauen) has cooperated with the Federal Building Ministry of Germany for a long time to establish common criteria and guidelines and to run pilot projects. Now, the DGNB certificates are discretionary and focused on projects realized by the private sector, whereas the ministry has developed its own evaluation structure BNB (Bewertungssystem Nachhaltiges Bauen) for public buildings.

In order to quantify the sustainability of a building, DGNB initially defined over 60 individual criteria that can affect it. There are now only 36 criteria left for the DGNB "New Office and Administration Building, Version 2015" label. The reason for this is the continual development of the system that results in the aggregation, addition and discontinuation of criteria. The criteria are divided into environment, economy and social aspects. It was not possible, though, to assign many of the criteria to only one of these three aspects of sustainability. Two additional indicators of general performance, namely 'Technical quality' and 'Process quality', were therefore defined in addition to the three pillars 'Ecological quality', 'Economic quality' and 'Socio-cultural and functional quality'. The goal of these two quality measures is to ensure that basic levels of technical and organisational performance are achieved in a sustainable manner in all three pillars. The five qualities mentioned so far are applied to the building and end at the boundary of the building plot. In addition, the choice of location is also assessed.

LEED

The LEED (Leadership in Energy and Environmental Design) system was developed in the USA in 1994 through a vast cooperation between non-profit organizations, public authorities, architects, engineers and building contractors. As the name suggests, this system is mainly focused on the environmental quality of buildings, defining the single objectives for climate protection. The evaluation parameters are divided in 9 different categories:

1. Water efficiency
2. Innovative design
3. Location
4. Materials and resources
5. Indoor environmental quality
6. Energy & atmosphere
7. Sustainable building sites.
8. Integrative process
9. Regional priority

Certificates can have four degrees of evaluation: Certified, silver, gold or platinum. The assessment uses different parameters according to the building´s use destination. The various LEED schemes address commercial, institutional and residential buildings, as well as neighbourhood developments. There are additional guidelines for interior design, operations and maintenance and neighbourhood development. The aim of all of these systems is to optimise the use of natural resources by promoting regenerative strategies. Any negative environmental and health impacts of construction should be minimised and high-quality interior spaces created for the inhabitants of buildings. For the US Green Building Council (USGBC), the main emphasis is on meeting seven objectives:

1. Reversing the contribution to climate change.
2. Improving the health and well-being of the individual.
3. Protecting and restoring water resources.
4. Protecting and restoring the diversity of species and the ecosystem.
5. Promoting sustainable and regenerative material loops.
6. Establishing a more ecological economy.
7. Improving social justice, environmental awareness and quality of life.

GREEN STAR

Green Star is the Australian certification system, launched in 2003 by the Green Building Council of Australia (GBCA). Its approach is, in many ways, comparable to that of BREEAM and LEED. It considers building management, internal comfort, energy demand, water consumption, materials and ecology degradation. The certificates can be achieved for both new and already existing buildings, with two different dedicated rating procedures. The final rating is given in stars:

- 4 stars: Best practice
- 5 stars: Australian excellence
- 6 stars: World leadership

Buildings that receive less than 4 stars are not labelled.

As of now, more than 600 projects in Australia have received the certification. From 2007, the Green Building Council of South Africa (GBCSA) adapted the Green Star system as fit for local use, which made it interestingly applicable in other African countries provided some small further adjustment. The Green Building Council of Nigeria (GBCN) is in the final stages of developing its own rating system which is an adapted version of the South African rating system. This rating system covers residential buildings.

OTHER SYSTEMS

Miljöbyggnad is the certification system created from the Sweden Green Building Council.

HQE (Haute Qualité Environnementale) is the French certification for building construction and management as well as for urban planning projects. It operates both within France and internationally, spreading worldwide with thousands of projects, especially in the former French colonies.

CASBEE (Comprehensive Assessment Systems for Built Environmental Efficiency) is the Japanese certification system, especially developed for local issues in Japan and Asia. It offers four different assessment tools, for pre-design, new construction, existing building and renovation.

IGBC (Indian Green Building Council) has been developing new rating criteria for built environment in India since 2001. It includes assessment tools for landscapes and cities, along with the traditionally awarded categories (new and existing projects, schools, industrial buildings).

BRIEF COMPARISON

It is no easy thing to draw a complete and exhaustive comparison between the main certification systems, for the simple reason that they do not consider the building's characteristics in the same way and, albeit they follow comparable methods, results may differ consistently depending on the metre used. The same building could be labelled as 'Platinum' after one system, and not even fulfil the basic requirements of another. However, this does not mean that one certification is better or more vauable than the others. It is interesting to analyse where the different procedures focus the most. Since none of them is a compulsory condition for a building, it is up to the main stakeholders of each project to decide whether to, and which one to adopt.

This shows how the main certifications differ depending on the field of analysis. It is evident how, for instance, the DGNB puts less emphasis on the primary energy sources, on the use of drinking and rainwater and on the materials, as opposed to LEED and, in some cases, BREEAM and Green Star. On the other hand, the US system does not consider waste, which is mentioned by the other two. The project site is almost equally contemplated, whereas only BREEAM and DGNB pay a little attention on the construction phase. LEED gives more importance to the transport issues, such as public means proximity and availability of connections.

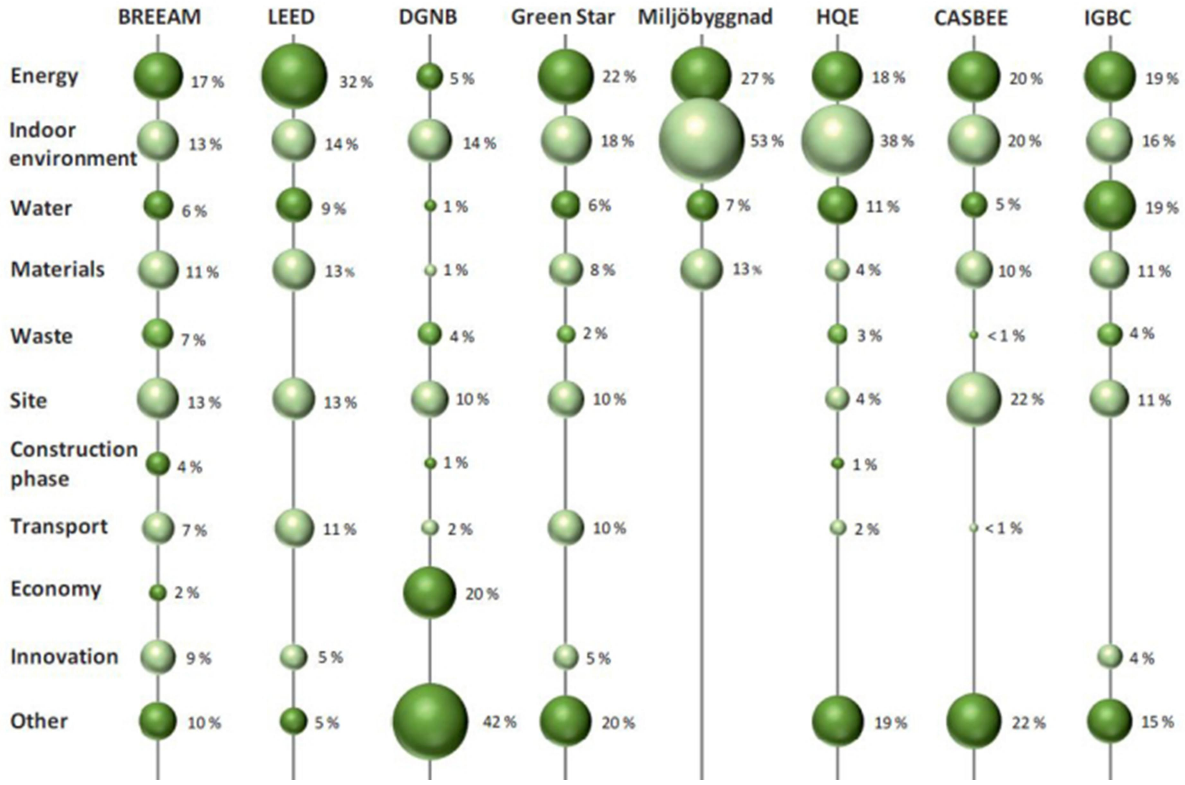


Figure 2.2: Weight distribution of the different factors in the main certification systems (the abbreviations are explained above) – *Source: The Value of Green Star - A decade of environmental benefits*

It is rather evident, on the other hand, how differently the building costs are considered. While DGNB values the economic sustainability in detail, little or no attention is given to it by the other methods. The contrary occurs on the evaluation of innovation, although none considers it a major factor.

The most visible difference, however, appears when looking at aspects like barrier-free compatibility, clean-friendliness, operating process and operating costs. In this area, DGNB strongly differs from the other systems, giving more importance to the evaluation of life cycle assessment and life cycle costs. Below shows how the three major evaluations can differ from each other, while still keeping similar procedures.

The chapter above is intended as a general description of the mainly used and most known certification systems, trying to underline the fundamental criteria and principles.

Table 2.2: Comparison of weight of different criteria in BREEAM, LEED and DGNB – *Source: Adapted from DGNB e.V.: Neubau Büro- und Verwaltungsgebäude – DGNB Handbuch für nachhaltiges Bauen, English version 2012, Stuttgart, 2012*

	BREEAM	***LEED***	***DGNB***
EPDs and life cycle assessment	• Mat 01 life cycle impacts	• Building life cycle impact reduction • Building product disclosure and optimization • Environmental product declarations	• ENV 1.1 life cycle sssessment • Emissions-related environmental impacts • ENV 2.1 life cycle assessment • Primary Energy
	3.8%	5.2%	15.5%
Risks for the environment and humans	• Mat 03 responsible sourcing of materials • Hea 02 indoor air quality	• Low-emitting materials	• ENV 1.2 local environmental impact • SOC 1.2 indoor air quality
	6.8%	3.1%	6.6%
Life cycle costs	• Mat 05 designing for robustness • Man 05 life cycle cost and service life planning		• ECO 1.1 building-related life-cycle costs
	3.1%	0.0%	9.6%
Recycling potential, demolition, dismantling	• Mat 03 responsible sourcing of materials • Wst 02 recycled aggregates	• Building optimization • Sourcing of raw materials • Building product disclosure and optimization • Construction and demolition waste management	• TEC 1.6 ease of dismantling and demolition
	12.8%	6.3%	4.1%

These systems, as previously mentioned, are voluntary assessment methods used to label the buildings and evaluate their performances, to be requested from the constructor or the owner. All the certifications refer to general requirements such as ISO and ANSI standards, which will be part of the following paragraphs. According to the importance they give to each parameter, some of them result more suitable in certain areas of the world.

In Nigeria, the LEED certification system has already been used to assess the construction of two office buildings, the new U.S. embassy annex offices and the Primetech main headquarters, both in Abuja (see descriptions in chapter 3.1). Such examples show that LEED could be successfully implemented in the country as a reference and indication for designers for holistic projects. However, some specific observations have to be made on certain criteria (such as connections to public transport, wastewater technologies and waste treatment) that cannot be evaluated at present time in Nigeria. The assessment can also encounter other problems trying to comply with material certification. For many local materials and components there are often few (or none) requirements about certifications and standards granting the quality or the provenience, fact that regularly leads to order them from abroad. That said, building professionals could use labels as examples to define their future guidelines.

Green Star is another useful means of comparison for echologically valuable buildings, particularly because the system is being currently developed from South Africa to other African countries, taking into account many of the typical climatic conditions.

COMFORT AND ENERGY DEMAND

Shelter and human comfort are the main tasks of buildings. Our senses of seeing, hearing, feeling, and smelling inform us continually, if our indoor environment where we spend 90% of our lifetime is comfortable for us or not. Discomfort will make us feel unwell, distracted, unmotivated and if it continues over a long period could lead to illness. There are three areas of comfort, which have a direct influence on the energy demand of buildings:

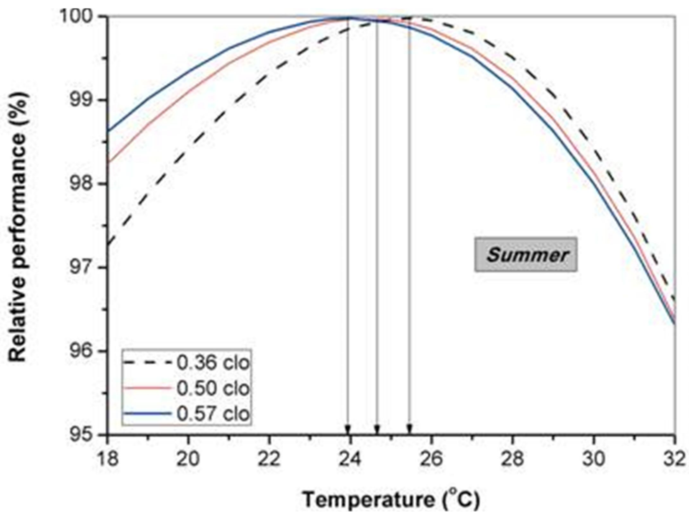


Figure 2.3: The relationship between indoor temperature and human performance at different clothing insulation levels for summer conditions – *Source: Federation of European heating, ventilation and air-conditioning*

- Thermal comfort (ISO 7730, ISO 10551, ANSI/ASHRAE 55), (BEEG Nigeria)
- Lighting, visual comfort (ANSI/IESNA RP-1-04, EN 12464, ISO 8995-1)
- Air quality (ISO 16814).

It´s an important task of the design team to find the right balance of requirements for comfort and energy efficiency of a building in the preliminary design phase.

» *Thermal comfort*

A person´s sensitivity to heat is influenced by physical activity, type of clothing[1], age and gender, health, time spent in the room, season and room climate. It is also affected by the air temperature and its distribution, by radiation conditions, air velocity and air humidity. A person must keep his/her core body temperature constant and therefore has to be able to transfer excess heat produced by his metabolism into the surroundings. Thermal comfort is characterized by the equilibrium of heat produced in the body and heat dissipated by it into the environment. Human performance is strongly influenced by comfortable room temperatures, as demonstrates.

The heat dissipation of a normally clothed person not engaged in physical activity in still air and an air temperature of 20°C occurs by the following physical mechanisms:

- Radiation: 46%
- Convection between body surface and air movement: 33%
- Evaporation from body surface (depending on air humidity): 19%

[1] A person carrying out light office work produces 1.2 met (1 met, "metabolic rate" = 58.15 W/m^2) from the heat of human metabolism. Normal office clothing in summer has a heat resistance of 0.5 clo (1 clo, "clothing" = 0.155 m^{2}K/W).

- Breathing: 2%.

The figure above shows that radiation and convection are the most important factors of heat dissipation, influenced by room surface temperatures, air temperature, and air movement. In most international standards, the operational room temperature is used to define thermal comfort: it is related to the average temperatures of the surfaces and the air temperature. The difference between the air and the surface temperatures should be a maximum of 3 K. Within certain limits, lower surface temperatures can be compensated by higher air temperatures and vice versa.

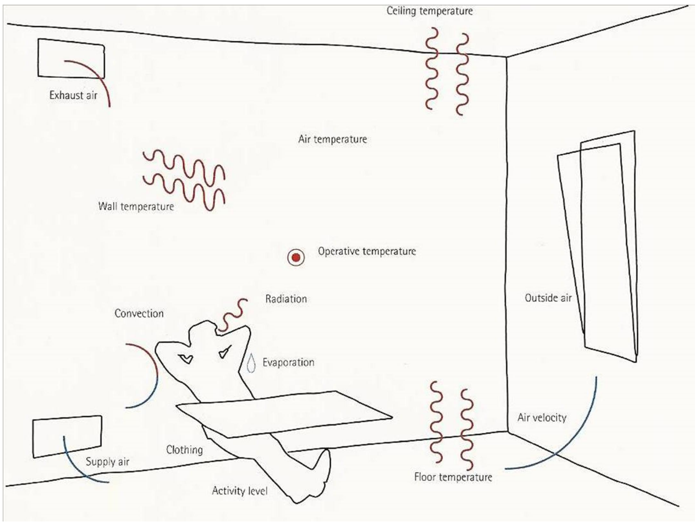


Figure 2.4: Schematic representation of the factors that determine thermal comfort - *Source: Gerhard Hausladen, Michael de Saldanha, Petra Liedl, Christina Sager, Climate Design - Solutions for buildings that can do more with less technology, Birkhäuse, Berlin 2005*

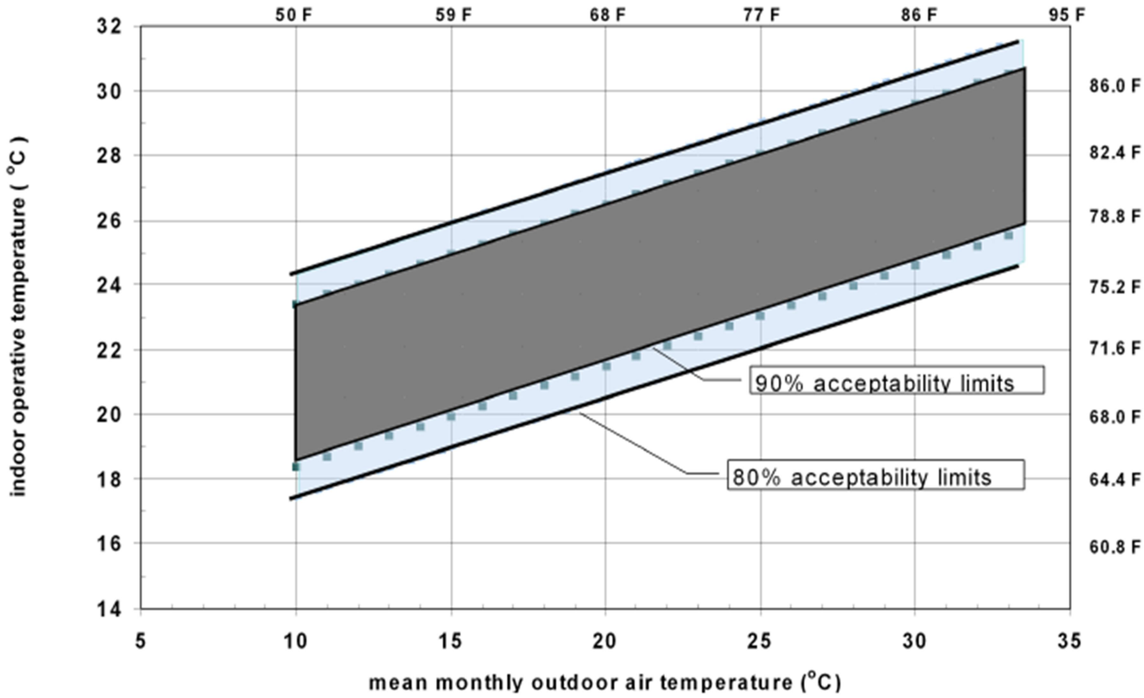


Figure 2.5: Adaptive chart for thermal comfort according to ASHRAE standard 55-2010

The floor temperature should range between 19 and 29°C and the vertical temperature gradient of the room temperature should not exceed 3 K. Ideally, the operational room temperatures should be between 20°C and 24°C, taking into account the factor of clothing appropriate to outdoor temperature. However, a room temperature of 24°C requires a high investment for cooling, and the temperature limit is accordingly set a bit higher.

For instance ISO 7730, defines a maximum room temperature for office of 24.5°C with three categories of deviations (A ±1.0°C, B ±1.5°C, C ±2.5°C). These requirements can only be fulfilled by active measures of air conditioning and cooling in most regions of Nigeria.

Higher room temperatures are acceptable according to the adaptive comfort model, which applies especially to occupant-controlled, naturally conditioned spaces, where the outdoor climate can actually affect the indoor conditions and so the comfort zone. The adaptive comfort model is based on the idea that outdoor climate influences indoor comfort because hu-

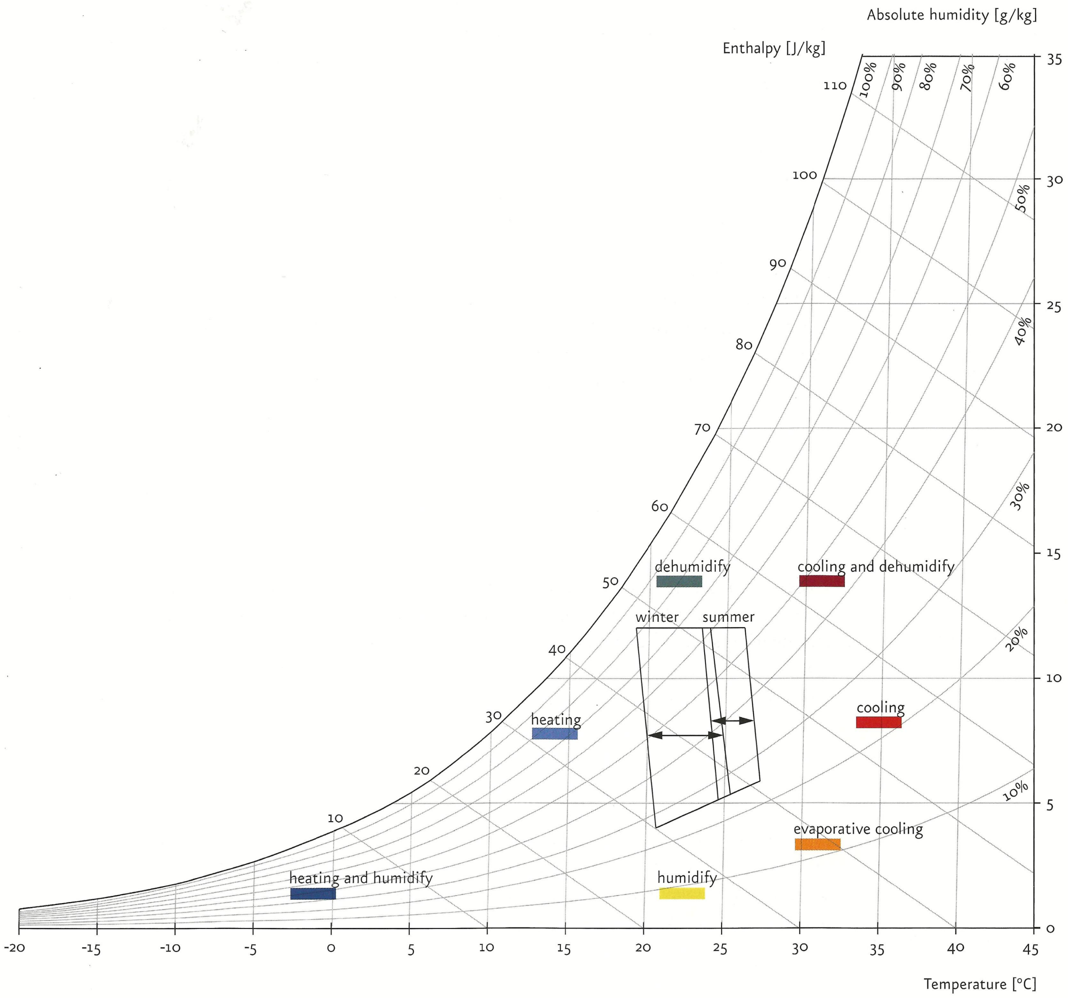


Figure 2.6: Room climate conditioning methods and comfort zones according to ASHRAE-55, shown in psychrometric chart format – *Source: Building to suit the climate: A handbook • G.Hausladen, P. Leidl, M. De Saldanha, Birkhauser, 2012*

mans can adapt to different temperatures during different times of the year. The adaptive hypothesis predicts that contextual factors, such as having access to environmental controls, and past thermal history influence building occupants' thermal expectations and preferences. Numerous researchers have conducted field studies worldwide in which they survey building occupants about their thermal comfort while taking simultaneous environmental measurements. The below shows the relationship between outdoor temperature and indoor operational temperature of a building

Psychrometric charts are used to show thermal comfort zones by temperature and humidity in relation to external climate conditions. Explains the room climate conditioning methods to create a comfortable room climate, which is determined by the comfort zones for winter and summer according to ASHRAE-55. If the local climate is defined in the psychrometric chart (examples for Kano and Lagos are given in BEEG), the necessary means of room conditioning for achieving thermal comfort become obvious.

Psychrometric charts are based on Richard Mollier´s h-x diagram also known as Carrier chart. The temperatures of locations are given on the X-axis, while their absolute humidity levels are given on the Y-axis. The graph curves represent levels of relative humidity. The isotherm line is almost vertical while the enthalpy lines run diagonally from top left to bottom right. The dew point temperature can be calculated from this graph by moving a point horizontally to the left until it meets the curve repersenting a relative air humidity of 100%, and by then shifting this point along the isotherm line towards the X-axis. The limit of cooling temperature can be calculated by moving a point along the enthalpy line as far as the representing a relative humidity of 100% and then moving the point along the isotherm line as far es thre X-axis.

» *Visual comfort*

Visual comfort, safety and the state of the user's eyesight are important aspects of room lighting, especially at work places. This can be by means of natural light, artificial light or a combination of the two. The lighting ambience is determined by the distribution and the level of illuminance, glare, light direction, light colour and colour rendering. Parts of the workplace with particularly high requirements for visual comfort are specially identified as visual task areas.

Daylighting is the most energy efficient way of illuminating rooms and the quality of daylight is optimal, as the human eye is adapted to it by evolution. Hence, daylighting should be used extensively during daytime only complemented by artificial lighting in core areas of buildings without daylight access and at night time, of course. If the minimum lighting requirements cannot be fulfilled by daylight, artificial light has to be used. Automatic control would be ideal to keep artificial lighting and its subsequent energy consumption on a minimum level.

The requirements for **visual performance and comfort** are defined in standards, e.g. ANSI/IESNA RP-1-04, EN 12464, ISO 8995-, BEEG:

- Illuminance (lx), i.e. light flux (lumen) received by 1 m^2 of a reference area (in dwellings and offices 75 cm above floor level); e.g. 300 lx - 500 lx for offices
- Luminance (cd/m^2) seen on the room surfaces and its distribution
- Glare limitation (high contrasts luminance distribution and direct sunlight create glare)
- Direction of light and modelling for 3-dimensional perception
- Light colour, e.g. warm white, white and cold white, defined by Kelvin temperature (K)
- Colour rendering defined in relation to daylight (CRI in %).

Non-visual requirements concern effects of light on the human 24-hour-cycle of activity and sleep, influenced by illuminance and spectral composition of light. Latest research has showed that there is a relationship between circadian effects and daylight conditions. According to DIN SPEC 67600 human activity (readiness to work) is supported by:

- Light colour: Daylight white, > 5,300 K
- Vertical illuminance at the eye: > 250 lx for 8,000 K (higher illuminance for lower colour temperature)
- Large-scale luminaires in the ceiling and upper window area, combined with redirecting daylight systems, are recommended for biologically effective room lighting in DIN SPEC 67600.

Finally, visual comfort means visual contact from the inside out and the outside in.

» *Air quality*

Hygienic comfort is not defined in standards. It describes the air quality and the influence of several factors of comfort in a particular space. These factors include:

- Dust
- Human exhalation and perspiration
- Pollutants from building materials, airborne particles from combustion and heating processes, cleaning[1]
- The influx of unfiltered outside air especially in industrial areas and near high traffic roads odours from food preparation.

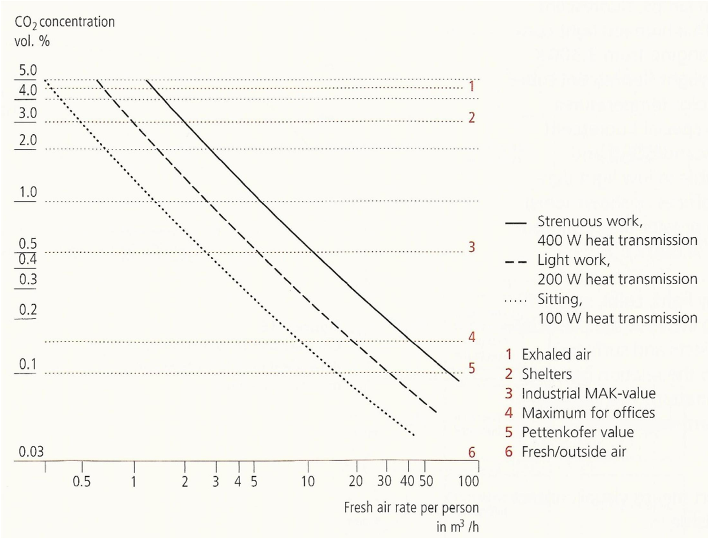


Figure 2.7: Fresh air rate per person for different permissible CO_2-concentration levels – *Source: Sustainaible building design in tropical and subtropical regions. Edition Axel Menges, Stuttgart Daniels, K. et al. Plusminus20°/40°latitude, 2007*

The carbon dioxide scale indicates the increase of exhaled CO_2 in closed rooms. It is used as indicator for impoverished air quality in rooms, notably odours and evaporation, which are especially noticeable in small, densely occupied rooms. When the CO_2 content rises above 0.1%, the air quality is judged to be poor (0.1 vol. % = 1,000 ppm). Toxic effects of CO_2 occur when levels exceed 0.25%. Figure 2.7 gives fresh air rates per person for different permissible CO_2 concentration levels.

The following minimum outside airflows per person is recommended for HVAC:

- Individual office: 40 m^3/h
- Open plan office: 60 m^3/h
- Conference room, circulation area: 20 m^3/h
- Training room, pub: 30 m^3/h

[1] See sustainaible building design in tropical and subtropical regions, Daniels, K. et al, Plusminus20°/40°latitude,. Edition Axel Menges, Stuttgart (2007)

2.2. INTEGRATED DESIGN STRATEGIES

INTEGRATED DESIGN PROCESS

An effective building design process is the key point to design and conceive a sustainable and energy efficient building. Such a process is only attainable with a full cooperation between architects, engineers and energy consultants and supervisors. In order to integrate the relevant knowledge about sustainability into the design, the process must involve all the different stakeholders from the very beginning, and approach problems and issues in a cooperative and efficient way. Every step of the building design must be oriented towards the general goals: A small ecological footprint, together with an overall quality for the user's satisfaction, and economy. Architecture, construction, materials, details and technical systems should be planned in an integrated manner to achieve the best performances. Energy efficiency, investment and operation costs, comfort and architectural quality are key targets to follow in each stage of the design process, in a close cooperation of all relevant professions.

BEEG Nigeria covers the integrated design process, comprehensively. It recommends the following steps to realise a successful project:

- Build a collaborative, open-minded team with communication skills.
- Draft the energy efficiency targets at an early stage.
- Use a whole life cycle approach when budgeting (i.e. taking into account operating costs as well as capital cost).
- Implement an iterative design process, including innovation, synthesis and decision-making based on the agreed objectives.
- It discusses the current design process in Nigeria and suggests ways of improvement.

The main steps and results of an integrated design process for energy efficient buildings are

- Basic evaluation: Boundary conditions (especially climate) and requirements (especially comfort and energy consumption / CO_2 emission)
- Sketch design: Urban and building design concept (especially bioclimatic design concept with an optimized integration of passive and active measures, as well as energy supply. Preliminary energy balance)
- Detailed design: Determination of construction, materials, dimensions, building services. Working drawings, specifications. Definite proof of comfort and energy consumption / CO_2 emission).

» *Strategies*

The typical elements of an integrated design process are, as shown in flow charts of through:

- Integrated approach: An interdisciplinary team works together right from the beginning. The team members set the main performance objectives (see chapter 2.1), and collaborate to fulfil them. The integration includes environmental, urban and building design, architecture, construction, building services, and energy supply as well as project management and quantity surveying. Life-cycle assessment as to energy or CO_2 footprint and costs: Considering all phases of building life cycle, from material manufacturing, transport and building erection; via building operation and maintenance to demolition and recycling (see)

- Building information modelling (BIM): Integrated building modelling by advanced software tools, which allows planning the building as a model from the very first stages, integrating different programs in the main design. Such programmes and tools help to assess in real time the building's performances in cooling, heating, CO_2 emissions, lighting and costs.
- Methodology of systematic design and engineering: From abstract task to definite building. Variation of complexity by analysis and synthesis (a complex task is broken down to separate functions, for which solutions are developed, which are combined again to complete solutions). In order to find the best of all possible solutions, a large variety of solutions has to be generated, which then is reduced again by assessment.

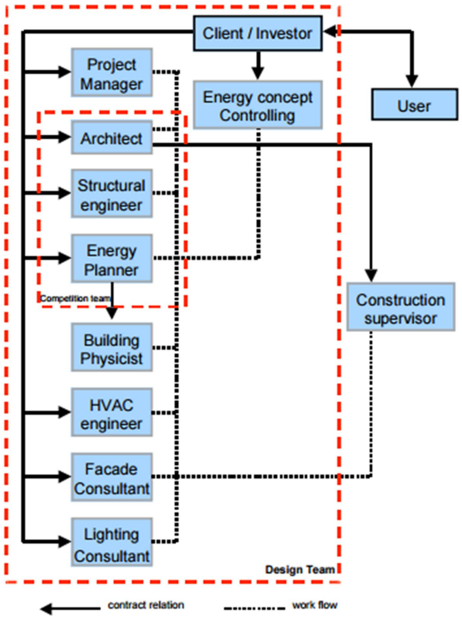


Figure 2.8: Management structure diagram of an integrated design program – *Source: Nils Larsson; The integrated design process; history and analysis, International Initiative for a Sustainable Built Environment (iiSBE) 2009*

In contrast to the traditional building design approach the integrated process starts with a collaboration of different actors right from the beginning. Such a task requires coordination and mediation, but, if achieved, can increase the project's quality consistently, leading to an optimal and sustainable result.

The table below shows a short list of the main differences between the two procedures, in an attempt to underline the advantages of a joint process, now universally known with the term 'charrette'. A charrette is a collaborative plan session organized to achieve a design project within a strict schedule. Initially used for urban design in particular, where many stakeholders have always been involved, it has been recently adopted also for single building projects.

Table 2.3: Comparison of traditional and integrated design approach – *Source: Building and Construction Authority of Singapore, Building planning and massing, ISBN 978-981-08-5313-6, 2010 Singapore*

Traditional approach	*Integrated design*
Limited involvement of project members	Inclusion of every professional involved from the beginning
Systems are considered singularly: Oversizing	Systems are thought along with the whole building performance assessment
Project members undertake limited responsibilities	All members cooperate and share responsibilities
Less time spent in the initial stages: The project gets more intensive in the final part	Projects start more intensively from the first meetings and the concept design
Decisions are made by the main stakeholders, owners and contractors	Decision are made collectively with brainstorming sessions and involving the users
First goal is to reduce initial costs	Main purpose is to plan a general reduction of maintenance and life costs

» *Project preparation*

In the initial stage, owners and promoters often are the stakeholders most involved, but in thoughtful planning they should be supported by experts, architects and engineers, while they assess the possibilities and consider costs and risks. Also setting the goals has become a fundamental process for sustainable buildings. Different objectives have different times to be matched and achieved, and so the initial team has to organize a draft time schedule.

In the early phase of basic evaluation not only the client and design team have to be involved but all parties affected by the project. Already in the phase of basic evaluation a supervisor for the issue of energy efficiency should be appointed to develop and control this issue throughout the entire design process.

For a project to be started in a proper way, various criteria, concepts and main requirements have to be considered thoroughly from the very beginning. Amongst these are:

- Project quality and systems
- Project duration: Goals and possible timetable
- Cost range and budget, investment, operational costs
- Target of environmental sustainability, energy efficiency, kWh/m^2a, carbon footprint (kg/m^2a)
- First concepts of thermal comfort: Thermal insulation, ventilation, visual comfort
- Use of the building, type of spaces, size, number of users
- Boundary climatic conditions, strengths and constraints of local environment
- Cultural or historical bonds or requirements.

» *Concept design*

Core of the concept stage are the graphical models, starting with the design concept itself, which begins with sketches and involves the design team in discussions and brainstorming. In a well-coordinated project, the local community should be made aware of the decisions and invited to meetings and events. In an integrated design approach, the following issues are to be dealt with principally:

- Building orientation and relationship with the surrounding environment must be determined in this stage of the work flow, as they contribute to the passive efficiency of the building.

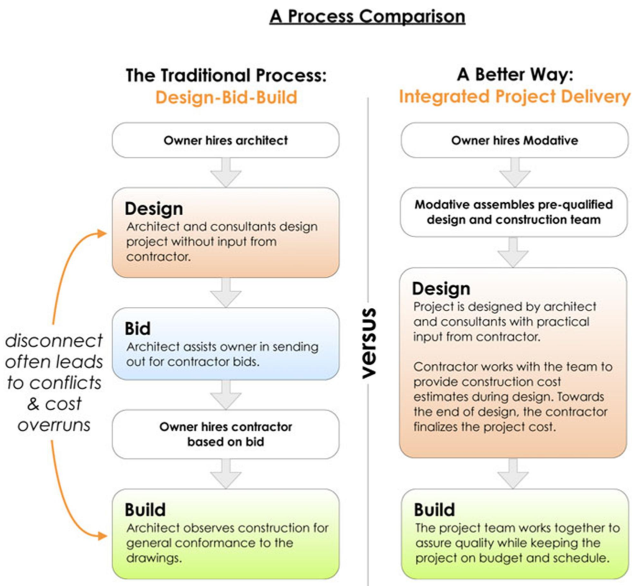


Figure 2.9: Flow chart comparing the standard and integrated design process – *Source: www.designingbuildings.co.uk*

- Influence of solar path and wind direction, along with building size and ratio of area of envelope to volume are to be investigated. Insolation and shaded areas should be calculated and thoughtfully planned.
- Landscape architects should decide about the use of plants and greenery around and on/in the construction.
- Strategies of energy efficiency, energy supply and sustainability. In this stage, some simulation programs help finding the perfect combination of form and orientation promoting daylighting and airflow.
- Building concept: Circulation, main spaces, coordination, sizes, and structural concepts.
- Concept of sustainability: Concepts for passive and active measures and their integration, tools for early calculations of energy and costs, insulation and thermal protection. Materials and embodied energy.
- Aesthetic design: The quality of the architectural design is a comprehensive task of high priority.
- User friendliness: The building and its environment has to be seen in relationship with its final users, thus there must be easy access for private and public transport including a sufficient grid of pedestrian ways.

In this phase, almost all the stakeholders must be involved, to minimize time losses, misunderstandings and cost increases during the following steps. Special attention must be given to the users and the local population, who will eventually make use of the final product. Communication is really important to improve the project quality, and therefore the project manager has to organise frequent and focused team meetings and brainstorming sessions. Project teams should contain multidisciplinary members as shown in Figure 2.8

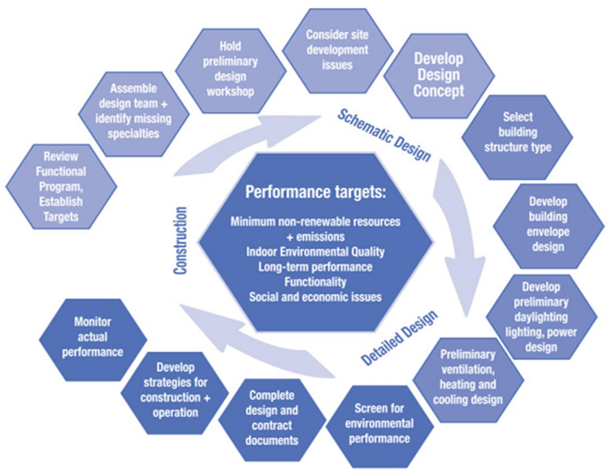


Figure 2.10: Graphic scheme showing the performance targets of a sustainable building, the phases of integrated design process and its results – *Source: www.climatetechwiki.org/technology*

» Detailed design

After the first two stages, the approved concept design enters the phase of detailed and technical design. The results of this phase include not only the building permission but all working drawings and detailed specifications for the construction and building services, including energy supply and proven energy consumption. The performance targets have to be matched and satisfied. A detailed cost plan has to be delivered, followed by a time schedule for the following building operations.

Energy consultants and certifiers are expected to work in close cooperation with the design team to give their know-how input, carry out detailed energy simulations and deliver the necessary proofs and certifications in the end.

» ***Construction***

The construction schedule should be determined in advance, including spot checks for issues of energy efficiency. Special consultants, such as a facade designer or HVAC engineers may be involved, especially for large-scale projects.

» ***Monitoring***

Both during the building process and after the building occupancy spot checks and performance monitoring should be carried out regularly. Especially the control of building services and building automation systems (BAS) has to be optimized by a post occupancy monitoring

DESIGN TOOLS

» ***BIM software***

In the last decade, the role of informatics in building design has had a sensational improvement. In particular, the process of building information modelling (BIM) has been consistently and successfully increasing its role in architecture and engineering, by taking a great part in the modern building process. More and more projects are now, partly or totally, managed with combined software systems, which work together as plug-ins for a core modelling programme. Many of the achievements and evolutions that have been reached during the last few years would not have been possible without the contemporary progress in computing calculations and software programming. Nowadays, complex large-scale projects are carried out by different agencies and firms often cooperating with each other, sharing documents in real time, results and updates via plug-ins based on a unique core software, used to create the main model. Furthermore, this system enhances the collaboration between different participants, minimizing delays and misunderstandings. BIM software can be used continuously in each step of the project, from the first concept to the last detailed design, and it could also serve as a monitoring system for construction and maintenance.

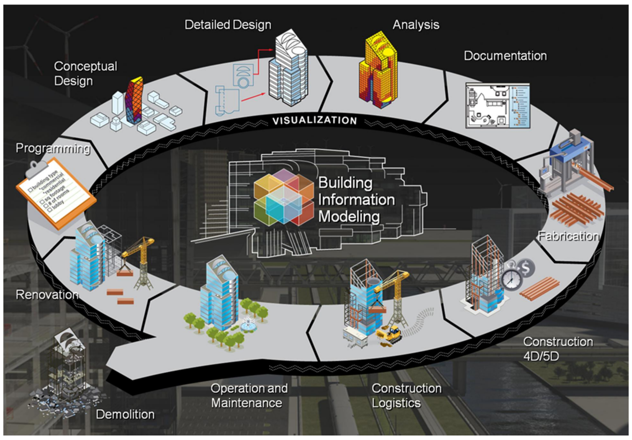


Figure 2.11: Schematic depiction of the areas of intervention of BIM software – *Source: www.westfilm.ch*

BIM TOOLS

Nowadays, hundreds of different software solutions can be used to improve whatever project. Many of them are drawing tools, while others are more complex simulation programs, which are now becoming the most useful instrument to design a sustainable building. The list below is intended as a selection of some particularly effective examples, with a special attention to their costs and usability. For sustainable architecture to be accessible to all, it is important to ensure that professionals have access to different options.

eQuest

eQuest (Quick energy simulation tool) is a sophisticated freeware building energy evaluation software, which estimates the project performance. Its building creation wizard helps the designer to set the building characteristics, going deeper in detail, thanks to a simple sequence of multiple choice questions and options, the programme will shape the design and run the simulations. After compiling the building description (which can be more or less accurate according to the purpose), the software provides a detailed simulation that shows a various range of results. Heating and cooling loads are calculated conforming to the materials of the building envelope, to the usage profile and to the interaction with outer conditions. Along with internal heat gain, many other supplementary energy-consuming devices are calculated, as well as plug loads for electronics. The estimation includes energy costs and lighting systems control.

Energy Plus

Energy Plus is a well-known energy simulation programme, which analyzes energy consumption, passive and active loads, and water usage in buildings. It does not include any graphical interface, and therefore results are given in text format. However, it constitutes the basic language used by many other programs.

Archsim and DIVA

Archsim is an Energy Plus-based simulation application, which works as a tool for the parametric design software Grasshopper. The latter consists of a widely used extension of the 3D design program Rhinoceros. Archsim allows creating multi-zone energy models, simulating them and visualizing results in the same tool. Archsim supports advanced daylighting and shading controls, ventilation modules such as wind and stack natural ventilation. Simple HVAC systems, photovoltaics and phase changing materials can be included in the calculations. It is often used for the early design analysis where building shape, openings, glazing and passive solutions are tested for their impact on the building environmental performances.

DIVA-for-Rhino is an optimized daylighting and energy-modeling tool developed for Rhinoceros. It allows the user to carry out a series of environmental performance evaluations of both single buildings and urban landscapes including radiation maps, photorealistic renderings, daylighting metrics, annual and single time step glare analysis, and single thermal zone calculations for energy loads. As for daylighting, the plug-in can be used for LEED and CHPS compliances. Starting from version 4.0, the software will be distributed together with Archsim, creating a new complete tool.

DesignBuilder

DesignBuilder is a useful software to test various parameters of a project, like energy needs, illumination or indoor comfort. It can be used both as a modeling tool, and as a platform where to import 3D projects from other BIM-related software. The different functions are delivered separately from the producer, so that every professional, architect, engineer or consultant, can choose the package he needs the most purchasing a tailored license. It gives also an overview of the biological footprints of the materials.

Sefira

It's a useful tool for real-time analysis of building performances, integrated directly in 3D modeling programs. It gives immediate feedback of the inner climatic conditions, working as a plug-in for both free (Sketch-up) and for-sale (Revit) programmes, and thus helping the designer to choose the most sustainable solution thorough the modeling process. Thanks to

DAYSIM- and radiance- based simulation engines, it delivers important information about thermal heat gains and daylight factors inside the building space.

Its additional tool Sefaira Systems works specifically to develop advanced and sustainable solutions for HVAC systems inside the buildings studying the impact of different solution from the early stages.

IDA ICE

IDA ICE (Indoor Climate and Energy), from EQUA, is a simulation software for thermal analysis and building performance, which allows executing multi-zone dynamic simulations for different rooms during all the year, directly importing the building geometry from 3D CAD files and models. The tool analyzes the building envelope as well as heating and cooling systems, along with daylighting and natural ventilation. Thanks to its updated ASHRAE catalogue, it matches the requirements for LEED and BREEAM certification systems.

Ecotect

Is an environmental analysis tool that allows designers to simulate building performance from the earliest stages of conceptual design. It combines analysis functions with an interactive display that presents analytical results directly within the context of the building model. It offers a wide range of functionalities to improve performance of existing buildings and new designs. It can be combined with other programmes from the same producer (Autodesk), both 2D and 3D, a characteristic that makes it part of the BIM software.

Table 2.4: Brief comparison of the main building analysis tools

	2D Models	*3D Models*	*BIM tool*	*Natural vent.*	*Dynamic lighting*	*Static lighting*	*Artificial lighting*	*HVAC*	*Freeware*	*LEED, BREEAM*
eQuest		✓	✓					✓	✓	
Energy Plus			✓		✓	✓		✓		
Archsim/ DIVA		✓	✓		✓	✓				
Design-Builder		✓	✓					✓		
IDA ICE		✓	✓	✓	✓					✓
Sefaira		✓	✓	✓	✓			✓		
Ecotect		✓	✓							
ReLux	✓					✓	✓		✓	
DIALux	✓					✓	✓		✓	

SPECIAL TOOLS

Athena impact estimator for buildings.

The Athena Sustainable Materials Institute in Canada offers an easy-to-use freeware tool for calculating the environmental impact of building projects. Its focus is on the life cycle analysis (LCA), whereby the results are given with a user-friendly interface via graphs and tables. It gives useful overviews on different alternatives, and it contains a special module dedicated to the 'end-of-life' calculation (the characteristics of every material to be recycled or re-used).

» Lighting Design

RELUX

ReLux is the most complex tool used for calculating various types of lighting systems. It has a sophisticated, but rather intuitive graphic interface, which ensures an optimal management of outcomes and results. The software can be used to simulate workstation lighting, roads and design applications. Every result can be printed or exported in pdf or jpeg format. Relux can measure both daylight and artificial light, either separated or compared, using the radiosity method. Accurate 3D renderings can be produced using raytracing. Artificial light calculations consider the maintenance factor of both the lighting system and the room (or the space around). The maintenance factor can be chosen using default settings, with a certain approximation, or calculated separately (and put manually overriding the settings). Technical drawings can be imported and the software recognizes points, lines and measures in .dwg and .dxf format.

DIALUX

DIALux is a lighting design software used for calculations of interior and exterior lighting with the option of photorealistic visualization and simple and intuitive control. It includes a vast catalogue of photometric data from the main lighting companies, with detailed descriptions of the luminaires. Daylighting as well as artificial lighting can be evaluated and analyzed with quick, yet accurate graphical renderings. Like Relux, it allows to import CAD files, and 3D elements as .dxf files. The software works with both radiance and raytracing simulations.

SUNRAYS

Sunrays is a programme for photographers and cinematographers that shows the sun's position during the course of a day. It uses Google Earth to display the positions. The direction of the sun can be displayed as 2D projection or as 3D vectors. The 3D option allows to see obstacles such as tall buildings already in advance. The program is shareware. The unregistered version is limited to a 2D display in Google Earth. The full version allows 2D and 3D display in Google Earth as well as .svg and .png images. It also includes a database with thousands of cities for when offline.

SUN EARTH TOOLS

Useful ensemble of different tools that allow calculating the sun-position in the sky on every place on earth at any moment of the day and of the year. The instrument delivers information about solar path, azimuth and sunrise/sunset hours. It also contains a schematic calculator to help sizing correctly a photovoltaic system.

Table 2.5: Different analysis tools and their application in the design phases

	Project preparation	*Concept design*	*Detailed design*	*Freeware*
eQuest		✓	✓	
Energy Plus		✓		
Archsim/Diva		✓	✓	
DesignBuilder			✓	
IDA ICE			✓	
Sefaira		✓	✓	

	Project preparation	Concept design	Detailed design	Freeware
Ecotet		✓	✓	
ReLux		✓		
DIALux		✓		
Athena	✓			
Sun-Earth Tools	✓			

CAD PROGRAMS

The following short list is meant to provide professionals of any type and country with some useful programs to achieve technical drawing. Although 2D and 3D drawing is not completely part of the main focus in this analysis, it may be helpful to know that some of the software tools are available free and out of charge.

- Drafsight, by Dassault Systemes, freeware 2D drawing program
- FreeCAD, freeware 2D and 3D parametric modeling program
- Open Scad, freeware 3D software for engineers

2.3. CLIMATE, MICROCLIMATE, URBAN DESIGN

CLIMATE

Key task for an energy effective and sustainable project is to study and understand the local climate and its characteristics, to exploit them in the most proper way avoiding any waste of energy for the inner comfort. Throughout history, humanity has always managed to achieve a responsive and adaptive relationship with local outdoor climate, understanding, despite the lack of measuring systems, the importance of weather conditions when shaping buildings. The advent of modernism and air-conditioning technology brought constructors and designers often to neglect the issues of regional climate and to entrust the users' comfort to energy consuming mechanical systems (international style). The behaviour is now changing consistently, as professionals gain awareness of the importance of climate data from the preliminary stages of the projects. Special classifications, such as Köppen and ASHRAE, help designers and engineers to analyse the local condition all over the world.

» *Elements of climate*

The main elements of climate, which are interesting for urban and building design

- Temperature
- Relative humidity
- Precipitation
- Sky conditions
- Solar radiation
- Wind

Data, which characterize these elements of climate for regions or sites in a suitable way for designers, are available in various statistical sources and often are offered in combination with building simulation tools.

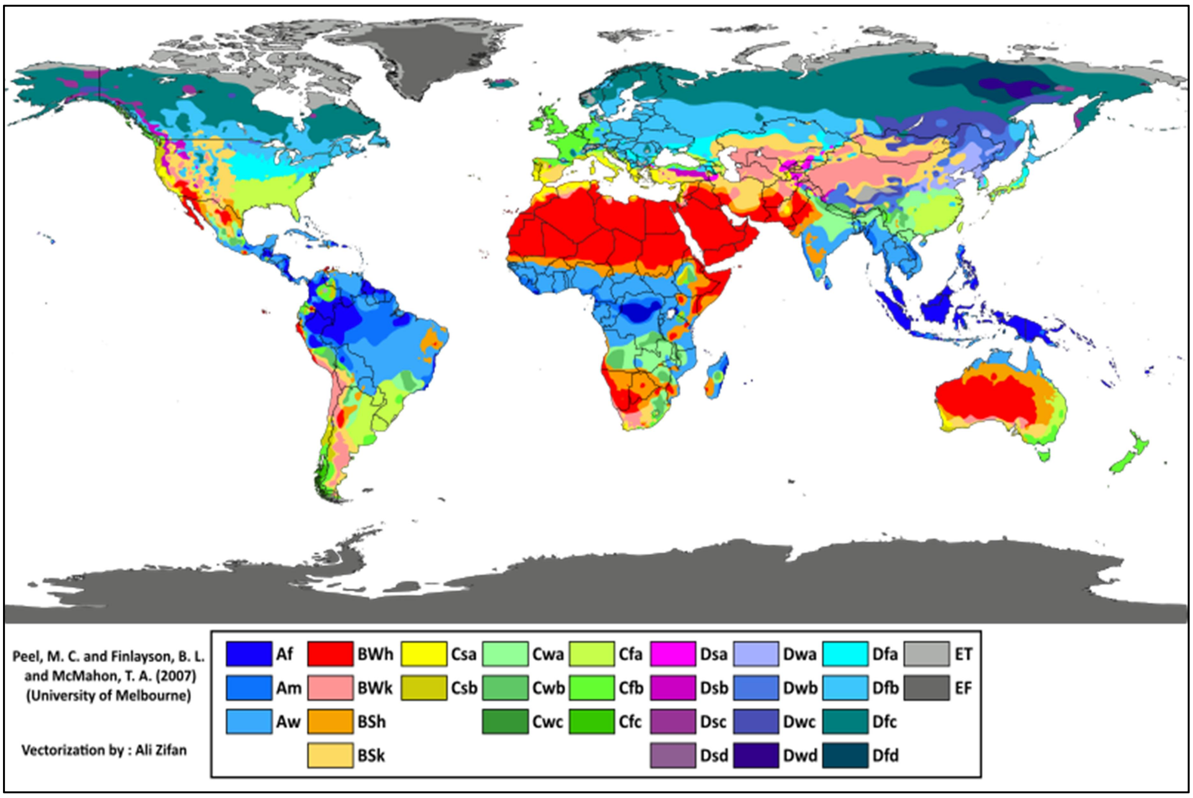


Figure 2.12: World map of the Köppen climate classification – *Source: webmap.ornl.gov*

» *ASHRAE definitions*

More suitable for comfort and energy efficiency of buildings are the definitions of climatic zones by ASHRAE code 4710/4711. They periodically supply and review a list of climate zones, to which the designer can relate when planning a building with optimal performance. The basis of this scale are heating and cooling degree-days, calculated by the daily difference between the ambient mean temperature and base temperature.

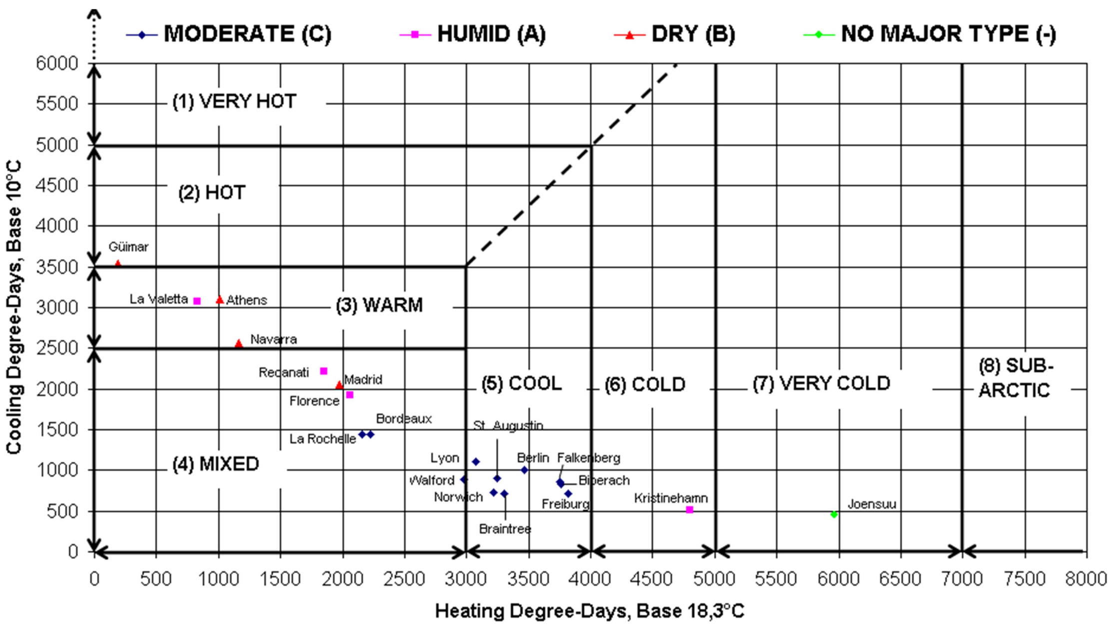


Figure 2.13: ASHRAE climate zone chart. Examples of cities in Nigeria: Lagos: Zone (1) Very hot, type humid (A) and Abuja: Zone (2) Hot, type dry (B) – *Source: www.ashrae.org*

For a cooled building, the base temperature is the outdoor temperature at which the cooling plant does not need to operate. ASHRAE climate zones are defined by a classification of cooling and heating degree-days (see Figure 2.13). The cooling degree-days of a location allow to calculate the cooling load of a building. Additionally there is a classification of relative air humidity (types). ASHRAE has a regularly updated list of climate stations around the world, with respective data for the degree-days. However, every location can be analysed by calculating the degree-days.

For Nigeria, as for all tropical countries, only cooling degree days shall be taken into account, since no attention has to be given to heating systems, as opposed to air conditioning and cooling, which constitute the main tasks for the energy performance.

» *Sources of climate data*

Since weather data and average temperature have become more and more valuable for building design from the very first steps, architects and engineers must have access to such information in a detailed and comprehensive way for any kind of project, virtually everywhere on earth. Internet has made such goal possible, and today diverse on-line tools and websites collect and provide detailed historical records for temperatures, sun direction and insolation, humidity, wind intensity and rainfall. To give some examples:

- "Climatemps" is a rather useful website to get information on local climate data for almost every location on the planet. Data is either assembled in a table, or given separately (www.climatemps.com)
- www.degreedays.net helps to define the amount of degree-days in a given place.

Apart from the internet tools, climate data can also be easily gathered from the closest available weather station. Especially for Nigeria, the Nigerian Meteorological Agency (NiMet) provides a detailed database of average temperatures and weather stats.

MICROCLIMATE AND URBAN DESIGN

Dealing with architectural and engineering projects, professionals always face local conditions and boundaries, and responsible planning must be thought in order to enhance the quality of the surrounding environment. With the ever-growing concern about sustainability, designers are being challenged not only to consider the issues of outdoor microclimate, but also to integrate them into the basic building design. Urban design and architecture have a great influence on local microclimates and its elements of solar radiation, temperature, wind, air

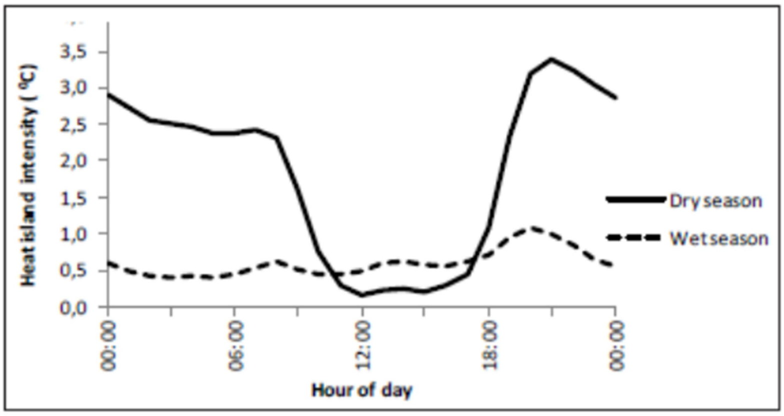


Figure 2.14: Diurnal variation of the urban heat island effect in Akure, Nigeria. Temperature difference between town centre and airport for dry and wet season in 2010 – *Source: www.die-erde.org*

quality, and noise. Thus it influences the comfort in external spaces as well as the climatic conditions and energy demand of buildings.

A microclimate can be defined as the characteristic climatic condition of a small area, for instance a small settlement, a neighbourhood or a park, and it can differ significantly from the regional climate. Yet, it is the unit that composes the general climate we live in, may it be urban or rural, and therefore it is essential to favour its sustainable development by applying smart strategies in urban design and master planning.

Cities, much more than rural settlements, work as gigantic heat storage, creating the so-called **urban heat island** (UHI), describing the temperature difference between urban areas with high and low density. Figure 2.15 shows an example of the UHI in Akure, Nigeria, with the temperature difference between town centre and airport. In the dry season UHI is higher with a maximum of 3°C at night than in the wet season with a nearly constant UHI of 0.5°C throughout day and night.

» *Strategies to minimise urban heat islands*

The increased temperatures in urban heat islands are influenced by the following parameters of urban design:

1. **Openness to sky** is described by the ratio height of building to width of street and external spaces (H/W). Narrow streets support the shading of facades and street surfaces against solar radiation, especially for S/N oriented streets. On the other hand, wide streets allow fast cooling at night (IR radiation to the clear sky, wind)
2. **Orientation of urban structure** is a compromise concerning solar orientation of facades with to respect external spaces and wind direction. Wind orientation often is more important in tropical climate. Air corridors in main wind direction improve air quality and avoids UHI. Wind incidence perpendicular to buildings reduces wind speed and cooling by convection.
3. **Urban surfaces** are usually hardscape surfaces, involving roads and public spaces as well as buildings and private surfaces. Hardscape, as opposed to the softscape (green and land), does not absorb water, creating dangerous conditions for floods and water damages. Porosity of the surfaces supports storage of rainwater and cooling effects by evaporation.
4. **Solar reflectivity and longwave emissivity** of materials influence the thermal ambient climate. Light colours have a high solar reflectivity and stay cooler than dark, solar absorbing materials. The longwave (IR) emissivity should be large in order to emit heat by radiation. Nearly all building materials have a large emissivity (0.8 - 0.9), except specular metals surfaces, e.g. stainless steel, polished aluminium (0.2 – 0.02). Compare Figure *2.15*.
5. **Green and water areas** improve the microclimate. Benefits of vegetation are visible and perceivable. Vegetated surfaces absorb and drain water avoiding excess, control solar radiation and cool the air temperature. Green roofs and wall, when feasible, are a good system to keep constant air quality inside of the buildings, enhancing the city landscape. Gardens and ground greenery help the urban microclimate, and tree canopy shades roads and buildings from direct sunlight. Characteristics see chapter 2.2.1.

6. **Shade for large outdoor areas**: Parking lots, squares and alleys contain great amount of hardscape surfaces, which are much likely to produce overheating when not conveniently covered. Vehicles are another source of heat waves, and contribute to the temperature rise even after the engines stop.

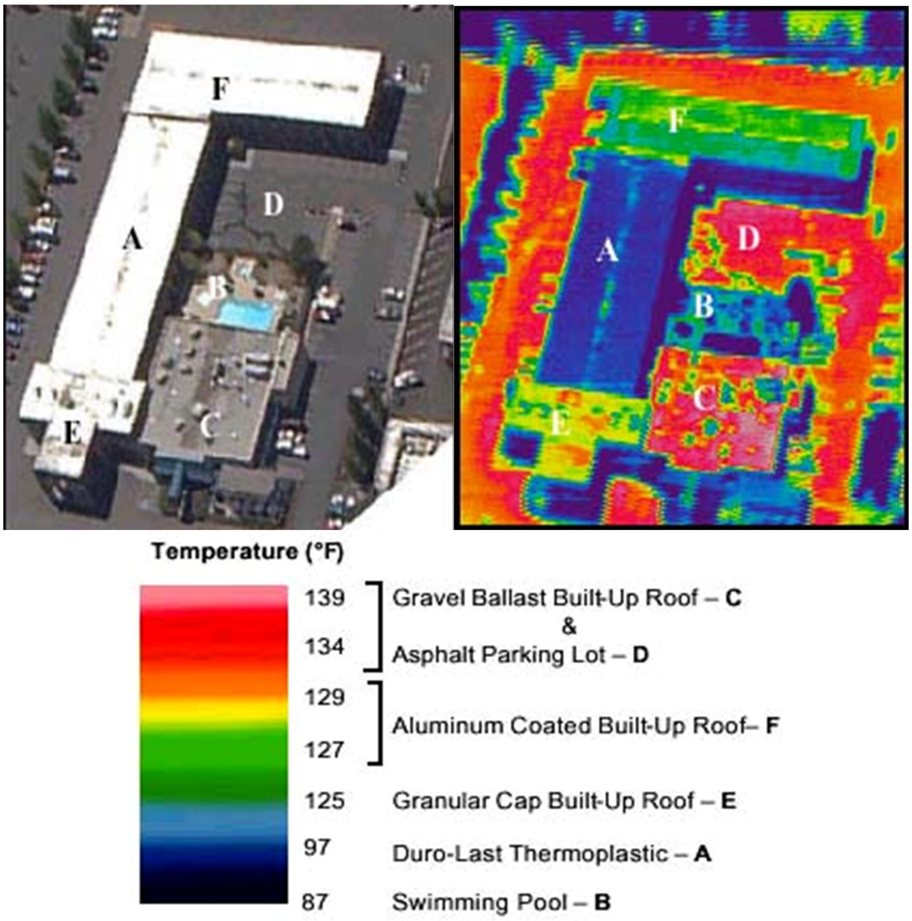


Figure 2.15: Temperatures of urban surfaces – *Source: Ali-Toudert 2008: From Green building to sustainable urban settlements: A new assessment method. Proc. Conf. PLEA 2008, 22-24 Oct. 2008, Dublin*

The microclimate could also be usefully exploited approaching the project site in a critical and analytic way, observing what, in the surrounding landscape, could become a natural shading facility, like trees, hills or neighbour buildings. A thoughtful design should also consider sources of possible disturbing glare situations to avoid discomfort. Water sources, for instance, can cause disturbing reflections and should be taken in considera-

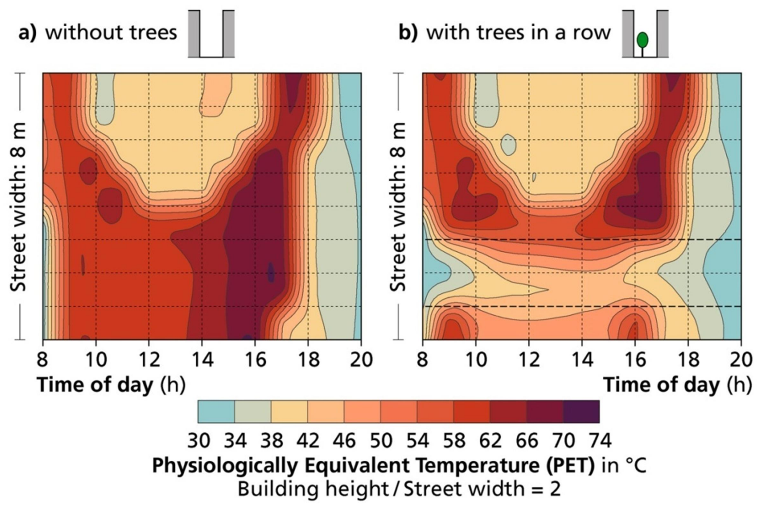


Figure 2.16: Example of the effect on a street canyon of a line of trees – *Source: Wilhelm Kuttler (2012). Climate Change on the Urban Scale – Effects and Counter-Measures in Central Europe, Human and Social Dimensions of Climate Change, Prof. Netra Chhetri (Ed.), ISBN: 978-953-51-0847-4*

tion when designing a building, but they can also be really helpful to mitigate the climate, if included contiously in the project.

SIMULATION TOOLS

There are simulation tools for the microclimate, taking into account the elements of climate (temperature, humidity, solar radiation, sky condition, and wind), all the urban design parameters named above, and the man-made heat sources, e.g. air-conditioned houses. Models like ENVImet[1] MetPhoMod[2] allow to quantify the microclimate for parameter variations and to define the external temperatures for building simulations more accurately in comparison to standard climate data.

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2. *Building planning and massing* • Building and Construction Authority of Singapore, ISBN 978-981-08-5313-6, 2010
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4. *International Organization for Standardization* • ISO 7730 and ISO 10551
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6. *Designing the urban microclimate: A framework for a design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process* • M. Pijpers-van Esch, Delft University of Technology, Faculty of Architecture and the Built Environment
7. *Department of urbanism, department of architectural engineering + technology* 2015
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9. *International Organization for Standardization* ISO 16814
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13. *Biologically effective illumination: Design guidelines* • DIN SPEC 67600, (2013-04).
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[1] www.model.envi-met.com/hg2e/doku.php?id=files:downloadv4
[2] http://pandora.meng.auth.gr/mds/showlong.php?id=109

RELEVANT WEBSITES

1. www.doe2.com/equest
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3. www.diva4rhino.com
4. www.designbuilder.co.uk
5. http://sefaira.com/
6. www.equa.se/en/ida-ice
7. www.athenasmi.org/
8. www.relux.biz
9. www.dial.de
10. www.westfilm.ch/en/sunrays
11. www.sunearthtools.com/dp/tools/pos_sun.php?lang=en
12. www.climatemps.com
13. www.degreedays.net
14. www.passivhaus.org.uk

3. PASSIVE AND ACTIVE MEANS FOR ENERGY EFFICIENT DESIGN

What this module is about

The module explains the main passive and active measures to achieve energy efficient design in buildings. Passive strategies are analyzed first, with a short retrospection on the traditional vernacular architecture and its adaptations to the local climate. Active measures are explained both alone and in combination with passive strategies.

Learning outcomes

At the end of this module, the participant is able to

- Understand bioclimatic building design for Nigerian regions
- Apply passive architectural measures for comfort and energy efficiency
- Apply active measures of building services for comfort and energy efficiency
- Integrate passive and active measures of comfort and energy efficiency
- Apply design tools for simulation of bioclimatic performance and energy demand costs

3.1. BIOCLIMATIC BUILDING DESIGN

CLIMATE ZONES OF NIGERIA

Climatic zones are based on similarity of temperatures as well as the annual precipitation. The map in Figure 3.1 shows the main climatic conditions of Nigeria according to the classification system of Koeppen. This system uses letter codes to identify the major climate zones: (A) tropical forest, (B) dry forest, (C) warm temperate rainy, (D) cold forest, and (E) polar regions. Further subdivision according to the temperature, rainfall, and seasonal variations is described through sub-codes.

A classification system developed by ASHRAE (code 4710/4711) also takes into account the heating and cooling degree days of a climate. This allows comparison and evaluation of the different energy consumptions of buildings resulting from climatic conditions. Although the system is based on standards and conditions of the USA, it can also be applied to African locations.

Climatically, Nigeria is entirely located within the tropical zone, but shows important variations in different regions of the country. The climate in the north is mainly hot and dry, with high temperature and humidity fluctuation, whereas in the southern area it is hot and humid, with quite continuous temperature and humidity levels.

» Monsoon Climate

Around the southern coastal area, seasons are not precisely different to one another, with the climate showing constant average conditions during the year. Temperatures rarely exceed 32°C, but humidity is very high and nights are particularly hot. This climatic area registers a strong influence from the monsoons originating from the South Atlantic ocean. Over 4,000 mm of rainfall is received in the region around the Niger delta. The rainy season normally starts in February or March when moist Atlantic air, known as the southwest monsoon, invades the country. The southern region of Nigeria has two rainy periods with dry seasons in between.

Figure 3.1: Division of the climatic regions in Nigeria according to the Köppen classification – *Source: World Koppen Classification.svg.*

Temperatures remain almost constant for the whole year, with very high humidity levels during the entire year. This area of the country falls within the Köppen classification "Af" (Hufty, 2001). Lagos, the most populated city, is located within the tropical humid-dry zone.

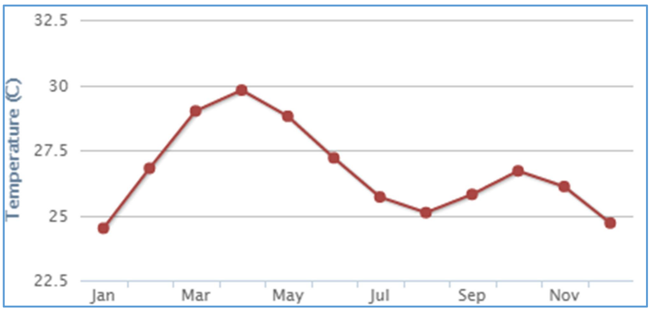


Figure 3.2: Average monthly temperature in Nigeria, historical data from 1900 to 2012 – *Source: Climate change knowledge portal*

» *Tropical savanna climate*

The tropical savannah climate influences the country remarkably. This type of climate consists of a rainy season and a dry season. Opposite to what happens along the coast, diurnal temperature variation is strong and significant between day and night. The Harmattan wind occurs during the hot season and brings dust from the Sahara desert. In northern Nigeria, the usual peak of the rain season occurs in August, thanks to the Atlantic currents that cover the entire country.

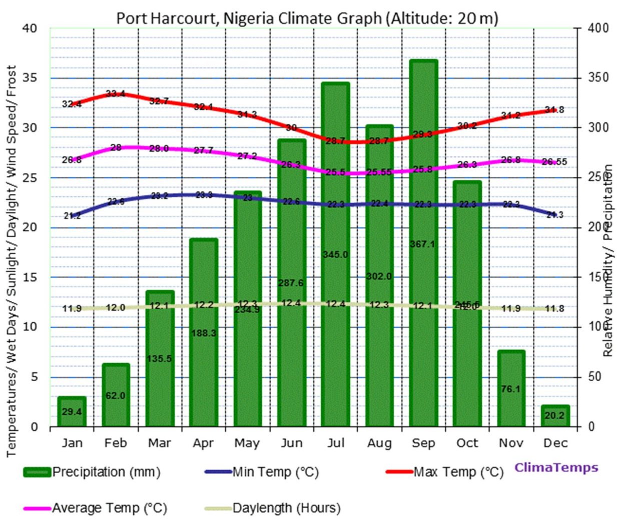


Figure 3.3: Climate data graphs for Port Harcourt, monsoon area – *Source: www.climatemps.com*

Throughout the country, temperatures are generally high, and diurnal variations are more pronounced than seasonal ones. Average high and low temperatures for Lagos are, for example, 31°C and 23°C in January and 28°C and 23°C in June. From September to November, the temperatures are generally milder in most of Nigeria, due to the northeast trade winds, which bring a season of clear skies and lower humidity.

In most areas there is a sharp alternation between wet and dry seasons, and thus rainfall is a key to understand and interpret how climate zones occur. Two main air masses control rainfall: maritime air moving north from the Atlantic ocean and dry continental air coming south from the deserts and arid areas in the north. Topographic relief does not intervene much in the climate, apart from the Jos Plateau the eastern highlands. Northern areas are mainly affected from the aforementioned Harmattan wind, whose effects could occasionally be felt further south, sometimes reaching the coast. Mean annual rainfall may vary from 4,000 millimetres per year in the southeast, to 500 mm/a in the dry savanna region.

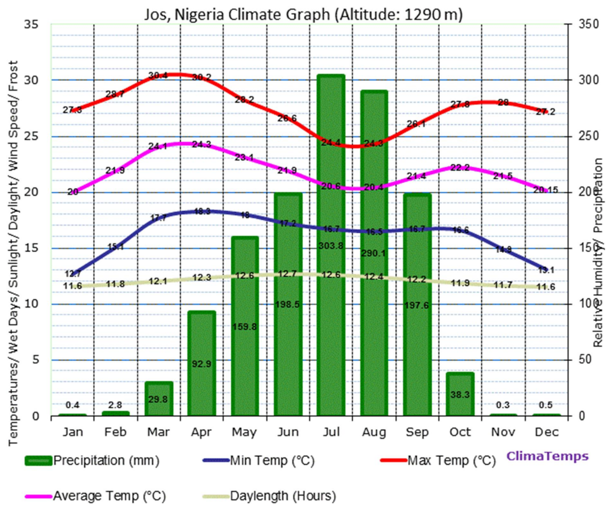


Figure 3.5: Climate data graphs for Jos – *Source: www.climatemps.com*

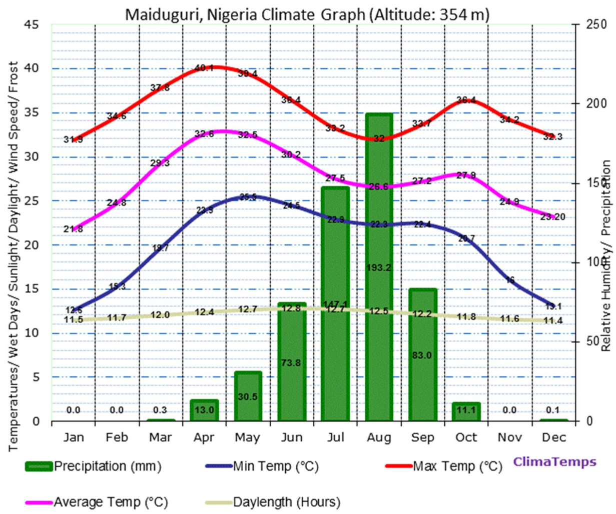


Figure 3.4: Climate data graphs for Maiduguri, in the semi-arid area – *Source: www.climatemps.com*

» *Warm semi-arid and desert climate (Sahel)*

In this area, total annual rainfall is lower than in the southern and central regions, with the wet season typically covering only three to four months. For the rest of the year the weather is remarkably hot and dry, with variable relative humidity depending on the rains. Temperatures can reach as high as 40°C. The daily temperature variation, as for the previously mentioned region, is significant. Similar conditions can be registered moving north from the savannah zone, which gradually becomes drier.

» *Factors affecting climate*

SOLAR RADIATION

Typical values of insolation are given for the months of the year in kWh/m² and day in for different locations in Nigeria. The fluctuations are rather small between 5.0 and 6.5 kWh/m²d with the maxima in spring and autumn and the minimum in summer because of higher humidity and precipitation. The annual insolation with 1,650 kWh/m²a in the southern regions and up to 2,100 kWh/m²a in the northern regions offers excellent options for solar thermal and photovoltaic utilization.

The sun path diagram in shows the positions of the sun for Lagos for the daytime and months of the year. This information is essential for the direct solar radiation on roofs and facades in different orientations and for the shading angles of vertical and horizontal shading devices. The highest insolation will be on horizontal roofs, followed by east and west facing facades during the mornings and evenings. South and north facades have a relatively low insolation and the vertical solar angles are high (> 60° / 75°).

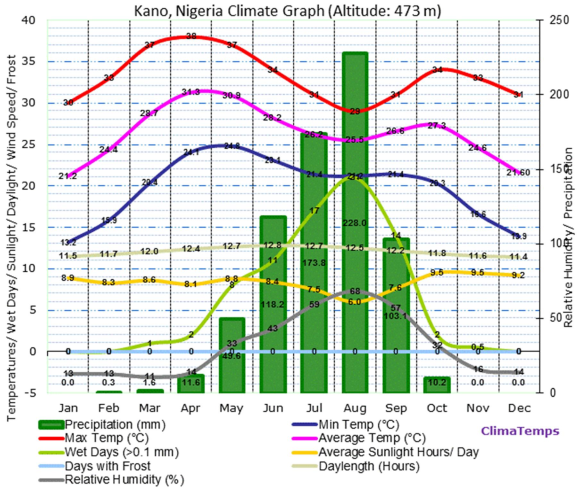


Figure 3.6: Climate data graphs for Kano, in the northern savannah zone – *Source: www.climatemps.com*

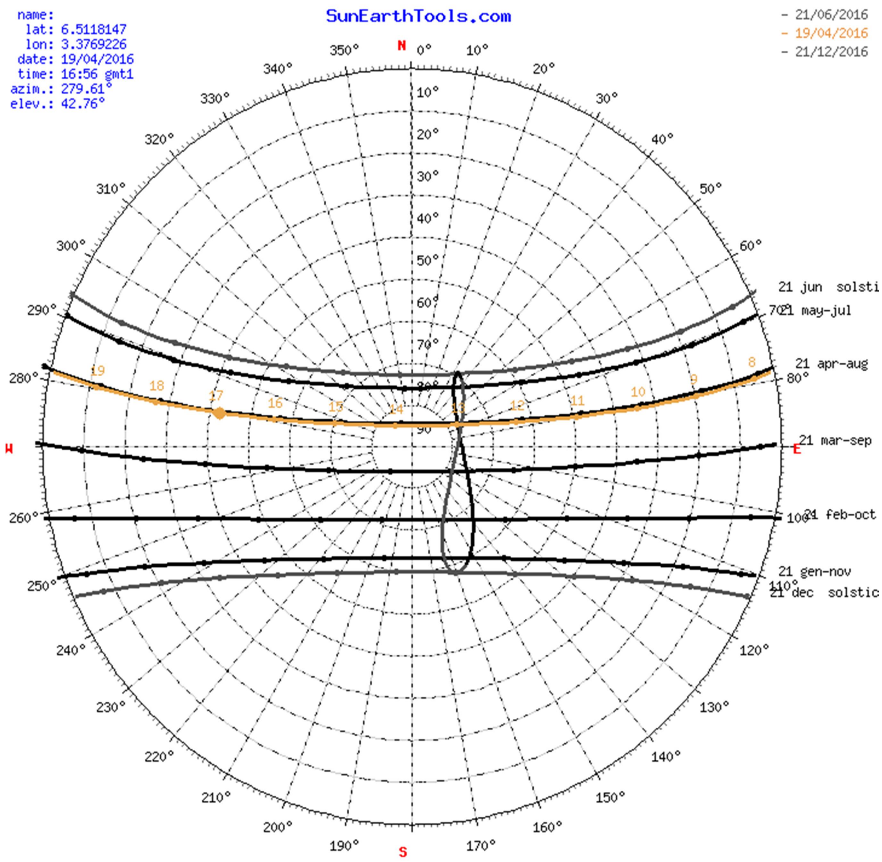


Figure 3.7: Sun path diagram for Lagos, *Nigeria* – *Source: www.climatemps.com*

WIND

Two principal wind currents affect Nigeria. The Harmattan, from the northeast, is hot and dry and carries a reddish dust from the desert.

The humid southwest wind brings clouds and rainy weather. These conditions result in four climate types distinguishable as one moves from south to north. As in most of West Africa, in fact, Nigeria's climate is characterized by strong latitudinal zones, which become drier as moving north from the coast.

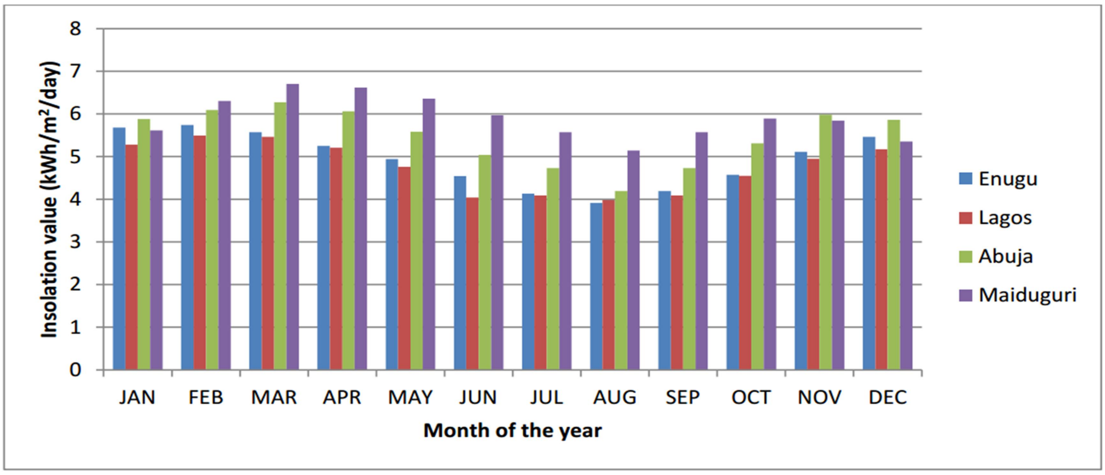


Figure 3.8: Insolation values at different months of the year for different locations in Nigeria – *Source: sdwebx.worldbank.org*

DEGREE DAYS

An international database supplies such parameters gathering information from thousands of weather stations around the world, monitored and updated by ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

There are currently around 40 weather stations in Nigeria, but none of them is included in the ASHRAE catalogue. However, climatic data can be easily gathered from the internet or from local sources.

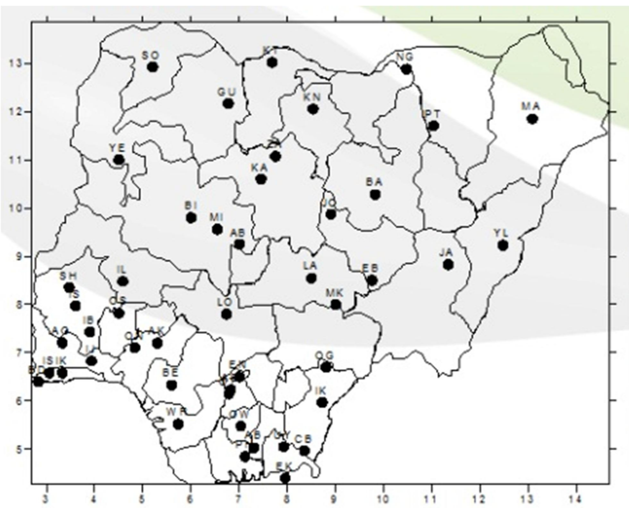


Figure 3.9: Meteorological station network in Nigeria – *Source: NiMET*

VERNACULAR NIGERIAN ARCHITECTURE

Traditional architecture has always been influenced by local climatic conditions and accessible materials. Local populations have found and perfectioned effective strategies to achieve a perfect combination of comfort and sustainability. The indigenous architectural style is a reflection of all the different ethnic groups, religions, cultures and climate zones that compose Nigeria. This obviously results in an exceptionally diverse and heterogeneous range of interpretations. A common ground could be found, however, in the use of locally traceable materials and in the big role that spirituality, community and family life play, which strongly shapes the form of the buildings. The majority of the settlements grew around a central community space that served as a gathering point for meetings and social life. The basic construction materials were local timber, mud bricks and palm leaves. Such structures did not live long, and had to be frequently repaired or replaced. However, this traditional approach had a really different life-span concept compared to buildings nowadays. Depending on the different climatic conditions, technology and material can vary consistently.

» Influence of climate

NORTHERN NIGERIA: HOT AND DRY

In the northern regions, the most common construction materials were mud and adobe, used to create sun dried blocks or *tubali*, a particular kind of brick reinforced with palm branches. Another typical wall structure, especially in the rural areas, is what is called 'wattle and daub', created merging mud and cane. Such constructions possess a **high thermal capacity**, really useful for temperature variations between day and night. In the main urban environments, adobe technology has been exploited at its best, particularly in the main city-states that arose from the 15th century, with effective structural systems and skilfully decorated walls.

SOUTHERN NIGERIA: HOT AND HUMID

In southern Nigeria, very little temperature variation between day and night characterize the climate, entailing particular building strategies. Open constructions are general preferred, as well as with very **low thermal capacity** and large openings. Cross-ventilation has always been the best mean to contrast humidity and heat, with large courtyards to allow every room to have different expositions. Roofs are frequently covered with straw, with large ledges, in order to give shelter from the rain and to drive off the water. The traditional materials in southern Nigeria are mud and timber. Palm tree is also largely used.

» Other influences

POPULATIONS AND ARCHITECTURE

Along with the surrounding nature, local culture and traditions have always had a remarkable input on the construction of both private and public buildings. Religion is often a predominant factor to determine how the settlements develop. Briefly analysing the main different ethnic groups can be another helpful way to realize how the building styles and forms differ from one another.

Figure 3.10: Traditional building in Hausa style – *Source: www.skyscrapercity.com/showthread.php?t=1293777*

Major population of the northern side of Nigeria is the **Hausa**, which is also the most numerous group overall in the country. Traditionally, they tend to constitute large communities, as cities like Zaria and Kano show. They have always been farmers (cotton, groundnuts and food crops) and traders in agricultural products, textiles and leather. The predominant religion is Islam, which has had a noticeable influence on the population's way of living over the years.

Spatial dispositions are especially shaped according to the particular cultural tradition. A typical dwelling includes rectangular and circular units, linked with one another by wall segments that contribute in constituting the exterior envelope. Famous features of Hausa architecture are its peculiar vaulting and the highly decorated and painted walls. The basic material is adobe, composed in egg-like bricks called *tubali* and then plastered with earth. Roofing is made of shallow vaults linked together with earth patches. The reason to build with massive walls and roofs is to exploit the components' high thermal mass, as to delay in time the heat penetration from the outer environment. During the day, sunrays hit the surface and the walls store it, slowly releasing the warmth during the night, when it is most needed due to the temperature fall. The same process happens with the vaults, which are the most affected part, since they absorb the main radiation ratio during the day. Their very shape, moreover, is typically suitable to convey rainwater: A real advantage where rains are not frequent.

Figure 3.11: A clear example of Hausa architecture: The Kano History Museum – *Source: www.skyscrapercity.com/showthread.php?t=1293777*

In the southwest region, the **Yoruba** represent the main population. Animism and later Christianism are the two most diffused religions, although Islam is present, with a high level of tolerance. They are predominantly agrarian, with a traditional vocation for fine art, with bronze casting, terracotta and wood sculpting. Even before the first colonizers came, their settlements were particularly large with modular houses. The basic size for a dwelling unit is 10 feet long and 10 feet wide. Single units are then linked with external walls forming the house, typically angular in shape. Walls are earth-made, with differences between the southern Yoruba, who generally use the monolithic cob technology, and northern groups who sometimes prefer to adopt the wattle and daub wall composition. As for roofing, the basic structured is of termite-resistant timber, with different covers: Gbodogi (sarcophrynium) leaves in the south, and elephant grass fibre to the north. Roofs are normally pitched.

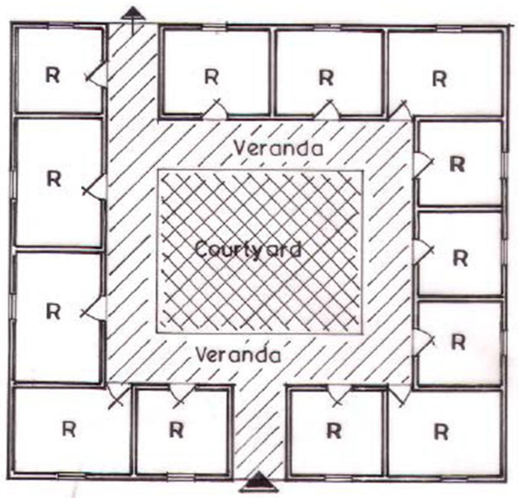


Figure 3.12: Typical disposition of a Yoruba compound – *Source: Cordelia O. Osasona, from traditional residential architecture to the vernacular: the Nigerian experience, Obafemi Awolowo University, Department of Architecture, Ile-Ife, Nigeria.*

The **Igbo** live in the southeast of the country. Their typical settlement is a small size community, in most cases coincident with a single clan, although colonisation influenced the construction in some larger commercial towns. The Igbo are traditionally dedicated to industry and commerce, but farming is still quite widespread. A big difference with the Yoruba architecture, otherwise conceptually similar, is the disposition of the building units, which follows a distinctive importance ranking. In fact, the main hut is where the rest of the building starts to develop. Since the two cultures are different, so the main symbolism also differs. The main symbolic character has been given in this case to the *Obi*, the main structure, by a decorated wood panelling indicating its spirituality.

COLONIAL INFLUENCE

British colonialists gave a definite mark on the national architecture, radically changing the building shapes and uses. First, infrastructures, such as railways and more geometric main roads were built, thus entailing a new evolution in building types (stations, post, etc.). Misconception about malaria caused the systematic construction of raised buildings, which were designed not to have contact with the soil.

Residential architecture was revolutionised by the introduction of two-storey buildings, the construction of which often needed materials and expertise to be imported from Britain. Despite the initial lack of interest towards integration, local labour had slowly but steadily got acquainted with the new forms, integrating them with local tradition, and creating a whole original style with interpretation of different archetypes. At the same time, local designers became familiar with more endurable and performing construction materials, such as concrete and steel.

Figure 3.13: Example of a building in the Afro-Brazilian style – *Source: Cordelia O. Osasona. From traditional residential architecture to the vernacular: the Nigerian experience, Obafemi Awolowo University, Department of Architecture, Ile-Ife, Nigeria*

Besides, British colonialists were not just imposing their own architecture everywhere, regardless of local cultures. In some cases, they enabled the environment for other influences to be absorbed and to evolve alongside. Bright example of this cross-integration is the strong South American (particularly Brazilian) influence in the architecture of Lagos after the return of Nigerian slaves from those countries. A complete new style, called Afro-Brazilian, came to life, with two-storey houses, loggias and porches enriched with decorations and stucco embellishments. Being mostly Catholics, these new citizens had a big influence in the construction of churches and other religious buildings, following a gothic revival style.

» *Integrating traditional technologies in contemporary architecture*

Vernacular materials have the right properties to perform at their best in the local climate of origin. Mud, as construction material, has a great potential for hot coun tries and it has been used from many populations in the past millennia. Easy to reach and to press in bricks, it is also simple to combine with other basic components, like straw, creating a reinforced mixture. Windows and openings in general are considered with care, reducing their surface to avoid dangerous solar gains. At the same time, designers took care of maximizing daylight, shaping them with narrow and long forms to enhance the penetration of sunlight.

Moving from north to south, the climate changes, and so do the building strategies. For humid and constantly hot climates, where few temperature variations between day and night occur, walls and roofs had to be thinner, as to avoid heat storage into the envelope. Cross-ventilation is the best solution for comfort, and therefore the openings have always been considerably large and numerous, placed in opposite sides of the buildings (rooms of space). At the same time, they have to be shaded to avoid thermal gains. As to maximise the airflow, the houses have been traditionally designed with large rooms and spacious corridors. Light material like palm leaves, has always been chosen for the roofs. Large leaves help to keep the roof cool and enhance air infiltration. The courtyards have always been important for ventilation and general healthiness, offering the possibility of build openings on two opposite sides in every room, thus enhancing the airflow.

Figure 3.14: Mud bricks, perfect for their thermal inertia (left), house in south Nigeria with light, walls and a palm roof, to enhance inner ventilation (right) – *Sources: news.bbc.co.uk, images.delcampe.com*

Figure 3.15: Standardized mud blocks production in Saudi Arabia – *Source: www.theconstructionindex.co.uk/*

A certain level of integration, more spontaneous and natural, has already been achieved in some cases, especially in many rural areas where traditional technologies never ceased to be used, and were mixed to the modern building practices that were reaching the settlements. There, economic benefits came into view from the very beginning. Another case is represented by architects whose ideology brought to re-experiment the old time's architecture using modern expression.

This is an example of the new awareness about the intrinsic value of these old traditions, both cultural and technological. The introduction in the past few centuries of modern building styles relegated such methods to the background, forcing native people to adopt the more expensive trend and to forget the more efficient and sustainable local heritage. Several projects are trying to introduce a combination of old and new technologies, to give traditional material the right flexibility and standardisation, which can make them easier to standardise and classify. New methods for the serial production of mud blocks, for instance, have been successfully studied and experimented by different European universities in some African countries. This helps local expertise to come in contact with modern technologies from developed countries.

BIOCLIMATIC DESIGN APPROACHES

Bioclimatic architecture is defined as an architecture which has a connection with nature. It is about a building that takes into account the climate and environmental conditions to favor comfort inside. This architecture seeks perfect cohesion between design and natural elements (such as the sun, wind, rain and vegetation), thus leading us to an **optimization of resources.**

Other authors speak about climate design, a planning discipline through which buildings can offer the user a maximum of comfort for a minimum of energy. Energy relates to the life-cycle energy balance, including fabrication, operation, maintenance and elimination of the building. Comfort does not only mean thermal comfort but extends to a person´s overall feeling of well-being. To achieve this goal requires an integrated approach to planning, in which urban design; architecture and building services technology cannot be planned in series but must be part of a concerted overall system. By activating synergy effects in this way, we can create energy efficient and comfortable buildings successfully.

» Main principles

The main principles of this bioclimatic architecture are:

- The consideration of the weather, hydrography and ecosystems of the environment in which buildings are built for maximum performance with the least impact,
- The efficacy and moderation in the use of construction materials, giving priority to low energy content compared to high energy;
- The reduction of energy consumption for heating, cooling, lighting and equipment, covering the remainder of the claim with renewable energy sources;
- The minimization of the building overall energy balance, covering the design, construction, use and end of its life;
- The fulfillment of requirements of hydrothermal comfort, safety, lighting and occupancy of buildings (see chapter 2.1).

Nigeria, like most of Africa, has a history of sustainable, climate-adaptive architecture. Its indigenous buildings share many of the same objectives with actual bioclimatic buildings. By analysing the different vernacular archetypes in Nigeria it is possible to define how such strategies have been perfected in the past in each area according to the local climate. Contemporary standards of living drive professionals to face various issues during the design process.

» Strategies

The process of climatic building design follows a sequence of strategies, which are ranked according to their influence on energy efficiency:

1. Site selection and orientation
2. Building form
3. Envelope design
4. Passive measures of comfort
5. Active measures of comfort
6. Energy supply and renewable energy

A good example for the influence of climate factors, in this case solar radiation, on the design strategies in different climatic zones is shown in Figure 3.16.

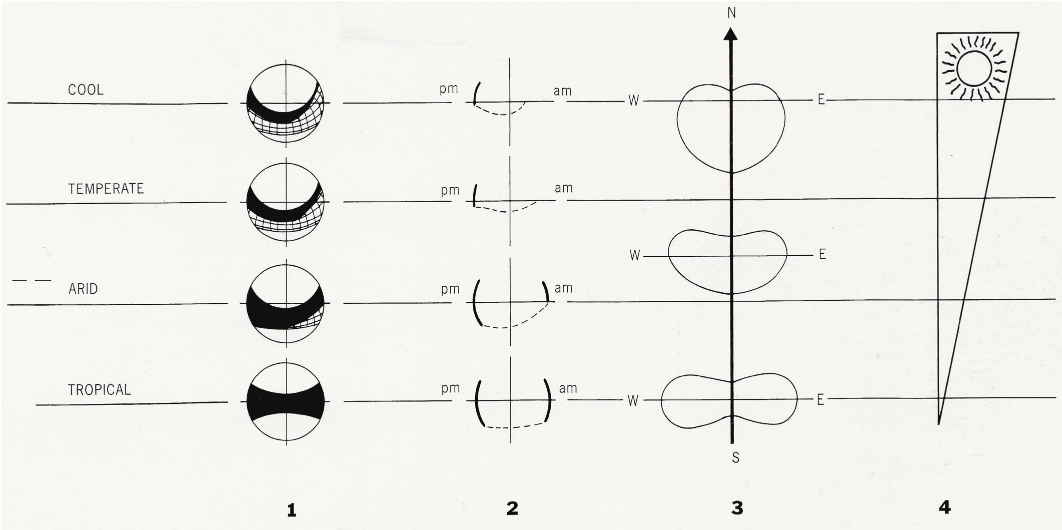


Figure 3.16: Insolation and its influence on bioclimatic building design in climatic zones – *Source: Ken Yeang: Bioclimatic skyscrapers. Artemis, London, Zürich, Munich, 1994*

1. Solar paths requiring shading (black) for periods of overheating: In tropical zones like Nigeria there is total overheating, i.e. shading throughout the year.
2. Sunshade analysis (vertical and horizontal) shows the optimal location for vertical sun shading, shielding the building from low sun angles in the morning and evening, and horizontal shading blocking the high midday sun (dotted line): In Nigeria buildings need both types of shading, i.e. vertical shading for east and west facing windows and vertical shading for south and north facing windows.
3. Insolation on facades in different orientations. In Nigeria the main direct insolation is on east and west facades: Much less on south facades and north facades. The highest insolation is on horizontal or slightly tilted roofs.
4. Sun requirement during winter: In tropical regions like Nigeria there is no need for solar heating at all, but the available solar radiation can be utilized for solar thermal and photovoltaic energy (see chapter 4.2).

SITE SELECTION AND ORIENTATION

The building orientation towards the sun and the wind are the main factors determining the energy balance of buildings since this will affect air movements and solar gains within the building. Chapter 2.1 describes these influences for Nigeria by the sun path diagram and main wind directions and speeds. Beside the regional climatic factors, the microclimate of the site has a strong influence on the ambient temperatures and access of wind. Chapter 2.3 describes the means of effecting the microclimate by urban design and vegetation.

For natural ventilation the main facades with windows should be oriented to towards the main wind direction to allow for cross ventilation, in hot and dry climate at night and in hot and humid climate throughout the day. The main wind directions are usually north-east and south-west (see chapter 2.1).

SOLAR PATH CALCULATION

Analyzing the solar path is fundamental for every building professional whether planning a new building or having to do with an existing one. The solar position (altitude and azimuth) can be found at every time of the year and hour of the day using the solar chart. This allows defining the incident angle of solar radiationon each surface of the bulding. This is necessary e.g. for shading facilities like roof overhangs or lamellas. Additionally, thermal simulation programs generate the solar position automatically to define the solar incident angle on building surfaces for calculating the solar heat gains by windows and opaque elements. The most used projection for the solar path is the "stereographic", which corresponds to the view of the sky from the horizontal plane (Figure 3.17).

Solar paths for every location in the world can be acquired from software and Internet tools, as mentioned before (see chapter 2.2).

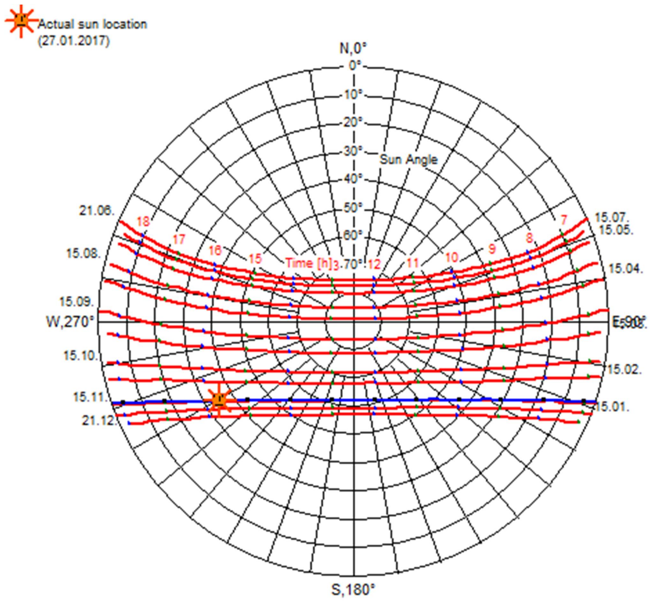


Figure 3.17: Solar position at 15.40 on January the 27th in Abuja. The concentric circles indicate the solar altitudes (shown on the central vertical line). The concentric lines show the azimuth with the main orientations (Nord, East, South, and West). The lines crossing the diagram describe the sun path during one day of each month. The hours of the day are indicated by dots. Additional days can be inserted between the given lines. The example is shown by the blue line for the 27th of Jan. with the selected time (3.40 p.m.) indicated by a bigger dot. The solar altitude in that moment is, about 35°. The azimuth is 238 ° – *Source: www.sunearthtools.com/dp/tools/pos_sun.php*

BUILDING FORM AND GEOMETRY

Strategies related to building form and geometry deal mainly with volume, envelope areas and configuration of rooms. A **compact geometry** with a small surface to volume (S/V) ratio reduces heat gains and cooling energy losses. As to solar heat gains envelope areas with large insolation should be reduced, i.e. horizontal roofs, east and west facades.

Thermal zoning for areas with different activities and comfort requirements improves the bioclimatic design. Buffer zones with reduced comfort requirements, e.g. circulation areas and shaded balconies, can be located to protect internal spaces with higher requirements from outside weather conditions.

Natural ventilation and daylighting are limiting the room depth. For rooms with single sided fenestration the maximum room depth is 5 to 7 m (assumed room height 3 m). Double-sided windows allow for cross ventilation and improved daylighting. Roof lights give more freedom for geometry in single story buildings. For multi-story and more compact buildings courtyards, atria or façade recesses help to improve natural ventilation and lighting. For more details see chapter 3.2 on natural ventilation and daylighting. Figure 3.18 show typical forms and geometries of residential and office buildings.

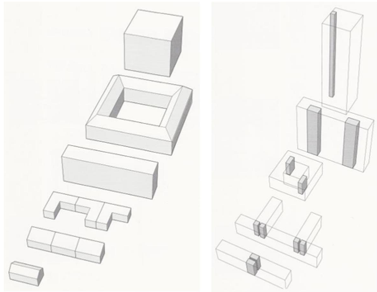


Figure 3.18: Typical forms and geometries of residential left) and office buildings (right) - *Source: Gerhard Hausladen et al.: Climate design. Birkhäuser, Munich, 2005*

ENVELOPE DESIGN

The building envelope protects the interior space against the unwanted impacts from the external environment, like rain, solar radiation, ambient temperature, wind, air pollution and noise. Beside these functions of protection, which include security as well, the envelope allows the transmission of air and light for natural ventilation and lighting as well as heat losses from inside to outside for passive cooling. Thus the envelope works as a kind of filter carefully controlling the exchange of matter and energy. The passive means of solar control, natural ventilation, thermal insulation and daylighting are described in detail in chapter 3.2. The coordination of these measures and their integration into the architectural design is goal of the envelope design.

One main task of the building envelope is to minimize heat gains. This is realized by shading and solar control of transparent elements allowing sufficient daylighting, by reflection of solar radiation at the surfaces of opaque elements as well as by ventilation of cavity walls and roofs and by thermal insulation. These issues are dealt with in detail in chapter 3.2. Another main task of the building envelope is to maximize heat losses by cross-ventilation.

» *Passive measures of comfort*

It is a basic principle of bioclimatic design to use passive means to full extent before active means of building services and technology are applied. Depending on the climate conditions and the user requirements, thermal comfort can be achieved without active measures – and without energy consumption – often. If this is not possible, only a minimum of energy consuming active technology should be applied.

Having to deal with Nigerian climate conditions, the most challenging task is to maintain the indoor ambient temperature at a comfortable level. Two main goals of **passive cooling** are to be followed and achieved.

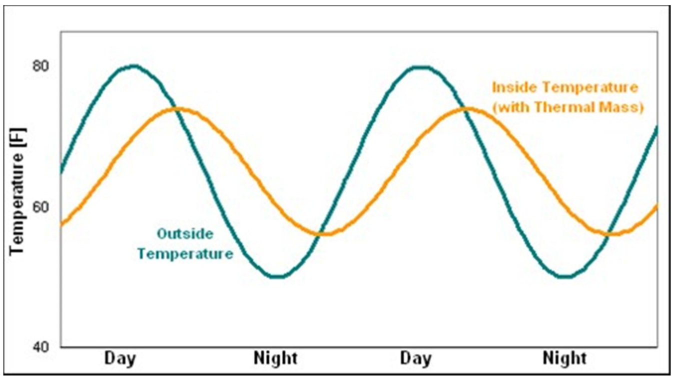


Figure 3.19: Schematic representation of the thermal mass effect – *Source: www.energydesignresources.net*

- **Minimise heat gains**. This is the most important objective, common to both the hot and dry and the hot and humid climates, which is to minimize the amount of heat gains inside the building. This objective concerns the building orientation, the thermal insulation of the building envelope, the solar control of windows, the ventilation and many other aspects.

- **Promote heat losses**. When outside temperature is low (for example at night in hot and dry climate), the building should be designed so that heat stored or generated in the building can be released. This forms the basis of most passive cooling techniques such as thermal mass in hot and dry climate, combined with air movement through the building at night (see Figure 3.19). Evaporative cooling by passive means like cooling towers can also be effective in hot and dry climate. In hot and humid climates continuous ventilation without thermal capacity is recommended.

Thermal comfort can be realized by measures of passive cooling, which is a major task of bioclimatic design in Nigeria. A bunch of effective solutions is available (chapter 3.2), which can be combined in an integrated design approach.

» *Active measures of comfort*

When all suitable means of passive design are applied in an optimized way and the comfort requirements are not yet fulfilled, it is necessary to apply active measures. A building cannot do without artificial lighting at nighttime; also if relative air humidity is to be kept under a certain level, air conditioning has to be applied in hot and humid climates. And if in specific rooms, maximum temperatures will be exceeded without active measures, cooling has to be applied. The different active technologies and solutions described in chapter 3.3 have to be integrated into the overall architectural design and combined with the passive means in an optimal way. If mechanical ventilation or air conditioning is selected, the building envelope should be airtight and well insulated in order make the technology work efficiently. Thus the compatibility of passive and active measures should be checked.

ENERGY SUPPLY AND RENEWABLE ENERGIES

The use of conventional or renewable energy is integral part of the bioclimatic design and cannot be left to experts at the end of the design process. If passive measures of comfort are combined in an optimal way with active measures the adequate energy demand should be covered by available sources of energy in a feasible and sustainable way. Depending on the situation of public energy supply renewable energies are an option for back-up or complementary systems. Whether for stand-alone situations or in hybrid systems where multiple renewable energy sources are combined or in some cases together with fossil fuel, the decision has to be made early in the design stage. Building integration of renewables, especially solar thermal and photovoltaic, is a challenging design task. For more details see chapters 4.1 and 4.2.

CONTEMPORARY ARCHITECTURE

» *20th Century architecture*

From the end of the 1930s, a modern movement in architecture started to become quite popular. The introduction of the flat roof was one of the first features to become evident and consistent, although not always with outstanding results, due to the predominantly rainy character of tropical areas. Lagos was the first city in Nigeria to host the construction of modern high-rise buildings, which began to appear from the 50s. Contrary to what happened in the Middle East in the same period, where western style had been largely copied to satisfy the owners' taste, in Nigeria such architecture was still somehow linked to the local climatic conditions and traditions, with some successful cases. This peculiar, regionally adapted international style is still dominant in the country, and it generally presents common characters with simple forms, geometrical shapes, large use of concrete on facades and external shading devices. Steel and aluminium are also largely utilized in various components (i.e., Management House and CSS Bookshop House in Lagos). Simplicity and functionality are the core ideas of this trend, along with clean geometrical forms in composition.

Figure 3.20: Senate building in Ahmadu Bello University, Zaria – *Source: Bogda Prucnal-Ogunsote, classification of Nigerian architecture, Federal University of Technology, department of Architecture, Akune, Nigeria.*

As modern style arose, both foreign architects and local professionals were trained abroad. The two groups merged together in quite a remarkable way, giving way to interesting and successful experiments. This rather unique mixture was part of what is commonly known as 'tropical architecture', a particular and British colonial branch of the modern architecture developed in Western Africa and Asia from the 1930s to the 1960s. European architects such as Otto Koenigsberger, George Atkinson, Victor Olgyay and others developed and applied an energy-conscious climatic oriented design. This style influenced largely the local Nigerian expressions. Buildings such as the University of Ibadan complex, University of Ife library, secretariat and agricultural science buildings, Elder Dempster's office building, and Olaoluwakitan house in Lagos are just examples of this trend. Regarding the Ibadan University, a remarkable contribution (between 1955 and 1960) has been given from architects such as Maxwell Fry and Jane Drew, two of the most famous British modernists, particularly dedicated to school buildings in West Africa and Asia. As widely accepted, tropical architecture can be divided in early tropical (pre-1955), mid-tropical (1955 to early 1960), and late tropical (late 1960s to early 1970s). After independence in the 1960s expressive forms and practices began to diversify and architects began to reconsider their discipline critically.

» *High-trop and low-trop*

With the advent of more affordable air-conditioning system and the rise of new technologies, architecture began to distance itself from the precept of ecologically responsible building. In the big cities like Lagos, the main trend for most high-rise buildings is the High-trop. Constructions of this kind are modern-like, composed by highly technological parts and systems, mainly used for offices or banks. However, some exceptions, as IMB building and First Bank headquarters (both in Lagos), explore different languages, separating themselves from the so-called 'bureaucratic movement' of pure forms and curtain walls. Despite the increasing diffusion of the modern style, some thoughtful precautions have never failed to be included even in the most technological buildings: High rise towers, for instance, were always planned with the appropriate orientation, never forgetting some sort of external shading device.

As opposed to the rich and wealthy aforementioned styles, the large majority of the buildings represent the more modest 'low-trop' category. Rather humble and unpretentious, this heterogeneous type is easy to see in cities and suburban areas, and it forms the Nigerian architectural landscape. Predominantly consisting of single-storey bungalows or two-story houses, this kind of buildings is made of local material, exploiting local labour. Nowadays, professionals are trying to face climatic problems implementing a responsible use of materials and technology and creating examples of contemporary sustainability.

» ***Today: Best practices***

The following examples are intended to focus on some particularly well designed examples of architecture, which are now successfully merging together energy savings and social and economic sustainability. Both local and international architects now working in Nigeria are highly sensitive for these issues.

PrimeTech Design Headquarters in Abuja

Figure 3.21: Front view of the PrimeTech head office
– Source: Bogda www.julius-berger.com/on-site/

The PrimeTech Design head office, by Julius Berger Plc. is one of the first buildings in Nigeria to meet the requirements for the LEED Certification standard. PrimeTech is a member of the Julius Berger Group and it's specialized in design and engineering services, feasibility studies and projects in gas and oil sectors. The building offers a comprehensive example of both passive and active measures of energy efficiency. Insulated walls and roofs, double glazing for windows and facades and simple yet functional shading devices ensure the perfect protection against overheating and energy losses. The envelope is carefully sealed and airtight. A particular mention should be made about the green roof, which, apart from helping the overall insulation, reduces considerably the echological footprint of the building. The HVAC system uses exhaust cool air to chill the incoming external air intake, thus saving energy for air conditioning (see chapter 3.3). Some of the requirements for the LEED certificate could not be met in Nigeria, for instance the ones regarding the availability of public transport.

It has to be said that many materials and components have been transported from Europe in order to achieve the required certifications, and that some of the above-mentioned solutions are not yet cost effective for countries like Nigeria. However, building like this should serve as demonstration of best practices for engineers and architects.

U.S. Embassy Office Annex in Abuja

The new office annex realised by BL Harbert International is the other LEED certified project in Nigeria, planned as an addiction to the existing embassy compound. Originally thought to reach the LEED Silver certificate, the building was eventually awarded with the LEED Gold, also thanks to its prominent sustainable design features, such as a consistent photovoltaic panel system on the top of the parking structure, and energy efficient LED-lighting. This features ensured a good score in the criteria regarding energy optimization and renewable sources. The heat gain on the thermal envelope is strategically minimised through sun shading devices. Particular attention has been taken on water saving and reducing of overall water usage. The lack of waste treatment and recycling structures in Nigeria, as well as the presence of non-certified construction materials, were critical points, whereas a positive assessment was reached concerning the indoor environmental quality.

Figure 3.22: View of the annex officese – *Source: Bogda www. blharbert.com/*

Floating School, Makoko, Lagos

The floating school by Arc. Kunle Adeyemi and NLÉ is thought as a pilot project to involve local population along the coastal areas and create awareness of innovative ways for urban evolution. It accommodates 100 students, floating on the water thanks to a system of 256 plastic drums under the basement. This way it creates the essential conditions for social aggregation and instructions in areas where both are much needed. The frame is constructed with local wood and was entirely built by Makoko residents, making local community participate actively to the process. Electricity is provided by solar panels on the roof, and rainwater harvesting would help operate the toilets. The building cost was only USD 6,250. In this project, a clear attempt has been made to reach social and economical sustainability, and for the eco-friendly choice of materials. Moreover, the simple structure makes the building easy to standardise and to reproduce in similar environments.

Figure 3.23: Floating school, Makoko, view of the building from the bay – *Source: Herz, Manuel et al.: African modernism – The Architecture of Independence.Parkl Books AG, 2015*

The Makoko floating school has been exposed in the 2016 edition of the Venice Biennale of Architecture, winning the Silver Lion Prize.

Brand new church building for Lagos

This interesting concept for a church in Lagos created by the London-based office DOS Architects shows a keen interest in combining monumental and devotional characters with sustainable strategies. Orientation and ventilation are deeply studied, as well as solar protection, without renouncing the contribution of natural illumination.

Figure 3.24: Church building for Lagos, 3D view of the concept design – *Source: http://futurecapetown.com/2014/04/the-move-to-green-*

3.2. PASSIVE MEASURES FOR ENERGY EFFICIENT DESIGN

SOLAR CONTROL, COOL MATERIALS

» Task

Windows have to control solar heat gains effectively in order to avoid uncomfortable room temperatures and its subsequent high energy consumption for cooling. The main design parameters of the façade influencing this performance are window area and orientation as well as heat gain coefficient of glazing and, last not least, additional shading facilities. The solar control of roof lights is of high priority as roofs have the highest insolation in tropical regions.

Solar control is a major measure for minimising heat gains of the building but nevertheless it should not affect main tasks of the window seriously, i.e. daylighting and view to the outside. Shading devices, which obstruct the visual contact to the outside or make artificial lighting necessary throughout the day, are no good solutions with regard to comfort and energy efficiency.

Solar control is an important design parameter for opaque elements of the building envelope as well. The solar reflectivity of material surfaces should be high to keep them cool.

» Principal solutions

Solar control can principally be positioned inside the building, outside or within the facade structure. For **shading devices** the outside position provides the highest reduction of heat gains while the inside position, which mainly is used for visual purposes like glare control or privacy, has a poor thermal performance. Solutions of **solar control glazing**, which are integrated in the window glazing, can perform very well if the absorbed solar radiation is not transmitted to the inside. Either a shading device is positioned in the gap of a double or triple glass unit or the glazing itself has a solar protective layer. In tropical regions there is no need for adjustable solar control, as heat gains must be reduced throughout the whole year. The window dimension should be designed with regard to daylighting and visual contact, always considering that heat gains increase with the glazed area.

» *Shading devices*

External shading of north and south facing windows can easily be realized by horizontal overhangs due to the high solar altitudes in Nigeria. For determining the vertical shading angle the sun path diagram of the location should be applied (see further in this chapter). For east and west facing windows shading is more difficult because of the low solar altitudes. Vertical elements have to be applied, often combined with additional horizontal elements. Large window areas with this orientation should be avoided if possible.

Figure 3.25: Combined shading and daylighting devices in north facade of BP Headquarter in Cape Town: Light shelves, roof overhangs, and balconies.

Daylighting can be improved if diffuse light from the sky or even part of the direct sunlight are reflected by the shading devices into the room. Horizontal **light shelves** in the upper window area are an approved solution for the tropics, if glare is to be avoided (see Figure 3.25).

Figure 3.26: Exterior shading by horizontal aluminium lamella (front) and reflective coating of glass (background, workers house) Kampala, Uganda

» *Solar control glazing*

Glass integrated solar control can be realized by glass coatings or by shading devices in the gap of double or triple glazing. Solar control coatings should be reflective, as absorbing (tinted) glass heats up and transfers part of the heat to the room. Reflective glasses are offered with hard coatings for single glazing and with soft coatings for double glazing. Generally and especially for air conditioned or cooled rooms double glazing is preferred, as it reduces the cooling energy demand in comparison to single glazing significantly. For good daylighting and high colour rendering performance, a selective reflectivity in the infrared spectrum of sunlight is optimal. These double glass units with soft coating look like clear glazing (no mirror effects) although they have a good solar control performance (high light transmittance of 50 – 65%, low heat gain coefficients of 25 – 30%, and low u-value of 1.1 – 1.5 W/m^2K. All glasses with solar control need an additional glare control, which can be realized by roller blinds or louvers positioned inside.

Glass integrated louvers are very flexible in performance, as the tilt of the lamella can be varied, allowing for view to the outside, protection against view to the inside, and sunlight redirection deep into the room.

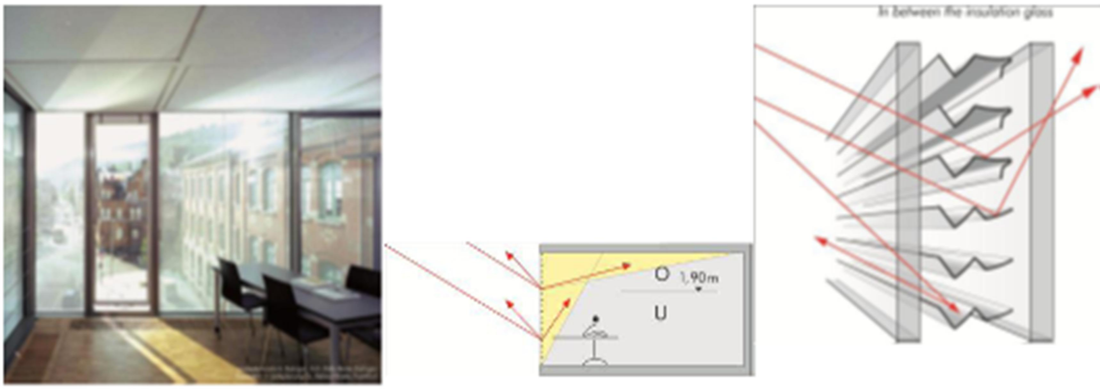


Figure 3.27: Louver system with retro-reflection and daylight transport integrated in double glass unit – *Source: H.F.O. Müller: Detailing daylighting and solar control of windows. Proceedings 10th International Detail Design in Architecture Conference ddia, Instanbul, 27th+28th Oct., 2011*

By special shapes of the lamella these functions can be optimized (see Figure 3.30). The louvers can be installed inside (no thermal solar protection) or in the gap of a double glass unit, where they serve for solar control as well. As the lamella are protected against physical impact and dirt, they have a perfect reflective performance for their lifetime. In order to avoid heat transmission from the lamella to the room, a low-e (low- emissivity) coating has to be placed on external surface of the inner glass pane.

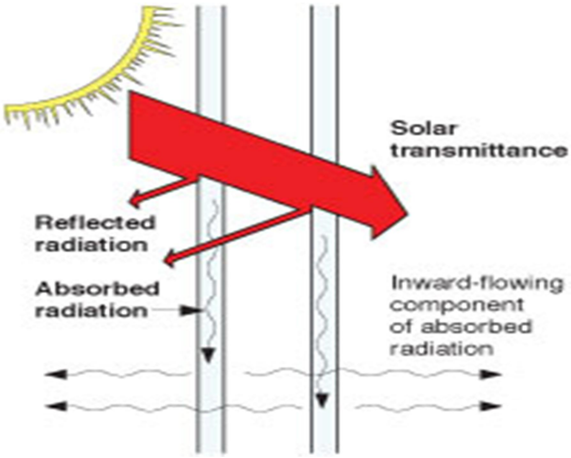


Figure 3.28: Solar heat gain coefficient of glass – *Source: Source: H.F.O. Müller: Detailing Daylighting and Solar Control of Windows. Proceedings 10th International Detail Design in Architecture Conference ddia, Instanbul, 27th+28th Oct., 2011*

In windows which offer no view to the outside but solely serve as daylight openings, **fritted glass** with a reflective white screen printing can be applied. As the transmitted light is scattered, deep room illumination is possible and the glass looks bright, which might cause glare.

» *Characteristics of solar control*

The solar heat gain Qs of windows is defined by the following equation:

$$Q_S = A_W * g * f_F * F_C * I_S \qquad \text{(kWh/a)}$$

Where,

- A_W = Window area m²
- G = Solar heat gain coefficient of glass (SHGC in the USA)
- f_F = Reduction factor for window frame (0.7 for assumption of 30% frame portion)
- F_C = Solar shading coefficient for shading devices
- I_S = Annual insolation (kWh/m²a)

The g-values of typical glass types are given in Table 3.1. The solar shading are dependent of type and climate zone. Coefficients given in Table 3.2 stem from the German standard DIN 4108-2 and should be understood as approximate indications.

Table 3.1: Characteristics of glazing types

Glazing type	***Visual light transmittance, T (high is good)***	***Solar heat gain coefficient, g, (low is good)***	***Heat transmission coefficient, u, (W/m²K) (low is good)***
Single glazing (clear)	88%	82%	5.8
Single glazing with hard coating – mild tint	60%	53%	5.8
Single glazing with hard coating – heavy tint	25%	34%	5.8
Single glazing with reflective hard coating	11%	23%	5.8
Double glazing, clear	79%	70%	2.8
Double glazing, clear, low-e coating, argon	79%	62%	1.3
Double glazing, solar selective coating, argon	62%	29%	1.1

Table 3.2: Shading coefficients of shading devices, DIN 4108-2, 2013

Position	***Solar shading device***	***F_C***
	Without shading device	1.00
Interior or between glass panes	Dark colours	0.85
	Light colours	0.75
	Highly reflective	0.65
Exterior	Roof overhangs, awnings	0.50
	Shutters and rolling shutters	0.30
	Louvers and lamella	0.25

» *Solar reflectivity of materials*

Solar reflectivity and longwave emissivity of materials influence the surface temperature caused by solar radiation. Light colours have a high solar reflectivity and stay cooler than dark, solar absorbing materials. The longwave (IR) emissivity should be large in order to emit heat by radiation. Nearly all building materials have a large emissivity (0.8 – 0.9), except specular metals surfaces, e.g. stainless steel, polished aluminium (0.2 – 0.02).

The temperature rise of the surface can be calculated and a solar reflectance index (SRI) be defined. Examples of roofing materials see Table 3.3. The surface temperature can influence the heat gain of the building, depending on the thermal insulation of the component and the option of a ventilated cavity. Ventilated double skin systems are often used to reduce the solar gains of walls and roofs.

Table 3.3: Solar reflectance index (SRI) for typical roofing materials – *Source: LBNL cool roofing materials*

Examples of typical roofing aterials	***Solar reflectivity***	***Infrared emissivity***	***Temperature rise***	***SRI***
Grey EPDM	0.23	0.87	38°C	21
Grey asphalt shingle	0.22	0.91	37°C	22
Unpainted cement tile	0.25	0.90	36°C	25
White granular surface bitumen	0.26	0.92	35°C	28
Red clay tile	0.33	0.90	32°C	36
Light gravel on built-up roof	0.34	0.90	32°C	37
Galvanized steel	0.61	0.04	31°C	46

Examples of typical roofing aterials	Solar reflectivity	Infrared emissivity	Temperature rise	SRI
Aluminium	0.61	0.25	27°C	56
White-coated gravel on built-up roof	0.65	0.90	16°C	79
White coating on metal roof	0.67	0.85	16°C	82
White EPDM	0.69	0.87	14°C	84
White cement tile	0.73	0.90	12°C	90
White coating – 1 coat, 8 mm	0.80	0.91	8°C	100
PVC white	0.83	0.92	6°C	104

NATURAL VENTILATION

» Tasks

The main tasks of natural ventilation, which has to be integrated in the building design, are:

- Fresh air supply for occupants
- Thermal comfort
- Promoting heat losses
- Control of air humidity

The fresh air supply for occupants is determined by the following influences: Oxygen supply, CO_2 exhalation, and emission of hazardous substances by building materials. It is controlled by the maximum CO_2 concentration of the room air: 1,000 ppm. Another, more user oriented, characteristic is the olfactory property (Olf) according to Fanger, the experienced freshness or pollution of air determined by trained people on a decimal scale. Depending on the room use as well as the quality of outdoor and indoor air (emission of hazardous substances) a fresh air rate is defined according to the number of persons: 30 – 50 m^3/person. Another term of reference is the room air change, i.e. the room volume per hour (V_R/h). Typical characteristics are: Dwellings 0.5 – 1.0, offices 1.0 – 3.0.

Thermal comfort is influenced by the temperature and velocity of air. Uncomfortable air drafts can be caused by cold air and high velocity (> 0.1 m/s). On the other hand a cooling effect by high air velocities and evaporation on the skin may be welcome. Thus, depending on the cooling or heating situation and turbulences, air velocities between 0.1 and 2.0 m/s are recommended. An accurate control of air velocity is likely rather by mechanical than by natural ventilation.

Promoting heat losses by natural ventilation helps to get rid of heat gains from solar radiation, heat conduction and internal heat sources. The temperature of supply air should be low and the necessary air change rate may exceed the fresh air requirement for occupants. Ventilation strategies, e.g. night cooling, can increase the efficiency. If means of mechanical cooling or air conditioning are applied, uncontrolled ventilation by windows or leakages through the building envelope can be counterproductive. In this case the building should be air tight in order to avoid cooling losses. Combinations of natural and mechanical ventilation are possible and can contribute to energy efficiency.

Control of air humidity by natural ventilation is the most energy efficient way to get rid of humidity produced in buildings by occupants (20 – 50 grams/hour), by bath or shower (appr. 800 g/h) and by cooking (appr. 1,500 g/h). Insufficient ventilation will cause not only uncomfortable conditions but also mould formation and damages.

» *Physical effects of ventilation*

Natural ventilation works by the difference between internal and external air pressure, basically caused by two different mechanisms: Wind and temperature difference (stack effect).

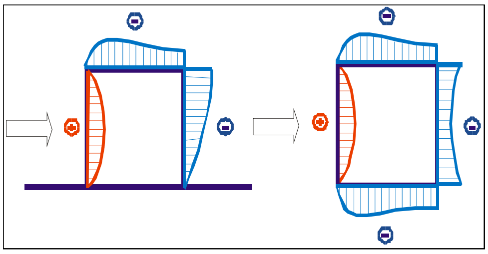


Figure 3.29: Distribution of positive and negative wind pressure on the surfaces of a building - *Source: Daniels, Klaus, Hindrichs, Dirk U. (2007): plus minus 20°/40° latitude. Sustainable building design in tropical and subtropical regions. Edition Axel Menges, Stuttgart / London*

Wind driven ventilation by pressure and suction on the building surfaces is shown in figure 3.30. Air change works, if there are at least two openings in a room, which allow the air to flow from the positive to the negative pressure. Thus, cross-ventilation between two opposite facades or facade and roof work perfectly for wind driven air change.

Equation (1) demonstrates that the wind speed V_r has a square influence on the pressure difference.

$$P_W = 0.5\, \varrho\, V_r^2 \cdot C_p \quad \text{(Pa)}$$

Where

P =	Density of air (1.2 kg/m³)
V_r =	Air velocity (m/s)
C_p =	Pressure coefficient (-), (measurement depending on direction, shape etc)

As the wind speed rises with the height above ground, high-rise buildings and upper floors are better off than one-storey-buildings. Additionally, the topography of the surrounding will influence the wind pressure on buildings. Urban structures of high density can cause very poor conditions for wind powered ventilation

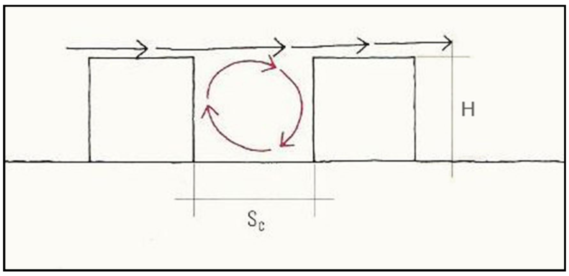
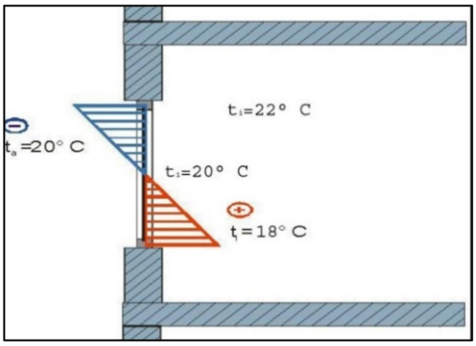


Figure 3.30: Reduced fresh air exchange between buildings by completely related roughness. SC = 1.4 H) in contrast to separate roughness with SC > 2.4 H, which allows fresh airflow to touch the ground between the buildings

The stack effect or thermal buoyancy works by the different density and weight of air in relation to its temperature: Warm air rises, cold air falls. Not only the difference between inside and outside air temperature causes movement but the temperature layering over the room height as well.

Figure 3.31 and equation (2) below show the influence of temperature difference and height between top and bottom opening of the room, e.g. the window height, on ventilation. The higher room and the windows are the better stack effect ventilation will work. Chimneys and high air shafts are effective means of stack effect ventilation.



$$P_t = \varrho_a \cdot g \cdot h \cdot (t_i - t_a) / t_i \quad [Pa]$$

ϱ_a	Density of external air (1.2 kg/m³)
g	Gravity acceleration (9.8 m/s²)
h	Height between top and bottom opening [m]
$t_{i,}\ t_a$	Air temperature inside, outside [°C]

Figure 3.31: Temperature differences cause positive and negative air *pressure* – *Source: Daniels, Klaus, Hindrichs, Dirk U. (2007): plus minus 20°/40° latitude. Sustainable building design in tropical and subtropical regions. Edition Axel Menges, Stuttgart / London*

» Design hints for natural ventilation

Urban design has a strong influence on natural ventilation by distances between the buildings and topography of the surrounding with mountains, valleys, water and vegetation, influencing the wind speed and the air temperature. The main wind directions and temperatures with their annual and daily alterations should be considered for the orientation of open spaces and ventilation openings of buildings. High rise buildings can expand into layers of high wind speed, which will strongly influence the air movements around the building. Figure 3.32 shows the turbulences that can be rather annoying and the partial alteration of wind direction. As simulations of airflow and turbulences around buildings are complex and not always accurate, wind tunnel tests with scale models are recommended. Natural ventilation is an integral part of the building design. A good example is the UNEP headquarter in Nairobi, Kenya (see Figure 3.33), where cross ventilation of offices and thermal ventilation of atrium by stack effect are combined.

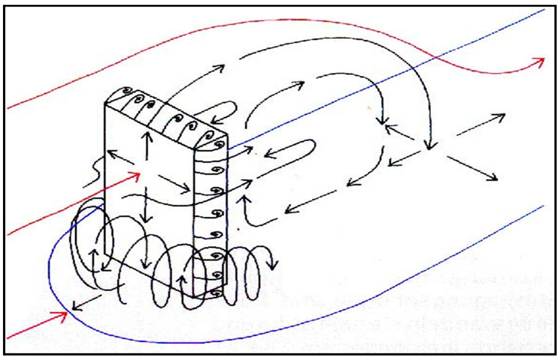


Figure 3.32:. Air flow and turbulences around high rise buildings – *Source: Daniels, Klaus, Hindrichs, Dirk U. (2007): plus minus 20°/40° latitude. Sustainable building design in tropical and subtropical regions. Edition Axel Menges, Stuttgart / London*

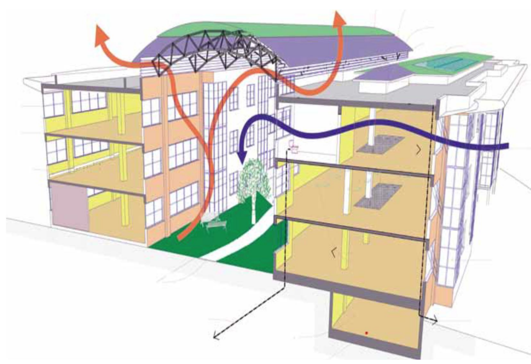


Figure 3.33: Example for natural ventilation in UNEP headquarter, Nairobi – *Source:* ***www.unep.org/gc***

The location, size and format of ventilation openings have to be adjusted to the overall design. Decisions for wind driven single-sided or cross ventilation as well as for stack ventilation by staircase shafts, atria, and double-skin facades have to be made. The magnitudes of air changes for various windows are shown in Table 3.4.

The typical air change of a controlled, mechanical ventilation system is 1 per hour. The position of ventilation openings and the distance between air intake and outlet have to be determined carefully. As the highest wind suction usually occurs in the top area of the roof, air outlets are most efficient here. The intakes should be at the bottom in the range of cool air, i.e. near open water, vegetation or shaded areas.

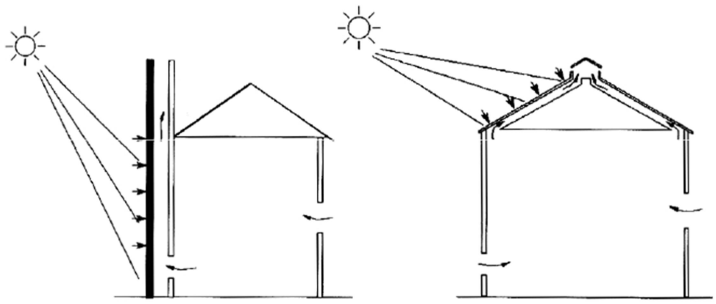


Figure 3.34: Solar powered stack effect: Chimney (left) and roof (right)

Table 3.4: Typical air change of a controlled mechanical ventilation system with respect to time

Condition	***Number of air changes***
Windows and doors closed	0.0 – 0.5 per hour
Window tilted	0.3 – 1.5 per hour
Window half open	5.0 – 10 per hour
Window fully open	10 – 15 per hour
Windows and doors opposite fully open	>40 per hour

INSULATION, THERMAL CAPACITY

» *Task*

The heat gains of buildings in Nigeria due to absorbed solar radiation by envelope surfaces, especially roofs, can be controlled by the insulation of the building envelope. Similarly, for buildings which are air-conditioned and airtight, the heat gains due to temperature differences between exterior and interior are reduced by insulation of the building envelope. Considering higher dynamic variation of ambient temperature in the 24-hour cycle in certain climate zones, the thermal capacity of interior building components can reduce internal temperature peaks, especially in combination with night ventilation strategies. It is important to underline and repeat that **heat transfer occurs in both warm and cold climates**, whenever the outer temperature is different from the inner one. The indoor comfort must be kept as constant as possible, and to do so air conditioning is essential. Insulation helps to minimize transfer of heat, therefore leading to energy savings for the cooling systems. An inicial cost for the insulation of the thermal envelope is paid off by sensible reduction of energy loads for cooling.

The thermal insulation of a building component is characterized by the heat transmittance (U-value in W/m²K). A low U-value indicates small heat gains. The inverse of U is the thermal resistance R, determined by the material thickness (m) and conductivity λ (W/mK):

R = s / λ. For multi-layer constructions the resistances R_1, R_2… are added. External and internal resistances R_{se} and R_{si} are added as well.

$$U\ (\mathrm{W/m^2K}) = \frac{1}{R_{se} + \mathrm{R1} + \mathrm{R2} + \ldots R_{si}}$$

A wider overview on transmittace, thermal resistance and conductivity is given in module 1. While the U value characterizes the heat transfer under steady state assumptions, e.g. for the long period of one year and mean temperatures, the periodic heat flow takes into account the heat storage and the speed of heat transfer under varying temperatures for a typical 24-hour cycle. Figure 3.35 shows the example of periodic heat flow for the diurnal variations of surface temperatures of a building component. The peak of the indoor surface temperature occurs later (time lag) and is reduced (decrement factor) in comparison to the outdoor peak. The thermal capacity C_p (J/kg K) is influenced by the density of the material (kg/m³).

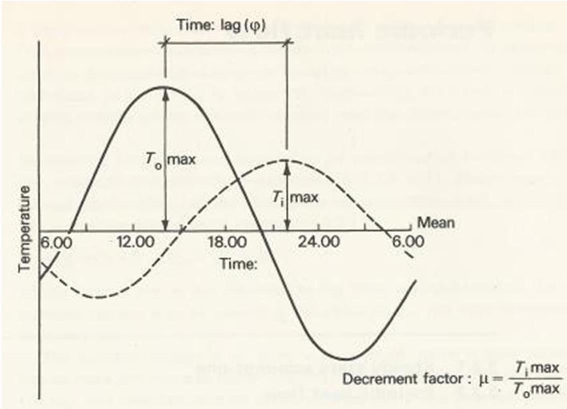


Figure 3.35: Periodic heat flow with time lag and decrement factor of outdoor (To) and indoor surface temperature (Ti) of a building component – *Source: Koenigsberger, Ingersoll, Mayhew, Szoloka: Manual of tropical housing and building, part one: Climatic design, Longman Group Ltd, London 1973*

» *Thermal insulation*

In hot climates thermal insulation has to reduce the heat gains by ambient temperature and by absorbed solar radiation on the envelope, especially the roof and east-west facing walls. According to South African building regulations the maximum U value of roofs is 0.37 W/m²K, which can be achieved by an insulation layer of about 10 cm (e.g. polystyrene foam or rock wool).

As structural building materials like bricks, stabilized earth blocks or concrete are rather poor insulation materials because of their high density, multilayer constructions with specific insulation material are applied often. Cavities in roofs and walls can be used for thermal insulation and for removal of excess heat as well. A thermal resistance of about 0.17 m²K/W can be assumed for cavities and added to the resistances of the other material layers. A comparison of U values for typical constructions is given in Table 3.5.

Table 3.5: Comparison of U-values and thermal resistances R for typical constructions – *Source: DesignBuilder*

Typical constructions	*U (W/m²K)*	*R (m²/KW)*
Metal roof, void, ceiling	1.95	0.51
Metal roof, void, 100 mm mineral wool, ceiling	0.31	3.22
Concrete roof with no insulation	1.30	0.77
Concrete roof with 50 mm polystyrene on top	0.37	2.69
150 mm hollow sandcrete block wall (rendered)	1.90	0.53
230 mm hollow sandcrete block wall (rendered)	1.60	0.65
150 mm hollow sandcrete, 25 mm polysterene, 25 mm cavity, 100 mm brick wall	0.80	1.28
150 mm stabilised soil block with internal render (class A)	3.06	0.33

It is important to remember, that uncontrolled air leakages are counterproductive to thermal insulation, as they increase heat gains (only relevant for air-tight buildings with air-conditioners)

» *Insulation materials*

Materials with a low conductivity are chosen to work as a protection, in order to reduce the heat transfer between interior and exterior. Depending on the origin and type of material, the manufacturing technology and the structure the properties differ and additional specific requirements can be fulfilled, e.g.:

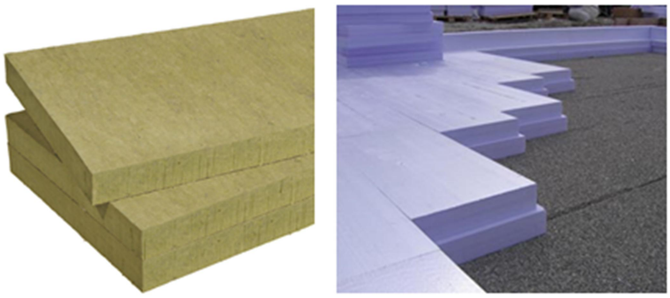


Figure 3.36: Mineral wool panels (left), expanded polystyrene (XPS) panels (right) – *Sources: www.archiproducts.com, www.baulinks.de/webplugin*

- Sound protection
- Fire protection (combustion)
- Water absorption
- Compressive strength
- Embodied energy

THERMAL BRIDGES

Special mention has to be made about thermal bridges, which are regions with a relatively high heat flow, as a result of typical geometric or structural disturbances. Geometrical heat bridges derive from a local enlargement of the exposed surface like external corners and edges of the building. Structural thermal bridges are created by physical and chemical differences of materials, e.g. by structural elements like a concrete balcony slab penetrating insulation layers like a mineral fibre insulation of a facade. Especially in well insulated buildings heat bridges are counterproductive, increasing the overall heat transfer and resulting in humidity and moisture accumulation by condensation. Hence, insulation has to be planned carefully and thoughtfully in order to achieve a good result. In existing buildings heat bridges can be traced by thermographic cameras. Such devices are to be used with a certain knowledge and attention: In summer, high insulation can cause cameras to be uneffective. For conditioned buildings in warmer climate, a quite effective examination can be made from the inside, searching for warmer corners and temperature anomalies.

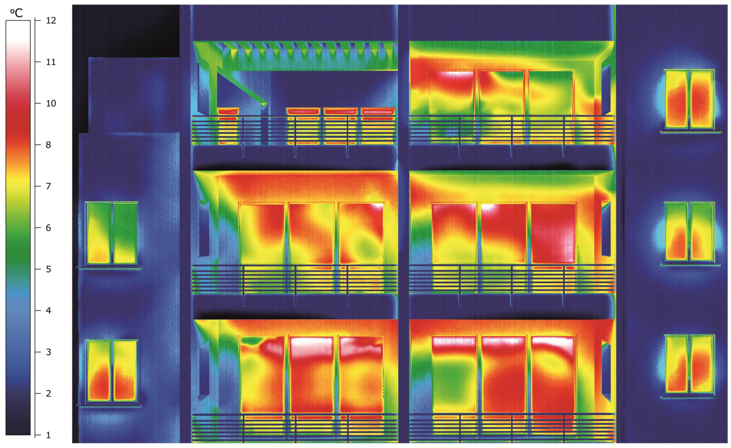


Figure 3.37: Example of a thermographic image of a cold-latitude building equipped with heating. Higher temperatures indicate thermal gain – *Source: https://testoltd.wordpress.com/2013/03/26/thermal-imaging-resolution-matters-simply-see-more/*

THERMAL MASS

Thermal mass can be helpful to control the diurnal periodical heat gain in hot and dry climates. In combination with **night ventilation** large internal areas with high thermal capacity can be cooled down at night to store heat gains during the day, when the ventilation rate is reduced. As a rule of thumb, temperature swings of less than 6°C are insufficient to allow night cooling; being optimal where they exceed 10°C. Thermal mass should be protected from outside conditions by thermal insulation and airtightness of the building envelope. Adding inside insulation on the thermal mass or decoupling it by suspended ceilings or heavy carpets will nullify its effectiveness. Characteristics for the thermal capacity of typical building materials are given in *Table 3.6*.

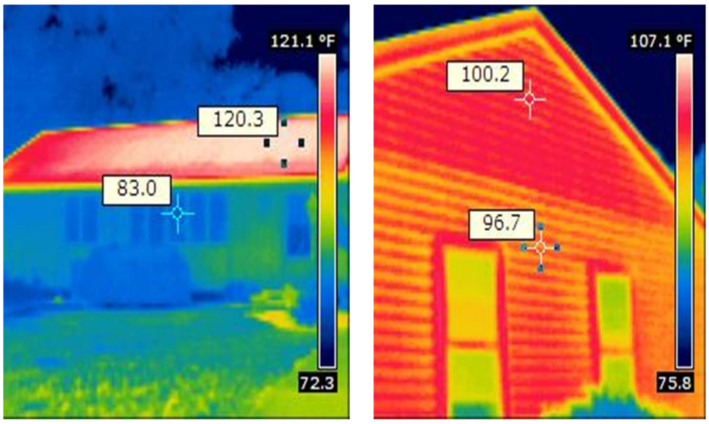


Figure 3.38: Example of the thermographic image of a building during summer. Temperatures indicate where excessive heat accumulates, on the roof and on the upper part of the walls – ***Source: bandersoninspections.com***

Table 3.6: Heat capacity of materials, DIN 4108-4

Material	*Heat capacity c_p J/kgK*
Inorganic building and insulation materials	1,000
Wood and derived timber products	2,100
Plant and textile fibres	1,300
Synthetic materials and foams	1,500
Aluminium	800
Other metals	400
Air (density 1.25 kg/m³)	1,000
Water	4,200

Phase change materials (PCM) are made of compounds that store and release energy when changing between liquid and solid phases at a set temperature. In building applications, PCMs are engineered to change phase at room temperature. These PCMs are solid at room temperature and as the ambient temperature rises due to external heat gain, the PCM absorbs the heat, preventing it from reaching the interior, and changes phase to a liquid.

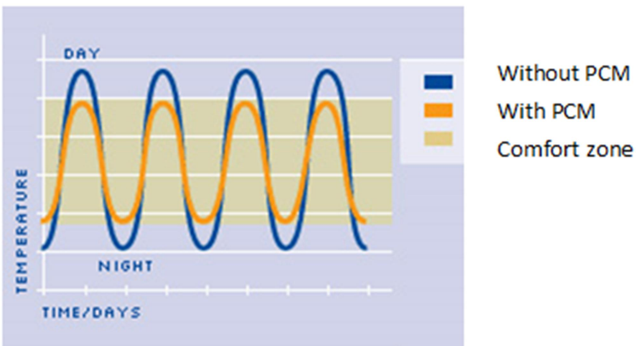


Figure 3.39: Influence of PCM on room temperature – *Source: www.micronal.de/portal/basf/ien/dt.jsp?setCursor=1_290814*

When the temperature around the PCM drops below room temperature, the PCM solidifies and releases the heat into the interior.

By microencapsulation of wax PCMs have been developed, which are integrated invisibly into the most diverse building materials, like wall and ceiling plaster or gypsum board. When the temperature rises, the wax melts and the phase-change material absorbs heat. When the temperature drops, the wax solidifies, and heat is emitted. During the phase change, the temperature remains constant. The PCM has demonstrated its effectiveness in practical use in diverse projects. In addition, a 16-month cyclic test involving 24 temperature cycles per day has attested to a minimum life of 30 years for the material. Its leak tightness and thermal storage characteristics remained unchanged throughout the test period.

DAYLIGHTING

» Task

Daylighting is for the comfort of human beings occupying buildings for most of their lifetime. As humans, our organism is adjusted by evolution to natural light and therefore we need it as a basic condition in our built environment during daytime. Its dynamical change is stimulus for our day and night biorhythm and it can influence our mood and health. Minimal lighting requirements for visual performance described earlier refer to artificial lighting and daylighting as well. Better lighting conditions for higher visual comfort and performance can be reached by daylighting without increase of energy consumption and CO_2 emission. The view from inside to outside is an important requirement for daylighting as well.

Energy use for artificial lighting will be decreased by sufficient daylighting in combination with an efficient lighting control. It can be described in terms of kWh/m^2a for lighting electricity and/or by daylight autonomy (sufficient daylighting of annual working hours in %). The luminous efficacy of daylight is high in comparison to many artificial light sources; nevertheless the solar heat gain of windows has to be considered. The overall energy consumption or CO_2 emission for lighting and cooling can be reduced significantly by the appropriate daylighting.

» Characteristics and availability of daylight

The light sensitivity of the human eye ranges between wavelengths of approximately 380 nm (ultraviolet) and 780 nm (red) which happens to be the band of highest intensity of solar radiation. Light accounts for about 65% of the total solar radiation reaching the ground (global radiation) the remainder being ultraviolet UV and infrared IR. The maximum light sensitivity of the eye decreases from its maximum at about 560 nm (green) to the boundary values given above. Because of this variable response of the eye to the wavelength the following SI photometry units are used to measure light (See Table *3.7*).

Luminance is the characteristic for measuring the image seen of an illuminated surface or room. It is used for the assessment of illumination quality by brightness, darkness and contrast of areas seen. Equipment for point measurements may be helpful, but luminance cameras (High dynamic range photographs) give a more comprehensive survey

Table 3.7: SI photometry units – *Source: Helmut F.O. Müller, daylighting, in: Sustainability, Energy and Architecture, Academic Press, Oxford 2014*

Quantity	Symbol	SI unit	Abbreviation	Notes
Luminous flux	F	lumen (= cd*sr)	lm	Also called luminous power
Luminous intensity	I_V	candela (= lm/sr)	cd	SI base unit
Luminance	I_V	candela per square meter	cd/m^2	Used for light seen on a surface
Illuminance	E_V	lux (= lm/m^2)	lx	Used for light incident on a surface
Luminous efficacy	------	lumen per watt	lm/W	Used for light sources

Illuminance describes the light incident on a surface and often is used for standards [e.g. minimum E_V on horizontal areas (desk level) or on vertical areas (walls in museums)]. It cannot characterize an image of illumination, which is influenced not only by the amount of incident light on a surface but by reflected light as well.

Luminous efficacy is used to evaluate the energy demand and sustainability of light sources. Daylight with 90 (sun) to 120 lm/W (clear sky) is much more efficient than most artificial light sources (e.g. incandescent lamps 10 – 15 lm/W, flourescent lamps 75 – 90 lm/W, light emitting diodes LED 80 – 120 lm/W) and completely free of CO_2 emissions. If solar protective glass is applied, which filters out the infrared and ultraviolet spectrum, daylighting can achieve 138 – 185 lm/W. As the human eye is perfectly adapted to the continous spectral distribution of daylight, **colour rendering** is optimal in comparison to artificial light sources.

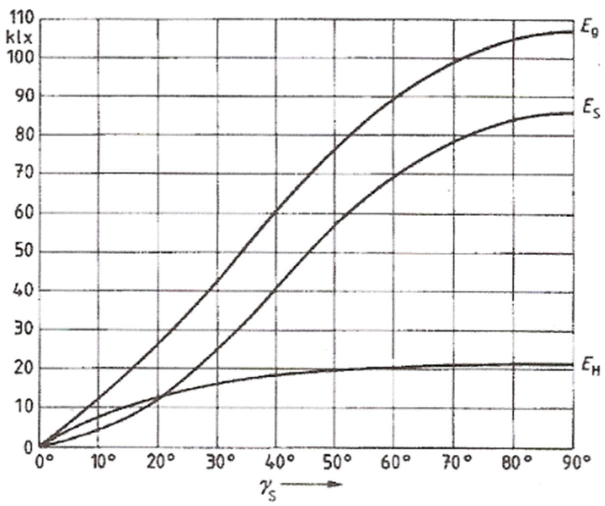


Figure 3.40: Horizontal illuminance for clear sky conditions in dependence of solar altitude. [1] ES by the sun, EH by the sky, EG total illuminance. Total turbidity factor (Linke) TL = 4.9 – *Source: Helmut F.O. Müller, daylighting, in: Sustainability, Energy and Architecture, Academic Press, Oxford 2014*

The **incident sunlight** is influenced by the daily and annual sun path and diffused more or less by the clear and cloudy sky conditions. The continuous change of intensity and color composition is typical for our natural environment of daylight. There are maximum horizontal illuminances exceeding 100 klx (100,000 lx) under clear sky conditions (see Figure 3.40) and mean values of about 10 klx under overcast sky conditions.

The daylight illuminating a given point in a room may reach it on the following ways:

- Direct sunlight on a straight line from the sun through a window to the given point;
- Diffused or skylight through a window;
- Externally reflected light (by the ground or other buildings) through a window;
- Internally reflected light from floor, walls, ceiling or other internal surfaces.

These **daylighting components** are influenced by climate and environment. The International Commission on Illumination (CIE) defines standard skies for daylight calculations, e.g. the CIE standard ‘overcast sky’ with a homogeneous luminance distribution from horizon to zenith by the factor of three.

There are several sources of information on daylight availability, e.g. meteonorm. The shading effect of buildings in the neighbourhood has to be taken into account. The externally and internally reflected light is influenced by the reflectivity of the surfaces.

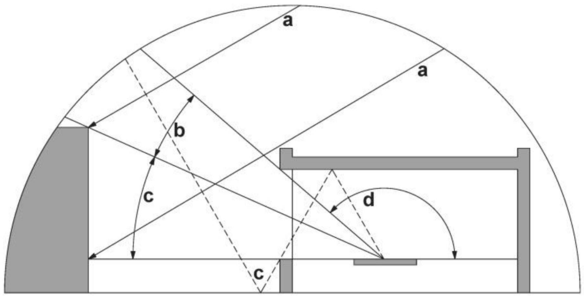


Figure 3.41: Daylight entering a building (vertical section) a: direct sunlight, b: diffused or skylight, c: externally reflected light, d: internally reflected light - *Source: Helmut F.O. Müller, daylighting in: Sustainability, Energy and Architecture, Academic Press, Oxford 2014*

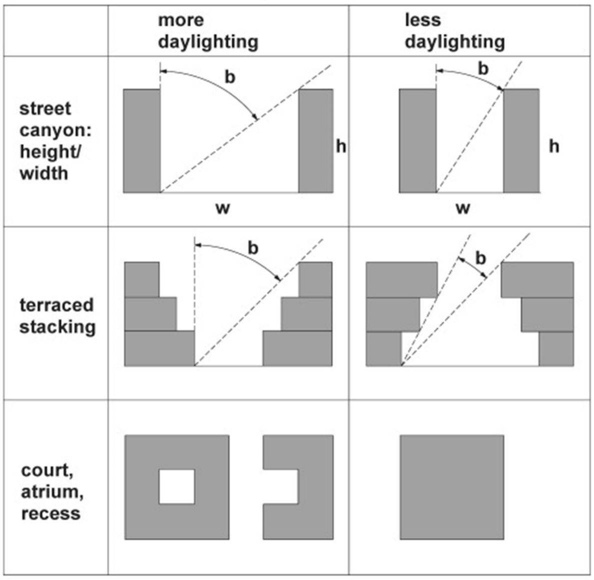


Figure 3.42: Means of urban design. b: diffused or skylight, h: height, w: width – *Source: Helmut F.O. Müller, daylighting, in: Sustainability, Energy and Architecture, Academic Press, Oxford 2014*

» *Daylighting Design*

The daylighting of rooms is not only influenced by building and window design but by **urban design** as well. The distance and height of neighbour buildings influence the amount of direct and diffuse daylight reaching the windows. The smaller the sky section, which can be seen from a room through the window, the smaller the incidence of daylight will be (Figure 3.42). The **orientation** of main window-walls is a significant design parameter: North and south orientation means direct sunlight only for certain seasons and from high solar positions, which allows for relatively simple shading devices to avoid glare and thermal heat gains. East or west facing windows receive direct sunlight from relatively low altitudes in the morning and evening hours respectively.

Solar glare and thermal heat gains are more difficult to control, thus north and south orientation is recommended for daylight openings.

The **building design** determines height and depth of rooms to be illuminated by daylight via side windows or roof lights. Stacked storeys can be illuminated only via vertical windows. This reduces the potential design solutions to a certain room depth, depending on the window (and storey) height. A rule of thumb recommends the following room depth for adequate daylighting under overcast sky conditions:

- Room depth = 2.5 x window height above desktop for one window wall.
- Room depth = 5 x window height above desktop for windows in two opposite walls.

An office room, e.g., 3 m high, with single windows 2.1 m high, will provide adequate daylight for a depth of 4.5 m. The deeper the room is the smaller the section of the sky seen from the middle of the room. And the incident light comes from a lower part of the sky, which has a lower luminance (ratio from zenith to horizon approximately 3/1 for continuously overcast condition). For clear sky conditions the boundary conditions are slightly better. Direct sunlight cannot be used for daylighting because of glare unless it is redirected or scattered (see references to sunlight redirection).

For increasing the depth of daylit buildings, the following architectural measures can be applied: Vertical lightshafts, courtyards or atria are inserted in the building shape or recesses and window bays are appied in the facade (). The lighter the colours of the room surfaces are the higher the reflection and daylighting. Black surfaces are most unfavourable.

WINDOW AND SKYLIGHT DESIGN

The illuminance of rooms can be influenced by size, location, orientation, and shape of the openings. Skylights in horizontal orientation are most efficient for daylighting, as they are facing the full sky hemisphere of 180°. Because of their high daylighting efficiency horizontal skylights should be applied for deep rooms, but never without solar shading against glare and heat gains. As they cannot provide an adequate view out, windows at eye level have to be located in the walls additionally. For vertical windows in walls the right position and size are important. The higher windows are located in the wall, the deeper the room will be illuminated. Window openings below desk level do not contribute to an improved room illumination but may be important for the view from high rise. The window area should be sufficient for daylighting, however fully glazed facades are not ideal. Glazed facade areas of more than 40 – 60% do not improve daylighting and tend to create glare and solar heat gain problems.

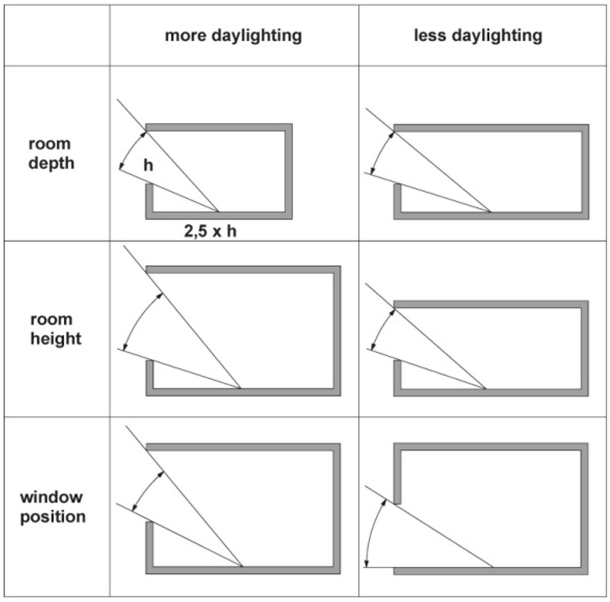


Figure 3.43: Means of room and window design. h: window height above desktop – *Source: Helmut F.O. Müller, daylighting, in: Sustainability, Energy and Architecture, Academic Press, Oxford 2014*

Clerestory windows are placed in the upper part of walls above eye level in order to improve the illumination of the room depth. They can be tailor-made for daylighting performance only as the view outside is offered by windows in lower position, which can be completely separate openings. Often light shelves or other light directing devices are integrated in clerestory windows.

GLAZING

The light transmittance of skylights and windows is influenced by the type of glazing and the area of casement frames. Although additional requirements like thermal insulation and solar control have to be fulfilled by the glazing as well, a high light transmittance and colour rendering is indispensible for daylighting. A single sheet of glass transmits about 90% of the incident light, a double glazing with a low-e coating about 75% and a solar control double glazing from 65% to 30%. Advanced solutions for solar control reflect predomiantly the infrared spectrum of solar radiation while the visible spectrum is transmitted. Typical ratios of light transmittance to solar heat gain coefficient are 66/33% and 50/25%. The surface of these glasses avoids the typical mirror effect of conventional solar reflective coatings (compare chapter 3.2.).

» ***Solar control***

The requirements of daylighting and solar control seem to compete with each other as natural room lighting can result in unwanted glare and solar heat gains and efficient shading can result in darkening and turning on the artificial light. In order to avoid this mismatch daylighting and solar control should be combined in a compatible way. A systematic survey of systems by the International Energy Agency (IEA) distinguishes the following principles:

- Diffuse skylight transmission
- Direct sunlight redirection
- Light scattering or diffusing
- Light transport.

For the climatic conditions of Nigeria direct sunlight redirection is a suitable solution. The great variety of systems can be separated in movable devices (e.g. louvers, solar tracked reflective lamellas) and fixed ones, which redirect the light from all solar positions in the wanted direction (e.g. light shelves, light directing glass). Solar tracked louvers are shown in chapter 3.2. Fixed horizontal lightshelves, which redirect sunlight through the upper window area and the lower window area and shade the lower window area, are shown in . For high solar positions the shelves can be inclined or composed of inclined lamella reflecting the sunlight to the ceiling and deep into the room. Sunlight redirecting glazing systems can be applied in clerestories, while the window area below is protected against heat gains by shading devices.

Figure 3.44: Lightshelves, a combination of horizontal shading and sunlight redirection – *Source: greenasiaforce.com*

Figure 3.45 shows a comparison with conventional louvre systems.

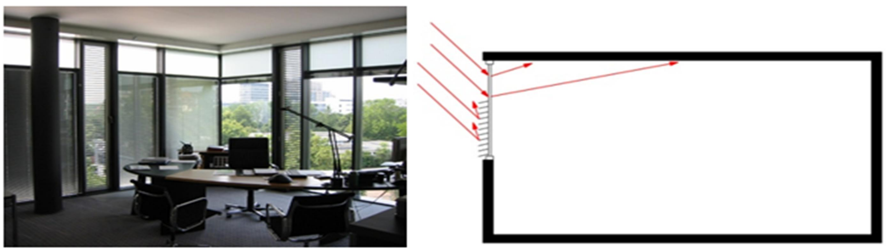


Figure 3.45: Sunlight redirecting glazing system in clerestory. Left: Spherion office building, Düsseldorf, Germany, Deilmann Koch Architects. Right: Principle solution

SOFTWARE TOOLS

For each step of the design, specific software tools can be used to analyse and assess daylight levels, in order to shape the best solution in accordance with the other parameters of bioclimatic design. For the first sketch design simple graphical tools and simple common rules can be used. For further design stages and details, more accurate computer programmes are available, which allow for simulation of complicated room geometries and varying surfaces under different sky conditions. Annual energy consumption of artificial lighting in dependence of daylighting can be calculated and photorealistic light and colour renderings can be produced in this phase. At the same time, scale models can help visualizing the light incidence with real light conditions, delivering visible impressions of what the final project could bring.

Concerning simulation tools, they generally use two different approaches, ray tracing or radiosity. Ray tracing follows the light rays "backwards" from the eye or camera, instead of covering their natural path. Doing so proves to be particularly efficient since the majority of rays coming from the light source usually do not arrive in the viewer's eye. Radiance is a programme based on ray tracing, applied in a variery of software solutions.

EMBODIED ENERGY OF MATERIALS

» *Task*

The main target of energy efficient building design is to reduce the energy consumption of a building over its whole life-cycle. The overall energy balance of the building is influenced by the operational energy for cooling, ventilating, and lighting as well as by the embodied energy in the manufacturing of building materials and those used for refurbishment and maintenance. The 'cradle to grave' embodied energy of a building therefore includes (excluding the operational energy):

- Initial embodied energy for raw-materials, their processing, manufacturing, transportation to site, and construction ('cradle to gate');
- Recurring embodied energy for refurbishment and maintainance of the building during its lifetime;
- Demolition energy for the disposal of the building at the end of its lifetime. Reuse and recycling of materials closes the cycle with an input to the initial energy for materials.

As buildings become more energy-efficient in operation, the ratio of embodied energy to lifetime operation energy increases. In standard houses the share of embodied energy is about 15%, in 'passive' houses of about 50%. Energy efficient operation thus turns the spotlight on embodied energy. Particluarly for 'zero- (operational) energy' houses the embodied energy takes a new significance. The amount of embodied energy varies considerably, depending on the type of building, the materials used, the regional construction technology, the durability of materials and components, the intervals of maintenance and the lifetime of the building.

» *Assessing of embodied energy*

Assessing the total of embodied energy over the life cycle of a product includes gas, electricity, oil, and so on for production and transport, but can also include features like greenhouse emissions, represented by CO_2 emission (embodied carbon). The units of measurement for embodied energy are represented as megajoule per kilogram (MJ/kg). This is the energy density of a material. Embodied energy can also be expressed in terms of MJ/m^2. Embodied carbon is measured respectively in kgCO_2/kg or m^2.

There are a number of international standards and tools that have been developed to help assess embodied energy, namely:

1. ISO 21930 covers environmental product declarations (EPD) for construction products since 2007.
2. The United States have now adopted the EN 15804 standard and offer compliant EPD.
3. The European schemes are united through the ECO platform organization, and there has been a rapid rise in the number of EPD, with over 2,000 EPD now available within ECO platform programmes and mutual recognition schemes in place for several of the members.
4. GaBi Build-it is used in Germany as part of the mandatory building LCA within DGNB.
5. In the United States, Tally® has been developed as a BIM plugin to provide building LCA with North American EPD and LCA data provided by Thinkstep.

» *Hints for material selection*

Calculation of embodied energy is complex, and exact figures for embodied energy vary from study to study. Fortunately, precise figures are not necessary for designers to make informed decisions based on the relative comparison of the embodied energy of a given product and its substitutes. Other considerations might include the deleterious nature of some materials, difficulty of disposal, ecological impact, waste generation, recycled component and recyclability, renewable resources, locally sourced materials, ease of deconstruction and separation, durability, efficiency in use, standardisation and so on (see sustainable materials for more information).

Top tips to reduce embodied energy and carbon are:

1. Focus on the elements of the building with highest impact. Have a look at the links to case studies.
2. Look at the form of the building – can you reduce the amount of key elements by changing the design of the building?
3. Investigate ways to increase the resource efficiency of these elements.
4. Consider alternative materials that can do the same job – the Green Guide Online
5. [1]Lets you compare the overall environmental impact and embodied energy of similar building elements.
6. Look at increasing the recycled and by-product content of the materials you are using – for example increasing the use of alternative cementitious materials like pulverised fuel ash (PFA) or ground-granulated blast-furnace slag (GGBS) as cement substitutes.
7. Examine environmental information provided by different suppliers – such as EPD or carbon footprints. Will their products have lower impact in your building?

Examples of embodied energy and carbon are given in the following table, a much-shortened and abbreviated adaptation of a survey published Geoff Hammond & Craig Jones.

[1] www.bre.co.uk/greenguide/podpage.jsp?id=2126

Table 3.8: Exemplary figures for embodied energy and carbon: 'cradle-to-gate' analysis

Material	***Energy MJ/kg***	***Carbon $kgCO_2/kg$***	***Density kg/m^3***
Aggregate	0.083	0.0048	2,240
Concrete (1:1.5:3 e.g. in-situ floor slabs, structure)	1.11	0.159	2,400
Concrete (eg in-situ floor slabs) with 25% PFA RC40	0.97	0.132	
Concrete (eg in-situ floor slabs) with 50% GGBS RC40	0.88	0.101	
Bricks (common)	3.0	0.24	1,700
Concrete block (medium density 10 N/mm^2)	0.67	0.073	1,450
Aerated block	3.50	0.30	750
Rammed earth (no cement content)	0.45	0.023	1,460
Limestone block	0.85		2,180
Marble	2.00	0.116	2,500
Cement mortar (1:3)	1.33	0.208	
Steel (general – average recycled content)	20.10	1.37	7,800
Steel (section – average recycled content)	21.50	1.42	7,800
Steel (pipe – average recycled content)	19.80	1.37	7,800
Stainless steel	56.70	6.15	7,850
Timber (general – excludes sequestration)	10.00	0.72	480 – 720
Glue laminated timber	12.00	0.87	
Sawn hardwood	10.40	0.86	700 – 800
Cellular glass insulation	27.00		
Cellulose insulation (loose fill)	0.94 – 3.3		43
Cork insulation	26.00*		160
Glass fibre insulation (glass wool)	28.00	1.35	12
Flax insulation	39.50	1.70	30*
Rockwool (slab)	16.80	1.05	24
Expanded polystyrene insulation	88.60	2.55	15 – 30*
Polyurethane insulation (rigid foam)	101.50	3.48	30
Woodwool board insulation	20.00	0.98	
Wool (recycled) insulation	20.90		25*
Straw bale	0.91		100 –110*
Mineral fibre roofing tile	37.00	2.70	1,850*
Slate (UK – imported)	0.1 – 1.0	0.006 – 0.058	1,600
Clay tile	6.50	0.45	1,900
Aluminium (general & incl. 33% recycled)	155	8.24	2,700
Bitumen (general)	51.00	0.38 – 0.43	
Hardboard	16.00	1.05	600 – 1,000
Medium-density fibreboard (MDF)	11.00	0.72	680 – 760*

Material	***Energy MJ/kg***	***Carbon $kgCO_2/kg$***	***Density kg/m^3***
Oriented strand board (OSB)	15.00	0.96	640*
Plywood	15.00	1.07	540 – 700
Plasterboard	6.75	0.38	800
Gypsum plaster	1.80	0.12	1,120
Glass	15.00	0.85	2,500
PVC (general)	77.20	28.10	1,380
PVC pipe	67.50	24.40	1,400*
Linoleum	25.00	1.21	1,200
Vinyl flooring	65.64	2.92	1,200
Terrazzo tiles	1.40	0.12	1,750*
Ceramic tiles	12.00	0.74	2,000
Carpet tiles, nylon (polyamide), pile weight 770 g/m^2	279 MJ/m^2	13.7 / m^2	4.6 kg/m^2
Wool carpet	106.00	5.53	
Wallpaper	36.40	1.93	
Wood stain / varnish	50.00	5.35	
Vitrified clay pipe (DN 500)	7.90	0.52	
Iron (general)	25.00	1.91	7,870
Copper (average incl. 37% recycled)	42.00	2.60	8,600
Lead (incl 61% recycled)	25.21	1.57	11,340
Ceramic sanitary ware	29.00	1.51	

* - figures by GreenSpec obtained from publicly available information

WINDOWS

Material	***MJ per window***	***$kgCO_2$***
Aluminium frame	5,470	279
PVC frame	2,150 -2,470	110 - 126
Aluminium clad timber frame	950 -1,460	48 - 75
Timber frame	230 - 490	12 - 25
Krypton filled add:	510	26
Xeon filled add:	4,500	229

PAINT

Material	***Energy MJ/m^2***	***Carbon $kgCO_2/m^2$***
Water-borne paint	59.0	2.12
Solvent-borne paint	97.0	3.13

PHOTOVOLTAIC (PV) CELLS

Material	*Energy MJ/m²*	*Carbon kgCO₂/m²*
Monocrystalline (average)	4,750	242
Polycrystalline (average)	4,070	208
Thin film (average)	1,305	67

3.3. ACTIVE MEASURES FOR ENERGY EFFICIENT DESIGN

MECHANICAL VENTILATION

» Functions of ventilation

The main functions of ventilation, described in chapter 3.2, apply for natural and mechanical ventilation. Mechanical ventilation is applied, if natural ventilation cannot provide the necessary air changes and related functions: Fresh air for people to breathe, filter external pollutants and take away internal ones, contribute to thermal behavior of building, control of external noise, and overall feeling of wellbeing. Combinations of mechanical and natural ventilation are possible, e.g. for certain climate conditions or certain zones of buildings. An optimized plan arrangement, keeping room depths to a minimum, increases the proportion of floor area that can be ventilated naturally.

Good air quality is a vital requirement, which is influenced by the emissions of equipment and building materials. By selecting materials with lower odour and pollution emission and dispensing with carpets and textiles, the required number of air changes can be reduced and energy saved. Improved air quality means that ducts require less cleaning. Recirculating air operation is not recommended because of hygiene.

The hourly supply air rate (BS EN 13779) refers to the number of persons (20 – 40 m^3/person) or floor area. Alternatively, it can be defined by hourly air changes of room volume (e.g. housing 0.5, offices, schools 4 – 5). Another aspect is the perceived air quality in decipol or the concentration of pollutants in the room air.

Heat recovery, adiabatic cooling, and underground ducts can be used in conjunction with mechanical ventilation, thus reducing the expenditure for cooling refrigeration. With appropriate building design, this technology is replacing conventional systems.

» Air conduction in rooms

There are three basic principles of air conduction in rooms: Mixed flow, displacement and (low turbulence) laminar flow ventilation (see Figure 3.46).

Mixed flow ventilation introduces supply air at high speed into the room. Depending on the diffuser design, the air is either blown far into the room or quickly mixed with the room air by swirl diffusers or induction effect. A high rate of air

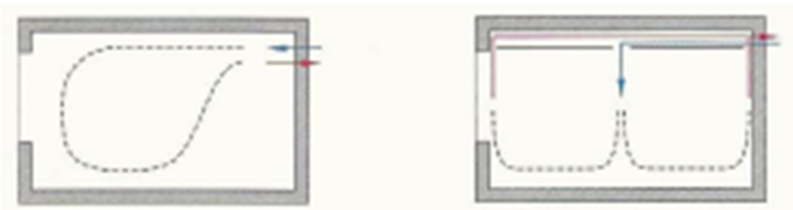


Figure 3.46: Air conduction in rooms: Mixed flow ventilation with tangential introduction (left) and radial introduction of air supply (right)

change is required and the dilution principle provides roughly the same air quality at all points of the room. It allows supply air at different temperatures for cooling and heating. The advantage of mixed flow ventilation is that the air can be introduced through small supply openings at all points of the room. Little energy is used, as temperature of supply air is independent from room temperature. Often it is applied in residential premises, where air quality must not be high because of low occupancy density. Because of the relatively high air change rate it is applied in rooms with high occupancy density as well. High cooling loads of more than 60 W/m² can be achieved.

Displacement ventilation introduces fresh air through large area diffusers at low air speed (less than 0.2 m/s) and approximately 2 K less than room temperature. Fresh air moves upward from a pool near the floor, when it is warmed by heat sources like people and equipment and extracted at ceiling level. As supply air temperature has to be in a narrow range of comfort, the cooling performance of displacement ventilation is relatively low (10 W/m²). Additional water operated cooling systems may be necessary. Displacement ventilation is particularly suitable for office buildings as it provides good air quality with relatively low volumes of air.

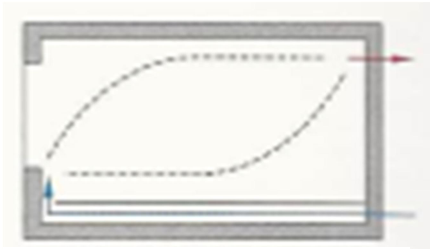


Figure 3.47: Air conduction in rooms: Displacement ventilation

Laminar flow ventilation makes the air flow from one room surface to the opposite surface, ensuring that the air is very clean. This may be required in clean rooms, laboratories or operating theaters, where micro-organisms or dust particles have to be removed. The introduction of air over large areas involves high installation costs.

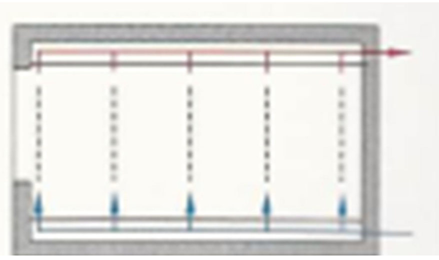


Figure 3.48: Air conduction in rooms: Laminar flow ventilation

» ***Air conduction in building***

The supply air can be conducted through the facade or through a central ventilation system into the rooms. As to air quality and user acceptance, it is preferable to deliver the air through the facade. A central ventilation system is required at heavily loaded locations, where high air change rates are necessary or special requirements are given. The principle solutions of mechanical air conduction are:

- Only supply air ducted (exhaust air routed through openings in envelope)
- Only exhaust air ducted (supply air routed through openings in envelope)
- Supply and exhaust air ducted.

The first solution allows for supply air to be conditioned for certain zone, while the exhaust air flow is more or less uncontrolled. The second solution generates a low pressure zones with bad air quality (e.g. bathrooms) and forces supply air in this direction. Minimal rates of air change can be guaranteed this way. An optimal performance can be achieved by separately controlled supply and exhaust air systems. They allow for air flow control in separate rooms, air conditioning as well as heat recovery. There can be a central ventilation plant for the whole house or distributed local ventilation plants for single rooms or dwellings. There is a trend for local and facade integrated systems, which need minimal space for ducts and shafts, thus reduce the building volume. The individual room control contributes to comfort and energy efficiency. Distributed ventilation equipment can either be used as supply air devices with a central exhaust air system or as supply and exhaust air devices with heat recovery.

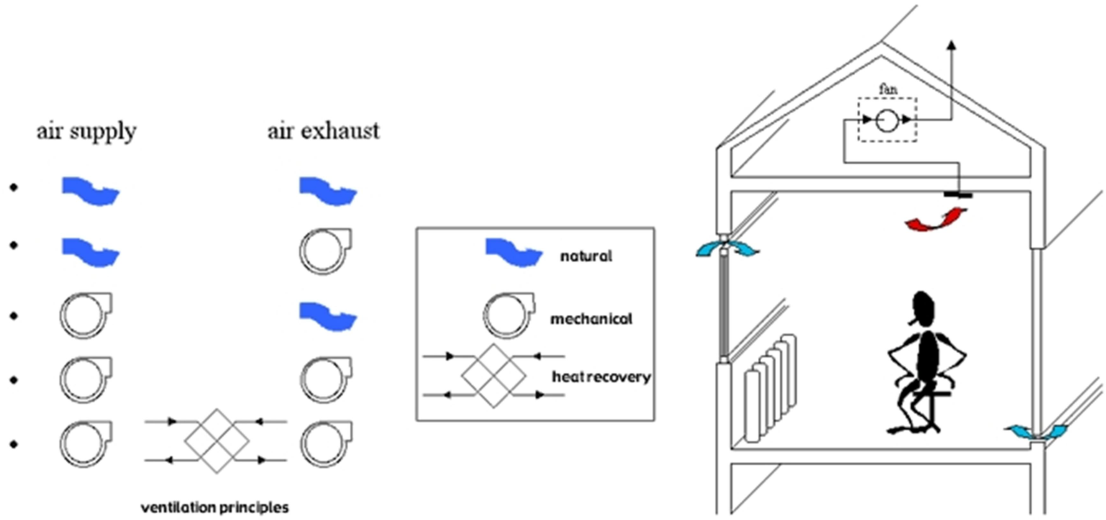


Figure 3.49: Ventilation options in residential buildings – *Source: new-learn.info/packages/clear/thermal/buildings/active_systems*

Cooling output can be limited by the dew point, if no condensate pipework system is available. A direct outfall of condensed water is usually not permitted.

Cooling devices can be positioned in the facade ventilation systems or located centrally, distributing chilled water to the local ventilation plants. Positive or negative wind pressure on the facade can cause a problem with the control of air change rate, which can be solved by double skin facades. A disadvantage of local façade ventilation systems is the high maintenance cost for a large number of single plants. This disadvantage can be lessened by modular design and easy access to the system.

The ventilation design is closely linked with the use of the building, its requirements, the facade design and the plan layout. Natural and mechanical ventilation can be combined, which is possible only in the early building design phase.

LOW ENERGY COOLING, AIR-CONDITIONING

» Approaches of cooling

If thermal comfort cannot be established by passive measures solely, active measures of cooling have to be applied. Depending on the magnitude of cooling loads and relative air humidity different **approaches** are possible:

- Air movement by ceiling or desk fans, helping to cool down the skin by convection and evaporation. Therefore, sitting under a fan feels cooler although the air temperature is the same. Energy consumption is much lower than for air conditioning systems. The efficiency of air handling units (AHU) is judged by the SFP (specific fan power), the electrical power to provide 1 liter/sec of air (W per l/s or Ws/l).
- Mechanical ventilation can increase heat gain, but the temperature of external air limits this approach. In combination with passive measures, e.g. thermal mass, mechanical ventilation strategies can improve thermal comfort, e.g. by night ventilation.

- Cooling of room surfaces by chilled water e.g. chilled ceilings, walls or floors. These solutions are often applied in moderate climates. In hot and humid climates condensation of water on cold surfaces can be critical and raised temperatures reduce the cooling load. No problems in combination with HVAC systems and conditioned air.
- Cooling the air volume of rooms by various means of cold transfer. If, in addition to the cooling task, dehumidification of air is necessary, air conditioning (AC) is applied.
- For tropical climate with high relative air humidity the dehumidification of air by latent cooling on a temperature level of 6/12°C consumes a lot of energy. Therefor advanced energy efficient cooling systems combine different approaches for air dehumidification and cooling for comfortable room temperature (e.g. combinations of air- and water-operated systems, absorption and desiccant cooling).

Recommendations for low energy cooling, depending on climate zone, building type, and passive measures, are given in Module 4.

» *Water and air operated systems*

Heating, ventilation air conditioning systems supply and condition air. They normally consist of several components to supply, filter, heat, cool, humidify and dehumidify the air. A heat recovery system could be incorporated but this is dependent on the need for heat by the building occupants. It is normally advantageous to heat and cool rooms with water-operated systems, as otherwise large volumes of air are required. As air has, compared to water, a 4 times smaller specific heat and 833 times smaller density, water is preferred as transport medium for cold or heat, resulting in smaller sections of pipes/ducts and reduced transport of energy (pumps/fans). Hence, only-air-operated systems are applied predominantly for buildings with a high fresh air change for hygienic reasons, like theaters, and in cases of air dehumidification or evaporative cooling.

Air-operated HVAC systems can be categorized as low- or high-pressure systems. The supply air is conducted at high pressure (and velocity, 10 – 25 m/s) or low pressure (and velocity) through a duct. In order to avoid drafts, high velocity is reduced in terminals before the air enters the room. Low pressure systems need larger duct sections but they consume less energy for air transport than high pressure ones. Variable volume flow systems have a constant temperature and control the cooling demand by variation of air flow volume. They are preferably applied in rooms with varying cooling loads, like offices, department stores, and schools.

Combinations of air- and water-operated systems are applied in different forms, like constant air volume systems with water cooled elements (e.g. chilled ceilings, convectors) as well as induction or fan-coil systems. The water pipes always have to be insulated to avoid condensation. Induction air conditioning systems transport the air to outlets, below windows or in ceilings, which cool or heat the air by induction devices, connected to a cold and hot water network. The induction process draws additional room air into the heat exchanger and allows for a higher cooling capacity for the given flow of fresh air. Fan-coil-systems are similar to induction systems, but the heat exchanger is equipped with a fan, which allows for more flexibility of room temperature and air flow rate. Fan-coil and induction devices often involve a high technical content.

Split-systems, air- and refrigerant-operated, come in two forms: Mini-split and central systems. In both types, the inside-environment (evaporative) heat exchanger is separated by some distance from the outside-environment (condensing unit) heat exchanger.

A mini-split system typically supplies chilled air to a single or a few rooms of a building. They typically produce 9,500 – 38,000 kJ per hour of cooling. Advantages of the ductless system include smaller size and flexibility for zoning. Flexible exterior hoses lead from the outside unit to the interior one(s). In addition, ductless systems offer higher efficiency. The primary disadvantage of ductless air conditioners is their cost. They cost about 30% more than central systems (not including ductwork) and may cost more than twice as much as window units of similar capacity.

» ***Cold generation systems***

Today the majority of cooling systems are electrically driven compression chillers (refrigeration cycle, heat pump). The average coefficient of performance (COP) of installed systems is about 3.0 or lower and only the best available systems reach about 5.0. To reduce the primary energy consumption of chillers, evaporation cooling and thermal cooling systems offer interesting alternatives, which can use solar thermal energy. All systems described here are on the market and are used commercially. Reseach and development is being carried out for advanced systems to optimise cost and the energy efficiency.

Refrigeration cycle cooling (compression cooling) is applied most often in AC systems. The refrigerant absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere to the external environment (heat sink). Conventional refrigerants like many halons, chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC), contribute to global warming and ozone depletion in the atmosphere. New refrigerants were developed that are safer for the environment, but their application has been held up due to concerns over toxicity and flammability.

Heat pumps are air conditioners in which the refrigeration cycle can be reversed, producing heating instead of cooling in the indoor environment. They are also commonly referred to as a 'reverse cycle air conditioner'. The heat pump is significantly more energy efficient than electric resistance heating.

Evaporative cooling systems draw outside air through a wet pad, such as a large sponge soaked with water. By water evaporation the incoming air is cooled, if its humidity content is low. Thus the system works efficiently only in dry climates.

Desiccant evaporative cooling works in humid climates as well, as air can be passed over common, solid desiccants (like silica gel or zeolite) or liquid desiccants (e.g. lithium bromide or lithium chloride) to draw moisture from the air to allow an efficient mechanical or evaporative cooling cycle. The desiccant is then regenerated by using solar thermal energy to dehumidify, in a cost-effective, low-energy-consumption, continuously repeating cycle (Figure 3.50). The open-cycle desiccant cooling is used for air-based systems, as supply air is conditioned directly.

Absorption cooling is a thermal cooling system that can be operated by fossil fuel sources, waste heat or solar thermal energy. Active solar cooling uses solar thermal collectors to provide solar energy to thermally driven chillers. The main technologies used are closed-cycle absorption chillers, which use either liquids or solids for the sorption process of the refrigerant. Solar energy heats a fluid that provides heat to the generator of an absorption chiller and is recirculated back to the collectors. The heat provided to the generator drives a cooling cycle that produces chilled water.

Absorption chillers are available in a range of 5 to 20,000 kW. Especially in hot and humid climates, the demand for cooling power is high. Gas driven absorption chillers reach COPs of 1.0 to 1.5, which can be raised by a combination with solar heating. Efficient absorption chillers nominally require water of at least 90°C. Thus, vacuum tube solar collectors are suitable rather than flat-plate collectors (*see chapter 3.2*). If there is a combined cooling, heat and power (CCHP) or trigeneration process, the heat is used to generate chilled water for air conditioning or refrigeration. Advanced absorption chillers with increased energy and cost efficiency are developed by ZAE Bayern.

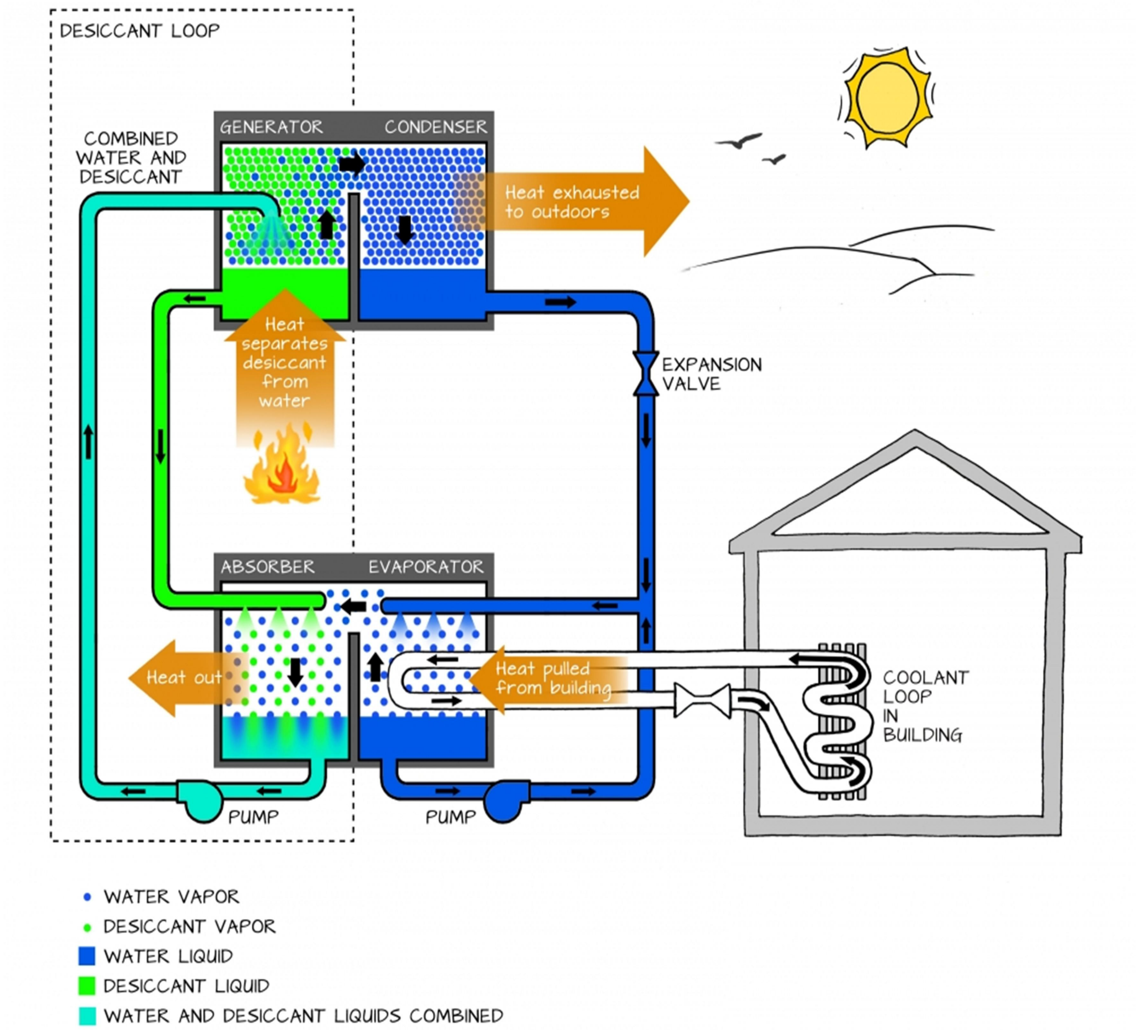


Figure 3.50: Absorption cooling system schematic

Combination of absorption cooling and desiccant cooling is a novel concept of air conditioning, often used to aim at a separation of fresh air conditioning and sensible cooling. The objective is to reduce the air-conditioning demand to the hygienically necessary demand. At high internal cooling loads, an air flow of about 5 to 10 times the hygienically necessary fresh air flow has to be used to remove the load in air based air-conditioning systems. Thus, in advanced concepts only the hygienically necessary fresh air flow is dehumidified and cooled (temperature level 6/12°C) to remove the latent cooling loads.

The remaining sensitive cooling load is removed by water based surface cooling, e.g. ceilings, with a temperature level of 16/20 °C (compare approaches of cooling). Open- and closed-cycle sorption processes can be combined to create highly efficient systems for simultaneous production of chilled water and dehumidified air. The combination of a special absorption chiller with a desiccant cooling system, COP 1.2 – 1.6, is shown in Figure 3.51.

Figure 3.52 above shows an example for a combination of closed and open cycle cooling technology with solar and back-up heating: Ambient air (1) is dehumidified, leaving the

desiccant wheel with a good supply air-humidity ratio but with high temperature (2). This air is subsequently cooled by the heat recovery (3) and the sensible cooler (4). The return air (5) from the room is adiabatically cooled (6) and takes up the heat from the supply air (7) and is heated up (8, out of the bounds) to regenerate the desiccant wheel (9). Figure 3.53 shows step (1) to (9) in a psychrometric chart.

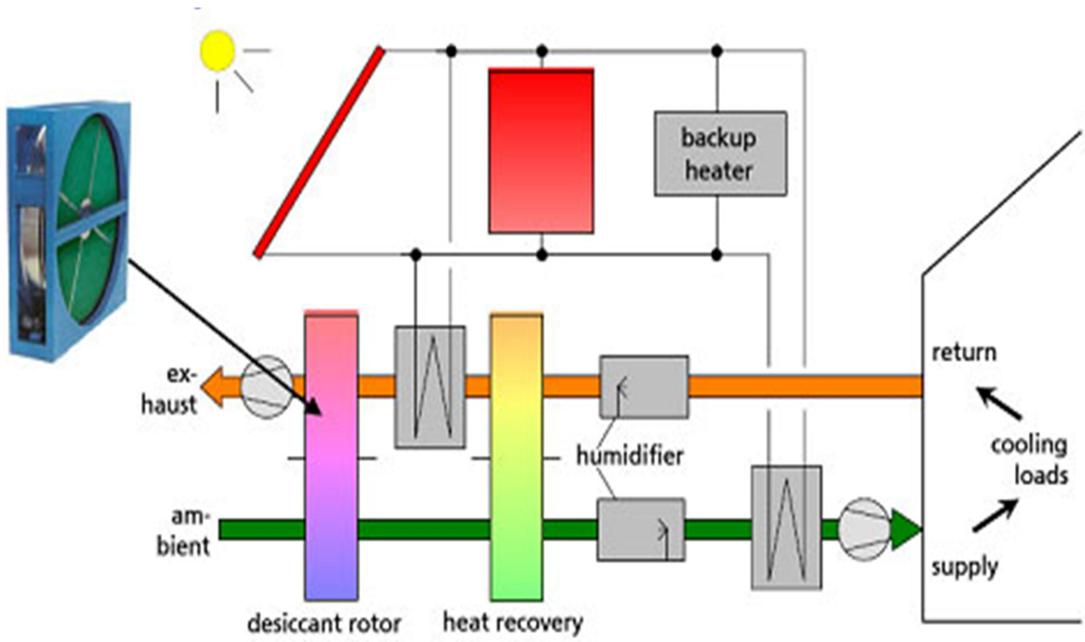


Figure 3.51: Desiccant evaporative cooling (DEC) system schematic

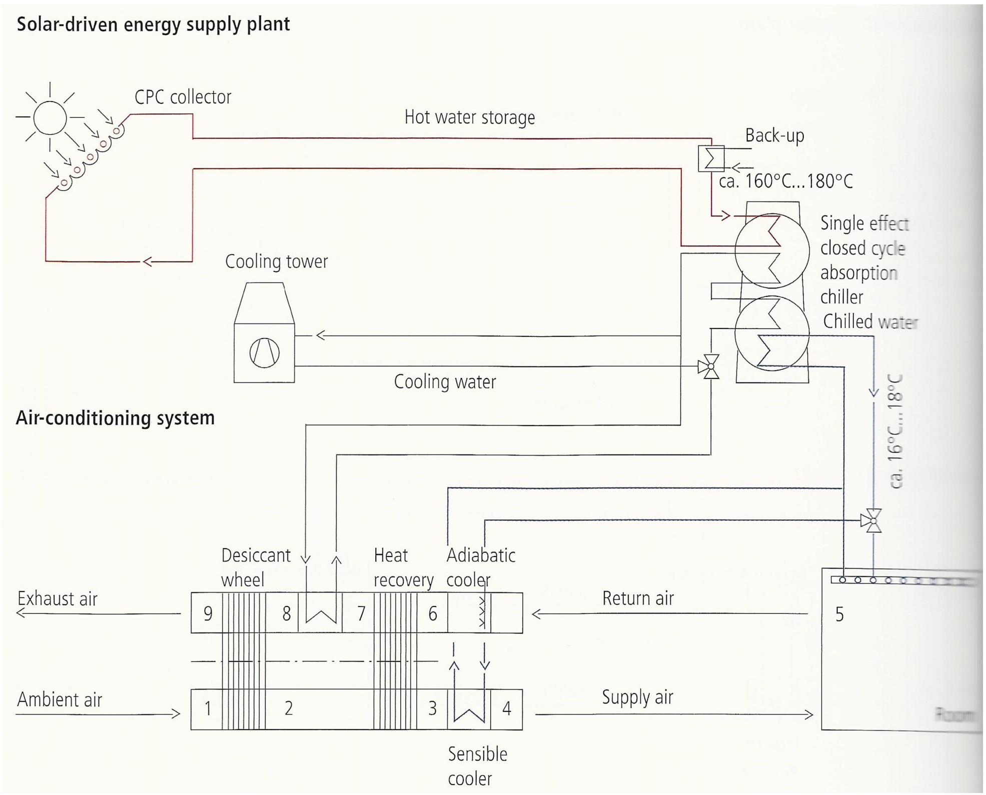


Figure 3.52**: Combination closed and open loop cycle colling technology –** ***Source:*** *Hindrichs, U., Daniels, K.: plusminus20°/40°latitude. Ed-A. Menges, 2007*

ARTIFICIAL LIGHTING

» Requirements of visual performance

Good lighting depends on the quality of lamps, luminaires, room surfaces and management system and on the interaction of these components. The technology is concerned with many features, each one of which has an effect on lighting quality. Not only is it crucial for vision, but it influences our sense of wellbeing and our mood. Thus, visual and nonvisual requirements are distinguished. See chapter on comfort and energy demand for details on visual and nonvisual requirements of lighting.

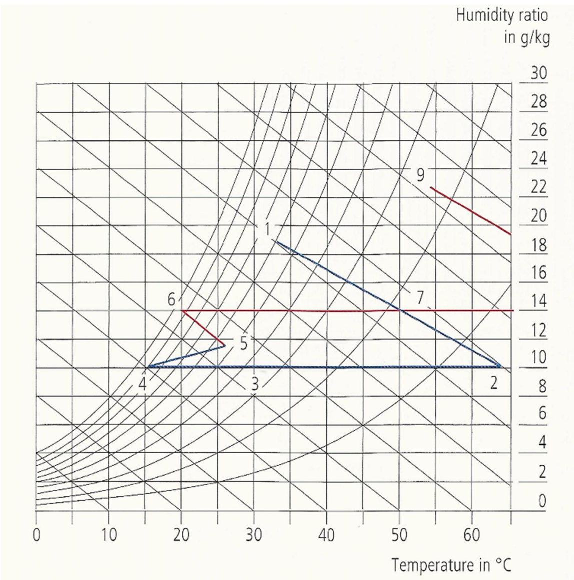


Figure 3.53: Psychrometric chart with an air conditioning process of a combined system: Beirut design conditions – *Source: Hindrichs, U., Daniels, K.: plusminus20°/40°latitude. Ed-A. Menges, 2007*

Energy efficiency and economy have to be considered as well, especially with regard to advanced LED light sources with luminous efficiencies of ≥ 120 lm/W. The cost assessment has to contemplate investment, lifetime, energy consumption, maintenance as well as disposal and recycling of lamps. One of the most effective measures for saving electrical energy for lighting is daylighting. Using an intelligent building design, most areas can be illuminated by natural light during daytime. It is possible to light an office building, e.g., with daylight for more than 80% of the working time. This energy saving potential can only be utilized if there is an automatic daylight related control of artificial light. For further detail, see chapter on daylighting.

» *Artificial light sources (lamps)*

There is a great variety of light sources available today, but the lamps can be divided in three main groups.

- Thermal radiators, heating a tungsten filament: Incandescent lamps, halogen lamps;
- Discharge lamps, sending an electrical discharge through an ionised gas or metal vapour;
- Low-pressure: Linear fluorescent lamps, compact fluorescent lamps (CFL), induction lamps, low pressure sodium vapour lamps;
- High-pressure: Metal halide lamps, high pressure sodium vapour lamps;
- LEDs (Light Emitting Diodes), semiconductor crystals that generate light when energised,
- and OLEDs (organic light emitting diodes).

A survey of the most frequently used lamp types in domestic and office buildings shows that LEDs are the light source of the future, thanks to their high luminous efficacy and life span (see Table 3.8). These characteristics have a strong influence on energy costs in comparison to the investments over the total life cycle (see Figure 3.54)

Table 3.9: Comparison of lamp types

Lamp type	*Wattage (W)*	*Luminous efficacy (lm/W)*	*Light flux (lm)*	*Lifespan (h)*	*Colour rendering index (%)*
Incandescent and halogen lamps	25 – 100 35 – 100	10 – 15 18 – 20	25 – 1,450 170 – 2,000	1,000 4,000	Up to100 60 – 95
Luminescent lamps: Compact (CFL) tubes	10 – 80 15 – 80	50 – 100 60 – 105	540 – 6.500 1.000 – 6.000	9,000 20,000	50 – 90 50 – 90
LEDs, white	0.05 – 1.0	65 – 140	0.2 – 100	60,000	80 - 97

There exist retrofit LEDs for the replacement of many traditional light sources, e.g. light bulbs or tubes. They allow significant energy savings, but their performance is not always optimal in combination with an old luminaire. In particular, when compared to the classic light bulb or halogens, the colour rendering index appears to be still less favourable.

OLEDS were envisaged for large luminous areas, such as OLED wallpapers, but at the time being they are mostly used in modular form, as arrays of small panels of 10 cm x 10 cm or less. In comparison to LED they have a much larger light emitting surface and consequently a lower luminance, which avoids glare. Currently they are hardly used as primary light source of a room due to their limited light flux and high costs (see).

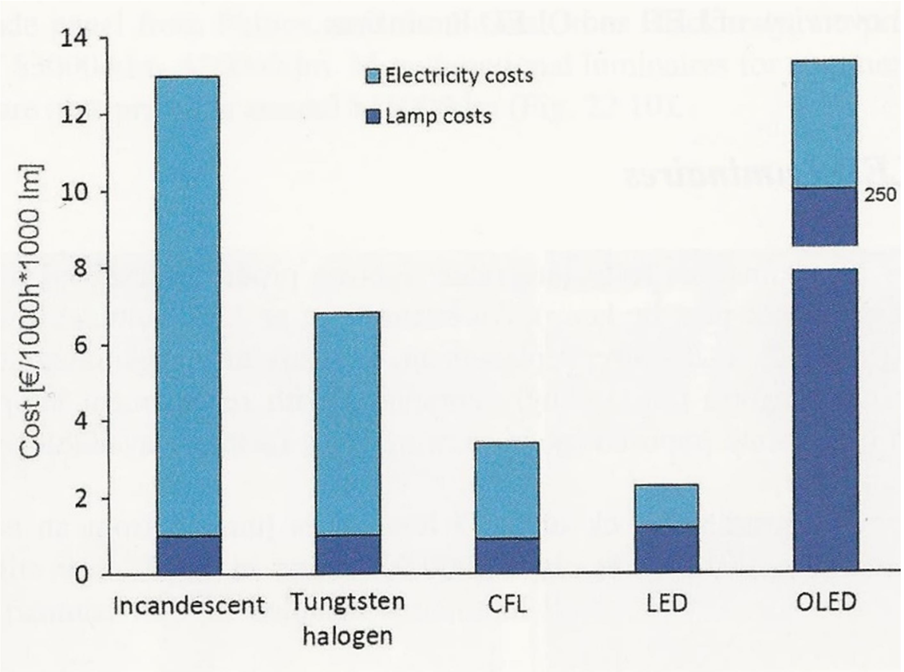


Figure 3.54: Comparison of the total costs of ownership of different types of lamps – *Source: Pohl, W. (2016): The State of the Art for Technologies Used to Decrease Demand in Buildings: Electric Lighting. In: Sofia-Natalia Boemi, Olatz Irulegi, Mattheos Santamouris (Ed.): Energy Performance of Buildings. Springer (2016)*

» ***Luminaires and room***

Lighting is realized in three steps: The lamp, the luminaire and the room. Furthermore, a proper control of operating time and dimming states is decisive for the energy consumption. The lamp (including controls and ballast) transforms electricity into light, the luminaire distributes the light into the room according to the visual requirements, and the room renders this light into visible luminance by the surface reflections, thus creating the visual environment. The overall energetic performance is characterized by three factors, the product of which gives the total energy utilization:

- Lamp (luminous) efficacy in l/W (including operating device)
- Luminaire light output ratio (LOR = Light output of luminaire / light output of lamp in %)
- Room utilization factor (RUF) in %.

Different lamp technologies require different luminaire construction principles and features. LEDs with specific properties, like small dimension, high luminance, and temperature sensitivity of light flux need a completely different luminaire design than compact luminescent lamps. The high luminous efficacy of LED supports the development of LED luminaires and their application. However, the low price and the high light output of luminaires with luminescent light tubes are still competitive to LED luminaires currently.

The fast development of LED with higher luminous flux and optimal LED luminaires will probably turn the market positions soon. Advanced luminaires are developed with microstructured light guides, which are edge lit by LED. They can be applied as surface-mounted, suspended or free-standing luminaires New developments allow for one or two-side light emissions in defined angles from the light guide panel

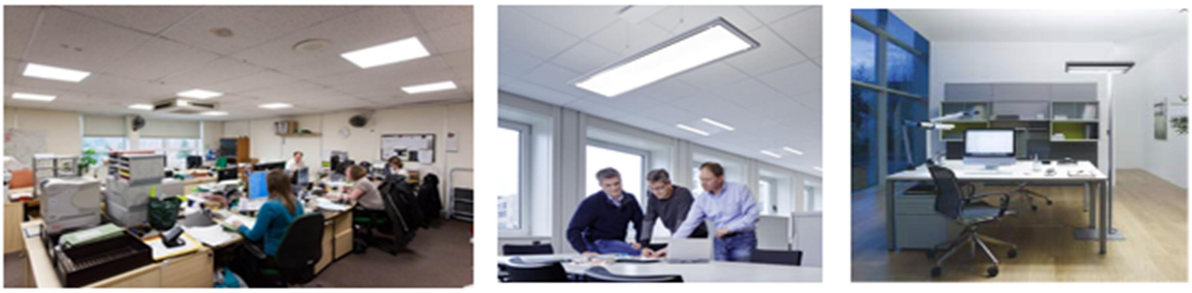


Figure 3.55: LED luminaires with edge lit light guide panels; surface mounted, suspended, and free standing

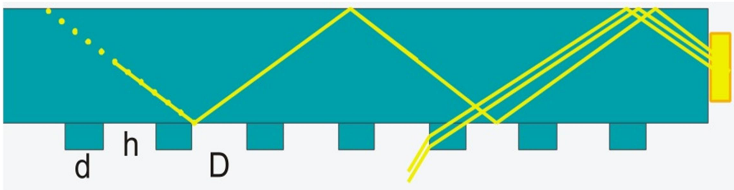


Figure 3.56: Edge lit light guide panel with microstructure of plane cylinders. Diameter d: 50 - 800 µm, height h: 50 – 800 µm, distance D: > 3 x d – *Source: Müller, H. (2014): Energy-Efficient Lighting by LED. Proceedings World Renewable Energy Congress WREC XIII, 03.-08. Aug. 2014, Kingston UK*

The luminaire design is influenced by architecture and lighting atmosphere of the room as well. In dwellings warm light for certain room areas is often preferred, while in offices general lighting of larger spaces is often chosen with cooler light temperatures, sometimes combined with task lighting of desks.

The room utilization factor (RUF) depends on, beside other factors, the reflectance of room surfaces. For a room with a mean reflectance of 20%, e.g., the additional indirect lighting (by multiple room reflections) is only 8% of the direct lighting, whereas for a mean reflectance of 70% it is 70%.

Figure 3.57: OLED luminaires suspended from ceiling, Audi visitor´s centre, Ingolstadt, Germany (photo: Mueller, H.)

The overall performance of a lighting system depends on a proper maintenance over the lifetime. Maintenance plans can save a lot of energy, too, if put in practise during the operation phase. The following measures should be defined by a regular maintenance schedule:

- Cleaning of luminaires, daylighting devices, and rooms (dirt depreciation)
- Relamping (usually before burnout)
- Replacement of other parts
- Renovation respectively retrofitting of antiquated systems and components.

BUILDING AUTOMATION SYSTEMS (BAS)

» Objectives of BAS

A building automation system (BAS) or a building management system (BMS) is the automatic centralized control of a building's heating, ventilation and air conditioning, lighting, security and other systems, like building intgrated energy supply. The objectives of BAS are:

- Improved occupant comfort
- Efficient operation of building systems
- Reduced energy consumption and operation costs
- Improved life cycle utilities.

BAS core functionality keeps building climate within a specified range, provides light to rooms based on an occupancy schedule and daylight condition, monitors performance and device failures in all systems, and provides malfunction alarms to building maintenance staff.

A BAS reduces building energy and maintenance costs to an extent of 15% to 20% compared to non-controlled buildings. Most commercial, institutional, and industrial buildings built after 2000 (in Europe) include a BAS. Many older buildings have been retrofitted with a new BAS, typically financed through energy and insurance savings, and other savings associated with pre-emptive maintenance and fault detection.

» Network and structure

Generally, the BAS term covers all control elements, including hardware, controllers, any linking network and central controllers. Most building automation networks consist of a primary and secondary bus-system, which connect three levels of control (see):

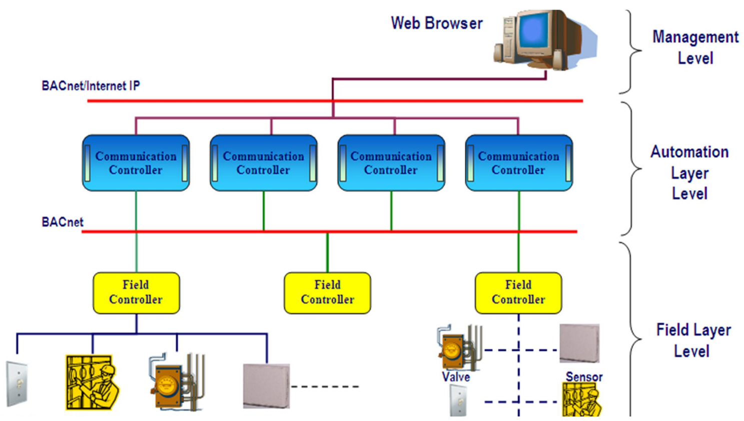


Figure 3.58: Basic structure of building management system – *Source: Yin, 2010: http://publish.ucc.ie*

1. The user interface on the management level (human interface device),
2. The automation level controllers and
3. The field level controllers and input/output devices (sensors and actuators). ASHRAE´s open protocol BACnet (Building Automation and Control Networks) or the open protocol LonTalk specify how most of such devices interoperate. The most important bus-systems are EIB (European Installation Bus), LON (Local Operating Network) and LCN (Local Control Network).

» Application

Almost all multi-story green buildings are designed to accommodate a BAS for the energy, air and water conservation characteristics. Electrical device demand response is a typical function of a BAS, as is the more sophisticated ventilation and humidity monitoring required of 'tight' insulated buildings. Most green buildings also use as many low-power DC devices as possible, typically integrated with power over Ethernet wiring, so by definition always accessible to a BAS through the Ethernet connectivity. Even a low energy or 'passivhaus' design intended to consume no net energy whatsoever will typically require a BAS to manage heat capture, shading and venting, and scheduling device use.

Building automation systems (BAS) can be related to building information modelling (BIM) to improve the process of generating and managing building data during the life cycle of the building. Data collected by BAS can be used for building modelling software to increase the productivity and energy efficiency in building design. And energy simulation models can be used as input in BAS for continuous building monitoring and optimal controlling.

3.4. INTEGRATION OF PASSIVE AND ACTIVE MEASURES

Comfort requirements for buildings can be fulfilled by passive measures of architecture completely or to a certain extent. Dependent on the climate, the type of building and its requirements certain active measures may be necessary. In order to achieve a sustainable building design all passive measures of environmental design have to be applied first, before active means of building services are considered for the remaining inadequacies. As passive and active measures influence each other, there should be an integrated design process with experts from all professions cooperating right from the beginning, as deminstarted, which should include energy nowadays, of course. If experts for building services, building physics, structure and building management start their work later in the design process, when basic architectural decisions are already fixed, optimal solutions of integrated design are no longer possible.

Table 3.10: Comfort requirements and options of passive and active means to fulfill them

Comfort	*Passive measures*	*Actives measures*
Room temperature	Thermal insulation Thermal capacity	Cooling
Relative air humidity	Sorption of room surfaces Natural ventilation	Dehumidification / Humidification
Hygienic air quality	Natural ventilation	Mechanical ventilation
Brightness, illuminance	Daylighting	Artificial lighting

» *Central or distributed air conditioning?*

This decision influences the organization of shafts and ducts, the amount of necessary space for plants and air distribution and the energy demand for air conditioning.

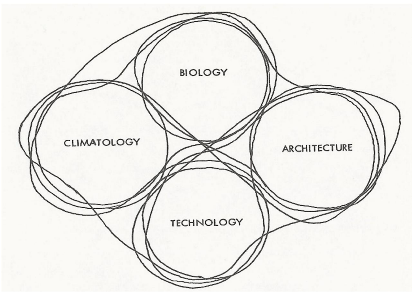


Figure 3.59: Interlocking fields of climate balance – *Source: Olgyay Victor: Design with climate. Princeton University Press, 1963*

Figure 3.60 shows design variations for central plants and a facade-integrated design with small, distributed air conditioning plants, which offers one or even two additional storeys of useful area. Many projects with facade-integrated AC have been realized so far. Facade elements with different functions can be integrated as plug-in elements, e.g. for AC, lighting, solar control, PV etc.

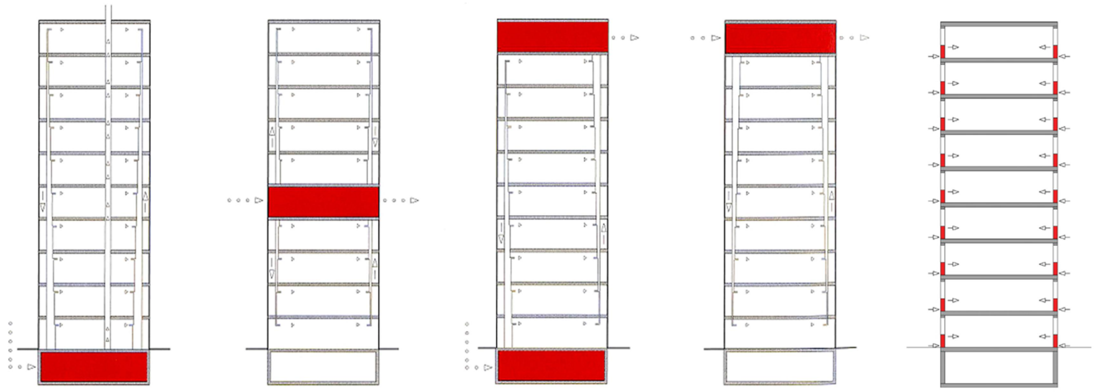


Figure 3.60: Vertical section of a high-rise building and space for central or distributed AC

Integration of building services and structure is a never ending story of modular, prefabricated and other building systems. Closed building systems including the whole building with all components had relatively short lifetimes, since they did not have the necessary flexibility to adjust to changing tasks quickly. On the other hand, smaller systems avoid the named disadvantages and offer perfect coordination of structural elements and building services, e.g. concrete slab systems with integration of pipes for the distribution of heating and cooling, ventilation shafts, electrical wiring and luminaires. The comprehensive concrete slab elements are prefabricated with high accuracy and mounted on site in high speed.

Figure 3.61: Capricorn office building in Düsseldorf, Germany, with facade integrated air conditioning. The complete technology for ventilation, heating, cooling and heat recovery is positioned in the 20 cm deep façade – *Source: Architects Gatermann und Schossig*

» *Thermal activation of building elements*

Thermally activated building elements like chilled ceilings, floors and walls are often applied in energy efficient cooling systems (compare chapter 3.3). The room surfaces are kept on a constant temperature by integrated water based systems. Sensitive cooling loads of 40 – 100 W/m² can be covered and the remaining latent cooling load for the hygienically necessary supply air is kept small. Because of the small air-change rates the AC system can be reduced in size. There is a great variety of water based chilling systems integrated in suspended metal ceilings, in the plaster of ceilings or walls or in the screed of floors. When the system is located in concrete slabs, their thermal capacity can be utilized for time phase shift, thus smoothing the peak loads.

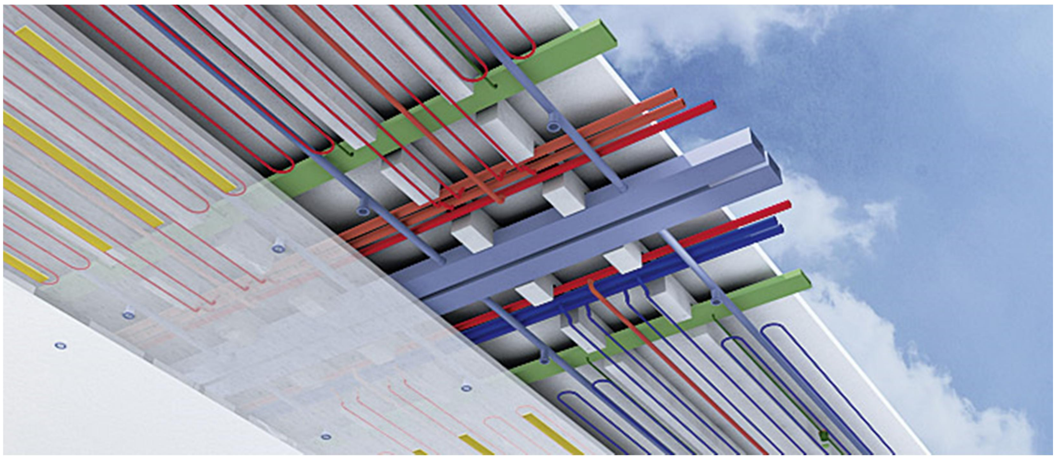


Figure 3.62: Example of integration of building services and slab, "Innogration" System – *Source: www.innogration.de/ceiltecr*

» *Recommendations of combined measures for climate zones in Nigeria*

For the boundary conditions of climate (hot & humid, hot & dry) and building type (housing, small and large office buildings) appropriate recommendations are given for:

- Bioclimatic design rules,
- Reqirements and
- Integration of passive and active measures.

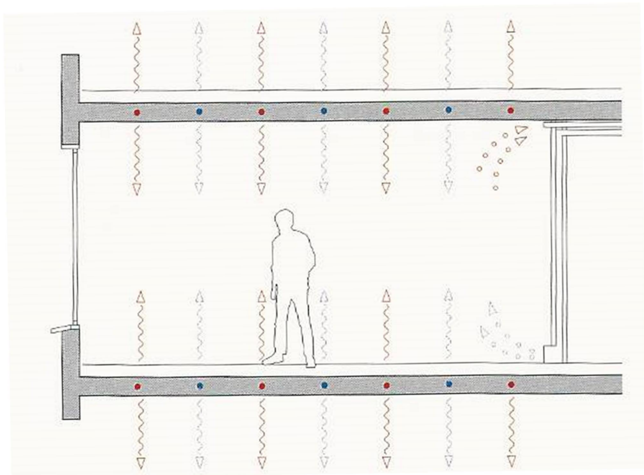


Figure 3.63: Thermally activated slab for cooling – *Source: Hegger et al.: Energy Manual.Birkhäuser, Basel, 2008*

Hot & humid climate (e.g. Port Harcourt)

Bioclimatic design rules:

- Reduction of solar and internal heat gains
- High average temperature limits passive cooling by night ventilation, earth ducts, thermal capacity
- Continuous demand for cooling and air dehumidification

Building type requirements:

- Housing with natural ventilation, active cooling, solar hot water and PV (dependent on budget)
- Small offices similar to housing, no solar hot water, improved lighting
- Large offices with air conditioning and air tight envelope

Passive measures:

- Window orientation (N, S), glazing percentage (≤ 30 %), shading devices and solar protective glazing with high light transmission

- Envelope with high solar reflectivity and insulation against solar heat transfer (especially roofs and east-/ west walls)
- Natural ventilation for buildings without air conditioning (cooling plus air dehumidification)
- Daylighting combined with solar and glare control (solar lighting)
- Active measures:Cooling by split units (natural ventilation possible)
- Central or decentral air conditioning (cooling plus dehumidification). Airtight envelope to avoid dew pointproblems. Cold recovery
- AC is applied for the fresh air rate only, while the remaining cooling demand is provided by water based systems (cooling convectors, ceilings). For air dehumidification desiccant cooling systems are recommended
- Renewable energies (solar thermal, biomass) can be applied for thermal cooling systems (absorption cooling or combined cooling, heat and power) and for hot water systems
- LED lighting, automatic control for offices, presence and daylight related.

Hot & dry climate (e.g. Kano)

Bioclimatic design rules:

- Reduction of solar and internal heat gains
- Daily and annual temperature differences to be utilized for passive cooling (night ventilation, earth ducts, thermal capacity)
- Temporary demand for cooling and air humidification

Building type requirements:

- Housing with natural ventilation, passive cooling, solar hot water. Temporary active cooling. Renewable energies (PV, solar thermal)
- Small offices similar to housing, no solar hot water, improved lighting
- Large offices with temporary cooling, air humidification, PV

Passive measures:

- Window orientation (N, S), glazing percentage (≤ 30 %), shading devices and solar protective glazing with high light transmission
- Envelope with high solar reflectivity and insulation against solar heat transfer (especially roofs and east-/ west walls)
- Natural ventilation combined with passive cooling strategy (night ventilation, thermal capacity, earth ducts, evaporative cooling)
- Daylighting combined with solar and glare control (solar lighting)

Active measures:

- Temporary active cooling by air or water based systems (low dew point for dry air)
- Evaporative (adiabatic) cooling combined with air humidification
- Coincidence of high cooling demand and high insolation is in favour of solar cooling: PV for compression cooling or solar thermal systems for absorption cooling (hot water in addition)

- Cooling towers and recooling in combination with low night temperatures
- LED lighting, automatic control for offices, presence and daylight related.

» *Case studies*

The BEEG demonstrates the potential of energy efficiency by passive and active measures in comparison to "buildings as usual" in four case studies. The conventional electricity demand is given in chapter 4.1 of this Handbook. They consider different buildings types (housing and offices, small and large), the main two climates (hot & humid and hot & dry), thermal comfort and, last not least, the aspect of financial affordability. There is an additional capital need for energy efficiency but the operation costs for energy are reduced, thus the the overall life cycle costs can be reduced as well. The key findings are shortly describedin the table below:

Table 3.11: A comparison to demonstration of potential of energy efficiency by passive and active measures

Building type	Floor area	Cooling type	Typical specific cost	Remarks
Bungalow	200 m²	no AC, passive	125,000 NGN/m²	Largest energy saving by energy efficient lighting. Passive measures especially in hot & dry climate (ventilated roof with insulation, window orientation N/S, shading, double glazing and insulation of external walls, solar thermal panels for DHW). Energy savings 31 - 37 kWh/ (m²a), (56 – 69 %). Additional capital needs 6% – 13%, simple payback period 1 year. 50 m² PV panels cover approximately the entire electricity demand. Additional capital needs 35%, payback period 15 years.
Apartment building	1,200 m²	no AC, passive	145,000 NGN/m²	Energy efficient lighting, solar thermal panels for DHW. Passive measures as above. Energy savings 51 – 63 kWh/(m²a), (52 – 64%). Additional capital needs 6% – 8%, simple payback period 1 year. 125 m² PV panels cover approximately 90% electricity demand. Additional capital need 16%, payback period 4 years
Small office building	800 m²	VAC	185,000 NGN/m²	Passive measures and higher VAC system efficiency have contributed to overall energy reduction especially in hot & humid climates. Energy savings 108 – 169 kWh/ (m²a), (40 – 59 %). Additional capital needs 4% – 9%, simple payback period 2 -3 years. PV integration in the roof is well-suited in this typology. 150 m² PV panels cover approximately 70 – 73% electricity demand. Additional capital need 20%, payback period 5 years
Large office building	7,400 m²	VAC	265,000 NGN/m²	Passive measures and higher VAC system efficiency have contribute to overall energy reduction Energy savings 105 – 223 kWh/(m²a), (36 – 76 %). Additional capital needs 2% – 3%, simple payback period 0.5 - 1.1 years. 500 m² PV panels cover approximately 79 – 82% electricity demand. Additional capital needs 6%, payback period 2 years.

Bungalow, 200 m², no AC, building cost 125,000 NGN/m²

Since there is no cooling, the largest energy saving is achieved by replacing conventional lighting with high energy efficient lighting, which is the same for both climate zones. Hours within thermal comfort (ASHRAE 50) improves dramatically with passive measures, especially in hot & dry climate (naturally ventilated metal roof with mineral fiber insulation, window orientation N/S, shading, double glazing and insulation of external walls, solar thermal panels for DHW). Energy savings 31 - 37 kWh/(m²a), (56 – 69%). Additional capital needs 6% – 13%, simple payback period 1 year. 50 m² PV panels cover approximately the entire electricity demand. Additional capital needs 35%, payback period 15 years.

Apartment building, 1,200 m², no AC, building cost 145,000 NGN/m²

Since there is no cooling, the largest energy saving is achieved by replacing conventional lighting with high energy efficient lighting, which is the same for both climate zones. A significant reduction in electricity for appliances is observed when more efficient systems are introduced. Electricity for domestic hot water (DHW) can be reduced by two thirds by a solar thermal system. Hours within thermal comfort (ASHRAE 50) improves dramatically with passive measures, especially in hot & dry climate. Energy savings 51 – 63 kWh/(m²a), (52 – 64%). Additional capital needs 6% – 8%, simple payback period 1 year. 125 m² PV panels cover approximately 90% electricity demand. Additional capital needs 16%, payback period 4 years.

Small office building, 800 m², VAC, building cost 185,000 NGN/m²

Passive measures and higher VAC system efficiency have the largest contribution in overall energy reduction since they affect cooling which is the main electric load. There is a slightly bigger reduction in hot & humid climates given the higher amount of annual operating hours for AC. Energy savings 108– 169 kWh/(m²a), (40 – 59%). Additional capital needs 4% – 9%, simple payback period 2 -3 years. PV integration in the roof is a well suited technology to offset non-renewable energy consumption in this building typology. 150 m² PV panels cover approximately 70 – 73% electricity demand. Additional capital needs 20%, payback period 5 years.

Large office building, 7,400 m², VAC, building cost 265,000 NGN/m2

Passive measures and higher VAC systems efficiency have the largest contribution in overall energy reduction since they affect cooling, which is the main electric load. Energy savings 105 – 223 kWh/ (m²a), (36 – 76%). Additional capital needs 2% – 3%, simple payback period 0.5 -1.1 years. 500 m² PV panels cover approximately 79 – 82% electricity demand. Additional capital needs 6%, payback period 2 years.

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4. ENERGY SUPPLY

What this module is about

After having minimized the building energy demand for electricity and hot water, the most efficient way of energy supply has to be found. Types of grid supply and back-up systems are described as well as renewable energies, which do not contribute to global warming.

Learning outcomes

At the end of this module, the participant is able to

- Assess the availability of energy sources
- Integrate energy supply, especially renewable energy technologies, in the building design

4.1. ENERGY SUPPLY AND DEMAND

There is a clear hierarchy in the process of reducing energy supply and demand of buildings; the higher priority is given to energy demand, depending on passive and active means of realizing comfort. Once the demand is minimized, efficient solutions for energy supply are developed. They avoid wasting energy in generation and transmission, even if it comes from low carbon sources. Low carbon energy supply should only be considered once the strategies for demand reduction have been maximized.

TYPICAL ENERGY DEMANDS

» Groups of energy consumers

The energy demand of buildings generally is broken down in the following users:

- Lighting
- Space cooling and ventilating
- Hot water
- Cooking
- All electrical appliances.

The energy demand for the first three groups of users is often fixed by building regulations. The last two groups of emissions are not regulated and therefore difficult to estimate. Generally about 75% of all electricity consumed in dwellings is for unregulated energy use. The following methods can be used to estimate the energy demand:

- Calculating the energy demand for cooling, ventilation, lighting and hot water by thumb rules or more accurate simulation tools
- Use existing energy bills of comparable and known buildings or good practice's benchmarks. Table 4.1 gives an example.

Typical energy demand benchmarks for residential and office buildings in Nigeria are given in the Building Energy Efficiency Guide for Nigeria. The following electricity consumption is given there fore"building as usual"- case studies for the two climate zones Hot and Humid (H&H) and Hot and Dry (H&D):

- Bungalow (200 m², no AC): 132 kWh/(m²a) for lighting, appliances and DHW
- Multi apt block (1,200 m², no AC): 96 kWh/(m²a) for lighting, appliances and DHW

- Small office (800 m², VAC): 270 kWh/(m²a) for H&H, 286 kWh/(m²a) for H&D
- Large office (7,400 m², VAC): 292 kWh/(m²a) for H&H, 290 kWh/(m²a) for H&D

» ***Building types***

Table 4.1: Approximate final building energy demand benchmarks in kWh/m²a

Building typology	*Ventilation, cooling*	*Lighting*	*Hot water*	*Cooking, catering*	*Electrical appliances*	*Total energy demand*
Dwelling, natural ventilation	0	10	55	15	25	105
Low-energy dwelling	200	10	55	15	25	305
'Passive house' dwelling	40	10	30	15	25	120
Office naturally ventilated	0	25		3	24	52
Office air-conditioned	400	25		5	44	474
Any building "Passive house"	75	Combined to be within 45				120

Potential reductions of energy consumption by passive and active measures are described in chapter 3.4.

Different forms of energy demand are defined as follows:

- **Net energy**: The demand of energy to keep a building on set-point temperatures and 100% efficiency assumed for the active building services;
- **Final energy**: The energy demand that is supplied to the consumer for all final energy uses like cooling, ventilating, and lighting, including the efficiencies of all active means and services;
- **Primary energy**: The total energy demand including losses of energy carriers from power generation (for example from oil or gas into electricity) and distribution, and the final demand by end users.
- The **primary energy factor** is defined as the ratio between primary energy and final energy. The lower the primary energy factor, the more resource saving and the more efficient the source of energy. According to European Directive 2002/92/EG (EPBD) the factors are defined in national standards.

[1] Passive house refers to a widely used German energy label. It is a voluntary label with stringent energy requirements; it requires keeping the overall energy consumption of a building below 120 kilowatt-hours per square meter per year – this is around one-third of energy demand in the average household in the United States and almost half of energy demand in the average household in the European Union. The passive house label was originally used only for residential buildings but is increasingly used also for non-residential buildings, such as office buildings and schools.

EFFICIENT AND SUSTAINABLE SUPPLY OF ENERGY

Energy efficient building design includes the selection of the most efficient energy supply. The efficiency of different energy carriers and supply systems can be assessed by primary energy factors or by CO_2 intensity.

CO_2 intensity is a characteristic to define the carbon impact of final energy in kgCO_2/kWh. Depending on the regional energy mix used for generation electricity, e.g., the CO_2 intensity will vary significantly. Table 4.2 gives an overview for grid electricity in different countries. Countries using a high proportion of renewable energies for power generation, e.g. hydro power in Norway, have a much lower CO_2 intensity than countries using mainly coal, e.g. South Africa.

Table 4.2: CO_2 intensity of grid electricity in different countries – *Source: Pelsmakers, Sofie: The Environmental Design Handbook. RIBA Publishing, London (2015)*

Europe	*Electricity kgCO_2 per kWh **	*Outside Europe*	*Electricity kgCO_2 per kWh **
Austria	0.227	Australia **	0.875
Belgium	0.206	Brazil	0.081
Denmark	0.339	Canada	0.178
Finland	0.197	China	0.817
France	0.065	India	1.102
Germany	0.501	Hong Kong	0.866
Greece	0.759	Indonesia	0.834
Italy	0.430	Japan	0.427
Iceland	0.00019	Malaysia	0.741
Ireland	0.462	Mexico	0.541
Netherlands	0.421	New Zealand	0.152
Norway	0.014	Pakistan	0.495
Poland	0.848	Saudi Arabia	0.838
Portugal	0.329	South Africa	0.961
Spain	0.323	South Korea	0.565
Sweden	0.018	Turkey	0.555
Switzerland	0.032	USA	0.537

*Figures include the emissions associated with the transmission and distribution of electricity to the grid
** CO_2 fuel intensity can differ significantly across regions, even in the same country. For example, in Australia, the CO_2 fuel intensity can vary by a factor of almost six

For Nigeria the CO_2 intensity of grid electricity is 0.44 according to BEEG. For many countries, the public electricity grid will be a suitable supply system. In Nigeria however, the public electric grid is so highly unreliable and diesel driven generators are a significant source of energy (40% according to BEEG), especially for commercial and industrial buildings, causing high operating costs and CO_2 emissions. Renewable sources, e.g. wind and/or photovoltaics with batteries or biodiesel generators, could be used for back-up and assisting energy supply for peak demands as well. Depending on the legislation and utility contracts, excess electricity from renewables, which cannot be consumed, may be supplied to the grid and are paid at a cost-based price for the renewable electricity. Pertaining regulagtion has been proposed in Nigeria but is yet to be operationalised.

For projects in regions without grid connection or for large projects an independent local energy supply can be chosen. Micro-grids have, in comparison to public grids, smaller transmission losses and the supply security can be higher. In contrast to the national grid, not every user is affected when part of the grid needs to be repaired. Beside the traditional energy sources low carbon energies can be applied, e.g. hydro, bio, wind, and solar energy. In high density areas, cogeneration of power and cold can be applied with a separate district system for cold storage and distribution.

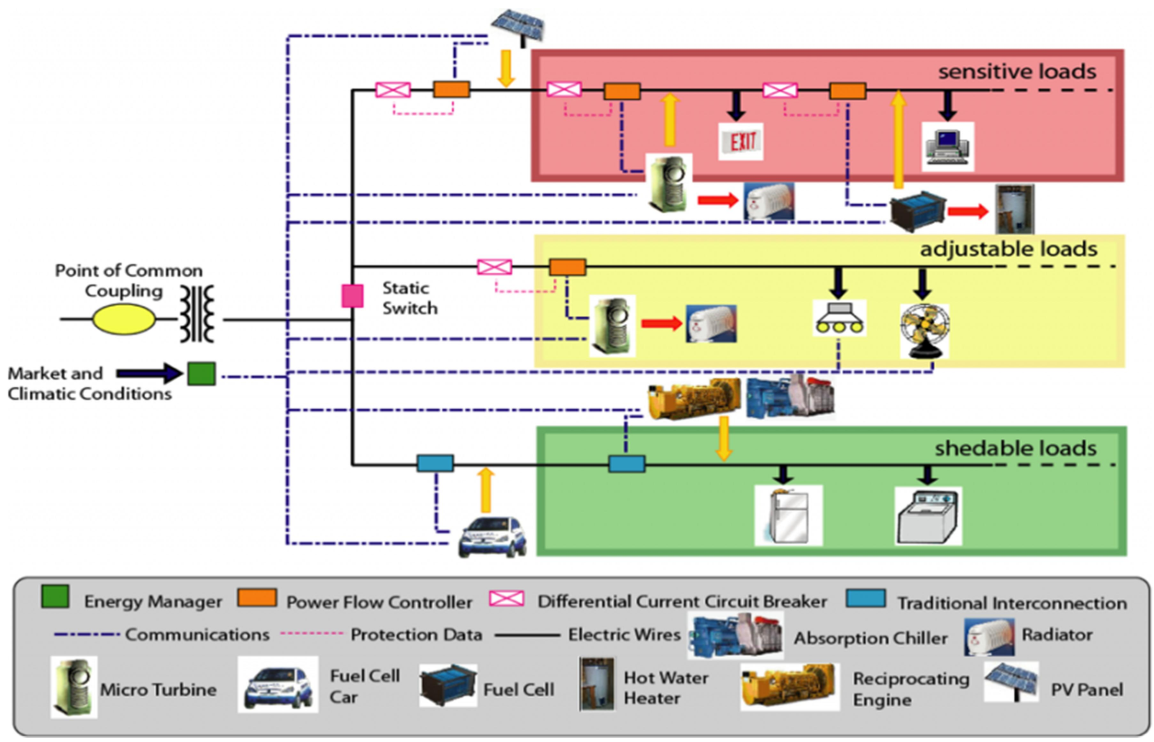


Figure 4.1: CERT Microgrid Schematic – *Source: **https://building-microgrid.lbl.gov/about-microgrids***

A microgrid is a localized grouping of electricity sources and loads that normally operates connected to and synchronous with the traditional centralized grid (macro-grid), but can disconnect and function autonomously (island) as physical and/or economic conditions dictate. A formal definition from the Conseil International des Grands Réseaux Électriques or (CIGRÉ) states: "Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded." Many microgrids will involve a combination of resources, sometimes a quite complex one. They can be powered by distributed generators, batteries, and/or renewable resources like solar panels. A microgrid is a locally controlled system and it can function both connected to the traditional grid (megagrid) or as an electrical island. In rural regions without net connection the microgrid can be the only grid connecting power sources and users.

4.2. RENEWABLE ENERGY AND COMBINED COOLING, HEAT AND POWER (CCHP)

AVAILABILITY AND DECISION MAKING

The annual CO_2 emission per capita of Nigeria, with approximately 0.5 t/person, is relatively low in comparison to other countries (US 20 t/p, EU 10 t/p), but it will increase due to economical and industrial development in the near future and contribute to the climate change. A reliable energy supply will not only support the economic development, but will reduce CO_2 emissions as well. A huge number of back-up diesel generators are currently used in Africa, with Nigeria being the largest importer of diesel generators with an estimated 9 million units in use. A 2015 study of GIZ suggests that agrregate diesel generator capacity installed ranges between 8 and 14 GW, well in excess of Nigeria's operationl power generation capacity. They are estimated to produce about 29 million metric tons of CO_2 each year, which could be reduced by 63% if standard power stations were used instead. By application of renewable energies, the climate protection would even be much higher and a technologically advanced, forward-looking development would start in the power sector.

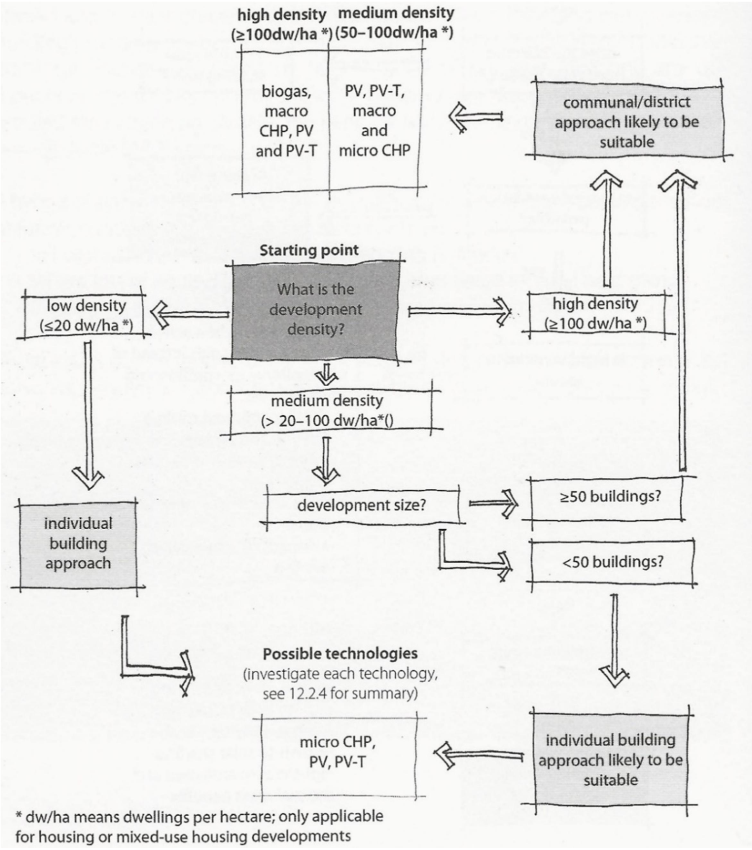


Figure 4.2: Renewable energy decision-making matrix: Electricity – *Source: Pelsmakers, Sofie: The Environmental Design Handbook. RIBA Publishing, London (2015)*

Renewable energy decision-making is part of the integrated design process, for energy efficient building design, and depends on the kind and size of project and the demand for electricity, cooling and heating energy. Additionally, it is important to understand the site location's constraints, and how these affect the suitability of different low-carbon technologies. In particular, the scale and densities of the development must be taken into account, e.g. how many dwellings per hectare (dw/ha). See.

» Local resources

In tropical countries like Nigeria, the relatively high availability of solar radiation is in favour of photovoltaic **solar energy**. Figure 4.3 gives a survey of the annual solar radiation on a horizontal surface; Nigeria receives 1,600 – 2,200 kWh/m² annualy. The maximum radiation flux is approximately 1,000 W/m².

The utilization of **wind energy** is in Nigeria is constrained. Wind turbines are to be placed where the wind is, requiring consistent average wind speeds of minimum 5.5 – 6.0 m/s. Such are found only in selected areas in the northern region and off-shore areas. In (sub) urban areas wind speeds usually are not high enough and too turbulent for an application of roof-mounted micro wind turbines. On high-rise buildings (> 45 m) and in rural areas an application of 1 – 2 kW wind turbines may be feasible but this options is fraught with difficuly of predicting yields, vibrations and noise (52 – 55 dB) apart from high turbulences. Before considering wind energy, it is important to collect a full year's on-site wind speed measurements.

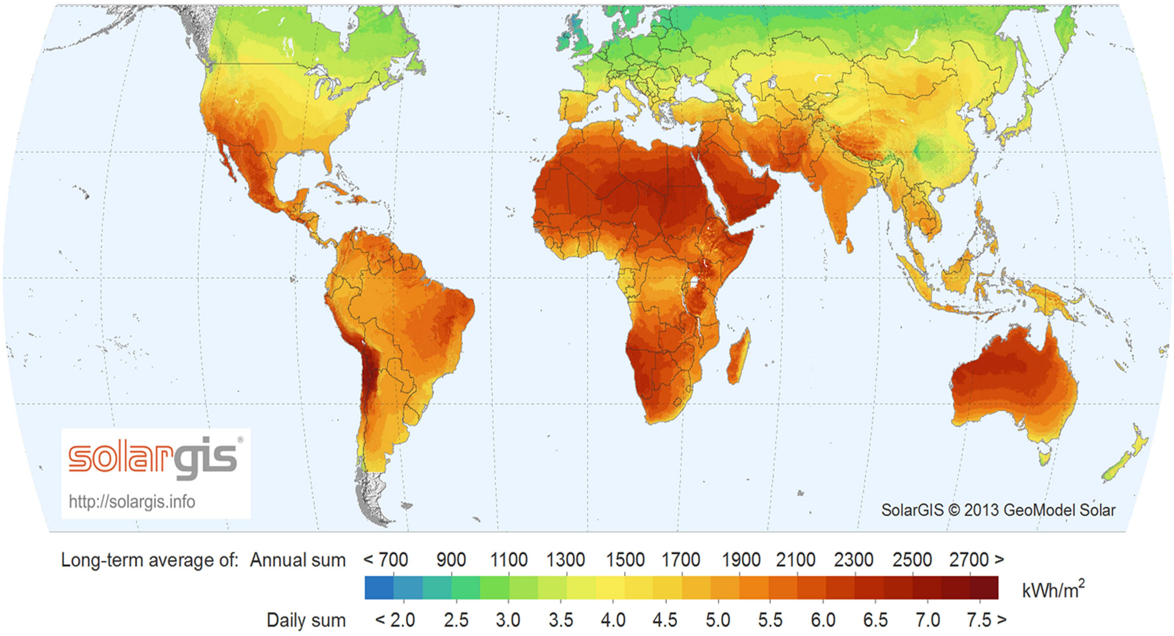


Figure 4.3: Solar radiation availability – *Source: By SolarGIS © 2013 GeoModel Solar, CC BY-SA 3.0*

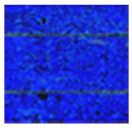
Shallow geothermal energy in a depth of 2 – 10 m could be used for cooling purposes. Horizontal or vertical heat exchangers in the ground are used as heat sinks for cooling plants. The efficiency is depending on the on the heat conductivity of the soil and on the ground temperature, which equals roughly the annual mean ambient temperature. In tropical climates with small seasonal and daily temperature differences the geothermal cooling effect is much smaller than in temperate climates.

PHOTOVOLTAICS

Solar radiation can be converted into electricity by photovoltaics (PV). A photovoltaic system is composed of solar cells, assembled to modules or solar panels, a converter and sometimes a battery amongst other components. The efficiency of the solar cells varies according to the type (Table 4.3). Thick-film cells are more efficient than thin film modules but more expensive. The efficiency is defined for a cell temperature of 25°C and will go down with rising temperatures. Thus, module temperatures should be kept low by good ventilation from both sides or by thermal utilization (PV-T).

» *Types of PV cells*

Table 4.3: Types of solar cells

Solar cell type		***Dimensions (mm)***	***Efficiency (%)***
	Monocrystalline silicon (thick-film)	156 x 156 125 x 125	14 – 20
	Polycrystalline silicon (thick-film)	156 x 156 125 x 125	15 – 18
	Amorphous silicon (thin-film)	576 x 976	6 – 9

A photovoltaic module or panel is a packaged, connected assembly of solar cells. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. Since 2011, factory-gate prices for crystalline-silicon photovoltaic modules dropped below the 1 USD/W mark. The 1 USD/W installed cost is often regarded in the PV industry as threshold point for the achievement of grid parity for PV. Technological advancements, manufacturing process improvements, and industry re-structuring, mean that further price reductions are likely in coming years. While modules with thick film cells are rigid, thin film cells offer flexibility and as such can be integrated into various materials.

A solar inverter, or converter or PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network.

» *Building integration of PV (BIPV)*

The integration of PV modules in the building envelope has many advantages, e.g. there is no land requirement, the energy source is close to the consumer, and the protection against external impact is relatively high. As solar tracking offers the highest amount of annual solar radiation on the module surface, it sometimes is used in combination with movable shading devices of glazed roofs or facades. But the standard solution is a fixed installation of modules because of reduced costs and maintenance.

The optimal orientation of fixed modules in Nigeria (geographical latitudes between 3° and 10°N) is south with a tilt of 9° (angle of inclination), i.e. nearly horizontal. As deviations of 10° to 20° do not reduce the annual solar harvest dramatically, an adaption to the building shape and roof tilt possible. For an accurate assessment a PV azimuth and altitude calculator should be used, e.g. which is combined with Google Earth and takes into account the shading by neighbouring buildings as well. Shading of modules should be avoided, even of small areas, as the wattage of the whole module array will be reduced by the shade unless parallel connection of the modules with by-pass diodes is used instead of series connection.

If the attachment of PV panels to the building follows functional requirements only, the harmony of the architectural design may be spoiled. Thus an architectural integration of the PV modules should be aimed at as well, following the shape and dimensions of the building. Figure 4.4 and 4.5 show examples of perfectly integrated PV roofs, using the PV panels as roofing material. The consequence is that the roof dimensions have to be adjusted to the standard module dimensions. The roof construction should allow good ventilation below the PV panels to keep the temperature of the solar cells low and the efficiency high. Alternative solutions mount the PV panels on top of a conventional roof with a distance of at least 10 cm for good ventilation.

Figure 4.4: Roof-integrated PV panels – *Source: images.google.com*

Figure 4.5: PV roof integration, UNEP building in Nairobi, Kenya

Figure 4.5 shows the largest PV plant in Africa (515 kW_P) with PV panels partly installed in a ventilated distance above the flat roof and partly integrated in the bent glazing of the arched roof. Glass modules with solar cells laminated between two glass panes fulfil the requirements of laminated security glass and allow for a balance of daylighting and control of solar heat gains.

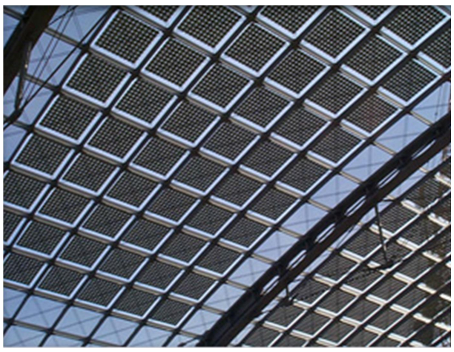


Figure 4.6: Roof integration of transparent PV modules .Central railway station, Ber-

» *Energy yield of photovoltaics*

There are various calculation tools for calculating the energy yield of PV plants can be approximated with the following equation. A detailed analysis is recommended but exceeds the scope if this manual:

E = A * r * H * PR

Where

E =	Energy (kWh/a)
A =	Total solar panel area (m^2)
r =	Solar panel yield factor/ efficiency
H =	Annual average solar radiation on tilted panels (shadings not included)
PR =	Performance ratio, coefficient for losses (range between 0.5 and 0.7, default value = 0.6)

In more detail,

r is the yield of the solar panel given by the ratio: Electrical power (in kW_P) of one solar panel divided by the area of one panel. Example: the solar panel yield of a PV module of 250 W_P with an area of 1.6 m^2 is 15.6%. Be aware that this nominal ratio is given for defined standard test conditions (STC). This can also be taken to be the efficiency of the solar panel used.

H for Nigeria approximately between 1,600 and 2,200 kWh/m^2a, depending on the region (see chapter 3.2 or solar radiation data. You have to find the global annual irradiation incident on your PV panels with your specific inclination (slope, tilt) and orientation (azimuth).

PR: Performance ratio) is a very important value to evaluate the quality of a photovoltaic installation because it gives the performance of the installation independently of the orientation, inclination of the panel. It includes all losses. Example of losses details that give the PR value (depending on the site, the technology, and sizing of the system):

- Inverter losses
- Temperature losses
- DC cables losses
- AC cables losses
- Losses due to shadings

» *Storage of PV generated electricity*

There can be different reasons for storing PV generated electricity:

- Energy independence in island solutions (off-grid) with solar PV, electricity storage and
- other energies sources
- High energy independence by installing enough solar PV and battery storage to get through the average day and night without having to rely on the electricity grid (even though you may have access to it). The grid can still be used as a backup if there is a multi-day spate of bad weather.

- Peak time independence by installing a system large enough to cover electricity usage when grid electricity is most expensive
- Reduced grid reliance during peak times
- Energy storage as emergency backup by installing a small energy storage system to be used mainly in the event of a short power outage.

Depending on the situation and on the boundary conditions, the size of PV plant and storage has to be optimized as to economy. There are different electricity storage and battery systems on the market, e.g. lead-acid batteries or lithium-ion batteries recently offered as 7 kWh and 10 kWh storage units by Tesla. In the near future electrical cars may be used as storage for surplus PV power. Alternatively, an indirect storage of PV electricity can be realized by hydrogen technology. Hydrogen is generated by electrolysis, cooled and stored in a pressurized container.

SOLAR THERMAL SYSTEMS (ST)

In Nigeria, all year round availability of solar energy, leads to favourable opportunities for solar thermal technology including: Domestic hot water systems (DHW) of 50 – 60°C or even process heat of 60 – 150°C for thermal cooling and industry applications. Low electricity prices however have not made the adoption of this technically commercially viable and electrical heaters are still favoured across the country.

Solar collectors convert solar radiation into heat by absorbers. Solar thermal systems are designed to deliver, in combination with a storage tank, a high percentage of the overall heat demand (e.g. 50 – 70% for DHW). A back up system operated by electricity or gas delivers the remaining demand. The required temperature level and efficiency is dependent on the type of collector.

The optimal orientation of solar thermal collectors in Nigeria (geographical latitudes between 3° and 10°N) is south with a tilt of 9° (angle of inclination), i.e. nearly horizontal. Small deviations will not reduce the annual solar yield dramatically. For an accurate assessment an azimuth and altitude calculator should be used, e.g. which is combined with Google Earth and takes into account the shading by neighbour buildings as well.

» *Type of collectors*

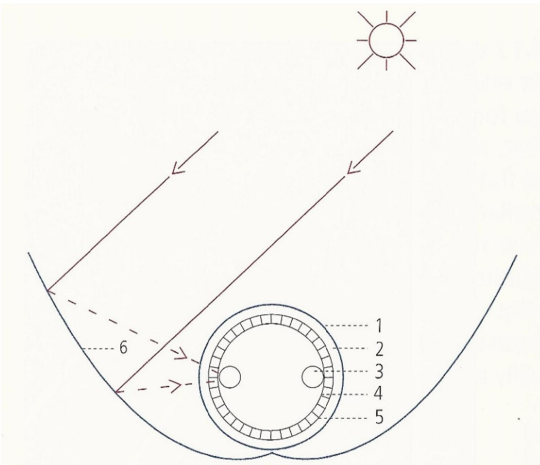


Figure 4.7: CPC Collector, focusing direct radiation on vacuum tube

Flat plate collectors are used for domestic hot water systems. The absorber plates, connected to a pipework system, are fitted into a well-insulated housing with a glass cover. A heat transfer medium, normally water, is moving through the pipework. The collectors can achieve temperatures of about 50°C and efficiencies if about 50 – 60%. Metals like copper or aluminium are normally used as absorber materials and are given special coatings to maximize the solar absorption and prevent radiation heat losses. Anti-reflective glass can be used to cover the collectors, increasing the transmission of solar radiation to between 90 – 95%. Flat panel collectors are also available in form of vacuum panels. The vacuum inside the collector reduces the heat losses due to convection.

Vacuum tube collectors offer improved efficiencies and higher temperatures. The evacuated glass tubes contain absorber strips. The vacuum keeps the ideal thermal separation and keeps convection heat losses to a minimum. The vacuum tube is connected at the end to a manifold and from there the solar energy is carried by heat transfer medium to the thermal store. A dry connection by a heat pipe can enable damaged vacuum tubes to be replaced even whilst the system is running. Vacuum tube collectors can achieve temperatures of about 100°C and are particular suitable for cooling and process energy. Compound parabolic concentrators (**CPC collectors**) can further increase the temperature of vacuum tube collectors. These reflectors concentrate the direct sun irradiation on the absorption surface (Figure 4.7). Temperatures of approximately 100 – 150 °C can be achieved. The reflectors increase the collector area slightly in comparison to standard vacuum tube collectors.

» *Heat storage*

A typical solution for domestic hot water by roof-mounted solar thermal systems is close-coupled thermosiphon solar water heaters. No pumping is required as the hot water naturally rises into the tank through thermosiphon flow. In a 'pump-circulated' system the storage tank is ground- or floor-mounted and is below the level of the collectors; a circulating pump moves water or heat transfer fluid between the tank and the collectors.

Figure 4.8: Roof mounted flat plate collector with close-coupled thermosiphon heat storage

1. Transparent window tube
2. Vacuum
3. Fluid U-tubes
4. Heat transfer fin
5. Selectively coated absorber tube6 Concentrating reflector CPC

» *Dimensioning*

For DHW the collector surface is 0.6 to 1.0 m²/person of flat plate collectors and 0.4 to 0.8 m² for vacuum tube collectors. The annual yield of hot water Q_{th} [kWh/a] is calculated as follows:

$$Q_{th} = A_K * (R_K / 100) * (R_V / 100) * I_S$$

Where:

A_K =	Absorber area [m²]
R_K =	Collector efficiency
R_V =	Coefficient for transfer losses, approximately 95%
I_S =	Annual solar radiation [kWh/m²]

BIOMASS

» *Forms and utilization*

Biomass is fuel derived from burning or gasification of trees or plants which have absorbed CO_2 during their lifetime. When timber burns or rots, this carbon is released back into the atmosphere. Hence, timber is best used as a building material, keeping the CO_2 locked in for decades if not centuries. For CO_2-neutral energy generation biomass is appropriate as well: Waste wood or agricultural waste can be used directly or indirectly as fuel. This biomass should come as waste from a sustainable woodland or agricultural management and not from deforestation or agricultural food.

Biomass is used in different forms:

1. Wood cuttings, chips or pellets to be burned in boilers of combined cooling, heat and power (CCHP) plants. Presently it's mainly used for cooking and hot water.
2. Biogas (mainly methane) can be won from waste disposals/landfills or be produced by
   anaerobic digestion, i.e. fermentation, of bio-waste. There are different ways of utilization:
   a. Power generation
   b. Combined cooling, heat and power (CCHP), injection of biogas in public or micro gas-grid, or
   c. Compression and bottling.

Although Nigeria has an abundance of biomass, energy use has not been commercialised yet and most attempts have been limited to either R&D or demonrtation plants.

» *Biogas plants*

The size of the biogas plant depends on the quantity, quality and kind of available biomass and on the digesting temperature. 2 m³ biomass per day will generate 2,000 l biogas per day. The capacities of larger digesters range from 10 m³/d to 10,000 m³/d. The following points should be considered:

- The gas demand can be defined on the basis of previously consumed energy. For example, 1 kg firewood then corresponds to 200 l biogas, 1 kg dried cow dung corresponds to 100 l biogas and 1 kg charcoal corresponds to 500 l biogas.
- The gas demand can also be defined using the daily cooking times. The gas consumption per person and meal lies between 150 and 300 l biogas. For 1 l water to be cooked 30 – 40 l biogas, for 1/2 kg rice 120 – 140 l and for 1/2 kg legumes 160 – 190 l are required.
- The size of the digester, i.e. the digester volume V_d, is determined on the basis of the chosen retention time RT and the daily substrate input quantity S_d.
- $V_d = S_d * RT$ [$m^3 = m^3/day \times$ number of days]
- The retention time, in turn, is determined by the chosen/given digesting temperature. There are unheated and heated (38°C and 50°C) digesters. Practical experiences with plants of simple design show retention times of 40 – 80 days.

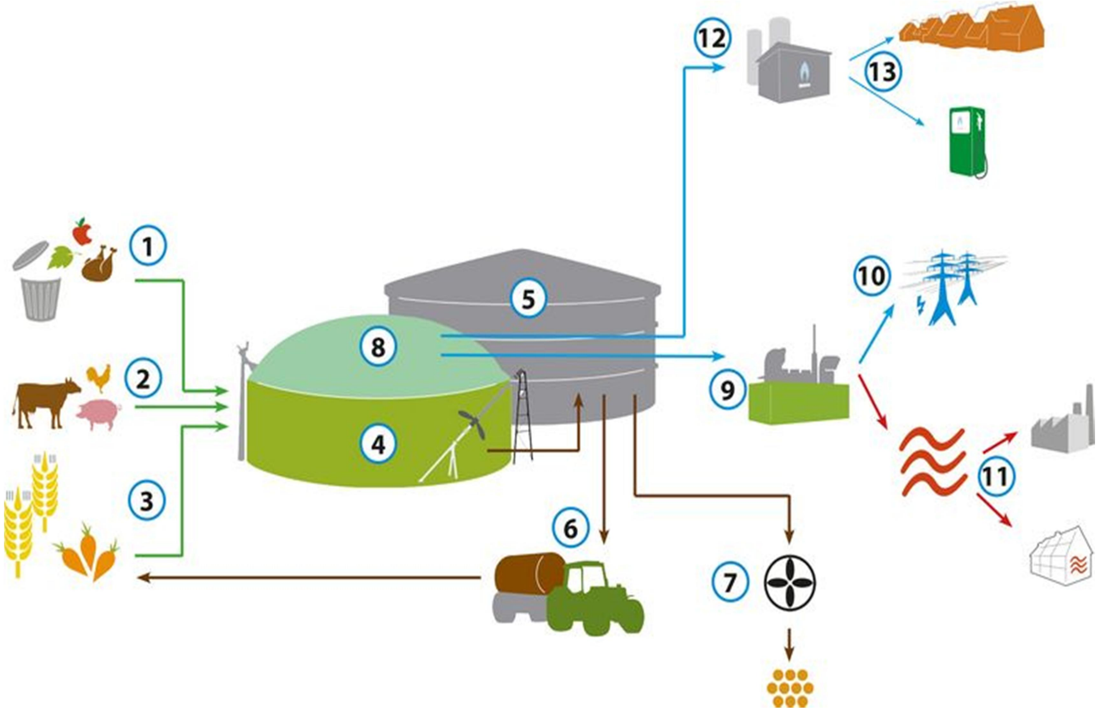


Figure 4.9: Schematic of a biogas plant - *Source: www.weltec-biopower.com/How-does-a-biogas-plant-work.1080.0.html*

Figure 4.9 above depicts a full cycle for biogas generation from all sources that may be available. It is fully explained below:

Step	*Meaning*
1, 2, 3	Organic input materials such as foodstuff remnants, agricultural waste, manure and dung
4	Fermenter/digester, heated to approx. 38 – 40°C, the substrate is decomposed by micro-organisms under exclusion of light and oxygen. The final product of this process is biogas with methane as the main ingredient and hydrogen sulfide, which can be aggressive for certain materials of the digester.
5	Once the substrate has been fermented, it is transported to the fermentation residues end storage tank and can be retrieved from there for further utilization as
6,7	High quality fertilizer or dry fertilizer.
8	The biogas generated is stored in the roof of the tank and from there it.
9	Is burned to generate electricity or to generate electricity, heat and cold in the combined cooling, heat, power plant (CCHP).
10	The electric power is fed directly into the power grid.
11	The heat generated can be utilized for thermal cooling or drying harvest products.
12	Processing of biogas; grid injection or
13	Gas supply to the national grid or gas filling stations.

COMBINED COOLING HEAT AND POWER (CCHP)

» Trigeneration process

Combined cooling, heat and power (CCHP) or trigeneration is the process by which power and heat are produced by a cogeneration plant and the heat is used to generate chilled water for air conditioning or refrigeration. Cogeneration is a thermodynamically efficient use of fuel (efficiency of up to 80% in some cases). In separate production of electricity, some energy must be discarded as waste heat, but in cogeneration some of this thermal energy is put to use. All thermal power plants emit heat during electricity generation, which can be released into the natural environment or captured and utilized. The heat is used close to the plant, or – especially in temperate and cold climates – distributed by a hot water grid for district heating and sometimes cooling as well with temperatures ranging from approximately 80 – 130°C.

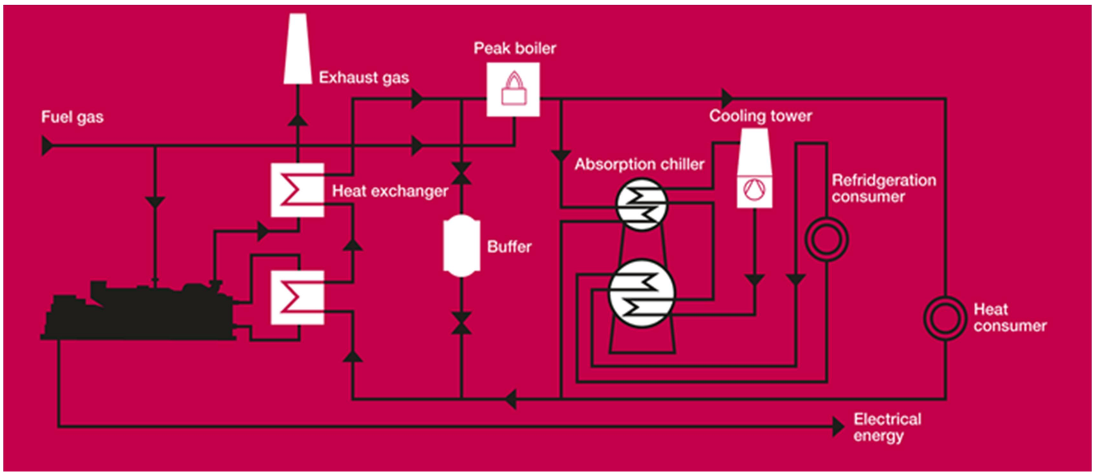


Figure 4.10: Schematic trigeneration of cold, heat and power (CCHP) – *Source: https://www.clarke-energy.com/gas-engines/trigeneration/*

At smaller scales of power generation (typically below 1 MW) a gas- or diesel engine may be used, preferably fired by renewable energies like biogas, biofuel or biomass. Trigeneration differs from cogeneration in that the waste heat is used for both heating and cooling, typically in an absorption refrigerator. CCHP systems can attain higher overall efficiencies than cogeneration or traditional power plants (thermal efficiencies above 80%) and advanced absorption chillers for CHPC or solar cooling with increased energy and cost efficiency were developed.

In comparison with conventional power stations with efficiencies of about 33%, typical trigeneration is much more efficient as the waste heat is utilized. The energy distribution below is represented in percent of total input energy:

- Electricity = 45%
- Heat and cooling = 40%
- Heat losses = 13%
- Electrical line losses = 2%.

» *Small and micro CCHP*

Distributed small CCHP plants are an example of decentralized energy supply. Trigeneration has its greatest benefits when scaled to fit buildings or complexes of buildings where electricity, heating and cooling are perpetually needed. Such installations include but are not limited to: Data centers, manufacturing facilities, universities, hospitals, military complexes and colleges. Localized trigeneration has additional benefits as described by distributed generation. Redundancy of power in mission-critical applications, lower power usage costs and the ability to sell electrical power back to the local utility are a few of the major benefits. Even for small buildings such as individual family homes, trigeneration systems provide benefits over cogeneration because of increased energy utilization. This increased efficiency can also provide significant reductions of greenhouse gas emissions, particularly for new communities.

Micro combined heat and power or '**micro cogeneration'** is a so-called distributed energy resource (DER). The installation size is usually less than 5 kW_e in a house or small business. The electricity can be used within the home or business and serves as back-up for grid outages. If permitted, it could be sold into the electric power grid. Heat can be used for hot water as well as absorption cooling. The development of small-scale CCHP systems has provided the opportunity for in-house power backup of residential-scale photovoltaic (PV) arrays.

FURTHER READING

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