GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 12 NO. 4 2006 : 553 - 558
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# BIOCLIMATIC DESIGN OF THE HABITAT IN TROPICAL CLIMATE: CASE OF COTE D'IVOIRE

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(Received 20 May, 2005; Revision Accepted 18 April, 2006)

**ABSTRACT**

This paper presents the methodology, data and results of the study of thermal comfort in the principal regions of Côte d'Ivoire. Analyses have been done on the measured climatic data to obtain physical building design specifications for climatic conditions found in these regions. The main aim is to come up with technical design criteria that would improve thermal performance, energy efficiency and comfort level within the built environment. The analysis consists of plotting temperature and humidity data in the Givoni's building bioclimatic chart (Givoni, 1992), and then identifying comfort strategies. Mahoney tables (Huet, et al., 1986) are used to give recommended criteria for building design. Results and corrective measures for each region are described in this paper.

**KEYWORDS:** Thermal comfort, Bioclimatic chart, Temperature, Humidity, Building design.

## INTRODUCTION

The fast development of the real parks, in the absence of energy conservation regulations and of a control of the recurring loads of exploitation and maintenance, is today at the base of enormous bills for certain countries. Indeed, the exploitation of the buildings of the tertiary and residential sectors in West Africa consumes approximately thirty percent (30%) (Bodou, 1998) of total electricity. Moreover, this energy of thermal origin contributes to disturbances of a climatic nature, by releasing certain greenhouse gases in the atmosphere. A bioclimatic design of the habitat can contribute to the reduction of the electric power consumption and to the stabilization of the atmosphere.

Even with the great wealth of knowledge about passive cooling or climate design, much of detailed thermal performance and interaction of our current buildings are not clearly understood. Moreover, most of the thermal standards accepted for mechanical air conditioned buildings have been found inappropriate for passive cooling buildings requirements. Designers or builders have lost touch with local environment, and so design with regard for climate. The present work is intended to highlight some of the basic issues and relationship between building and climate, and provide technical recommendations for better bioclimatic design improving thermal performance and energy efficiency of buildings. Many studies have been undertaken about bioclimatic analysis of building design in the specific climate of given country. Krüger et all (Krüger, et al., 2003) have recently developed a bioclimatic analysis of low cost houses in Brazil by plotting temperature and humidity data in the psychometric chart and therefore identifying comfort strategies. Kefa et all (Kefa, et al., 2003) have developed pre-design guidelines in Kenya that are useful in equatorial climates. The work of Tamakan (Tamakan, 2001) led to guidelines for bioclimatic buildings in North Cyprus. The specific case of Côte d'Ivoire is developed in this paper.

An analysis of the climatic data (for 10 year period), based on the traditional tools such as the Givoni bioclimatic chart (Givoni, 1992) and the tables of Mahoney (Huet, et al., 1986), is carried out to find an architectural response in the bioclimatic design of the buildings in Côte d'Ivoire. The analysis is carried out starting from the climatic data (temperature, humidity, and wind speed) for the various climatic zones of Côte d'Ivoire. (South, Centre, and North). The data used here were obtained from the Côte d'Ivoire meteorological department (SEKA, 2001). What is done is that the climate of a given location is analysed in its own terms, the analysis would lead to certain architectural response types, and finally to the selection of appropriate passive cooling control strategies.

### Climatic data and bioclimatic charts

The analysis of climatic data for a bioclimatic design of the habitat required the annual evolutions of the principal climatic factors affecting human comfort and the thermal performance of the buildings in various forms, such as the monthly variations of the local temperature, humidity, the wind speed, etc.; and also bioclimatic charts.

The bioclimatic charts facilitate the analysis of the climatic characteristics of a given locality, from the point of view of human comfort, because they make it possible to visualize at any moment on a psychometric diagram, the relative variations of temperature and humidity. They can also be used as indicators of directives of thermal design of buildings in order to improve comfort inside, if the building is not artificially air-conditioned. All such diagrams are structured and refer to a zone known as "comfort zone".

The comfort zone is defined as being the range of the climatic conditions under which the majority of people will not have a feeling of discomfort in term of heat or cold. The analysis presented here is based on Givoni bioclimatic chart.

### Characterization of the principal tropical climates

From the data of temperature, humidity and pluviometry, it has been possible to highlight "standard" climates (Huet, et al., 1986). Although this classification is approximate, it however makes it possible to define great zones of "climatic tendency". By taking the averages of the above mentioned climatic statements for the months of extreme conditions (in general January and July), one defines the characteristics of winter and summer of an area. The generally adopted limits refer to the temperature and the absolute humidity (Fig. 1):

(a) A zone at average temperature lower than 10°C is described as cold zone;

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(b) A zone at average temperature ranging between 10°C and 20°C is described as moderate zone;

(c) A zone at average temperature ranging between 20°C and 30°C is described as hot zone;

(d) A zone at average temperature higher than 30°C is described as very hot zone;

(e) A zone with absolute humidity higher than 0.0125 kg/kg (kg of water vapour per kg of dry air) is described as wetland;

(f) A zone with absolute humidity lower than 0.0125 kg/kg is described as dry zone.

One can visualize these various zones on a psychometric diagram (temperature – humidity).

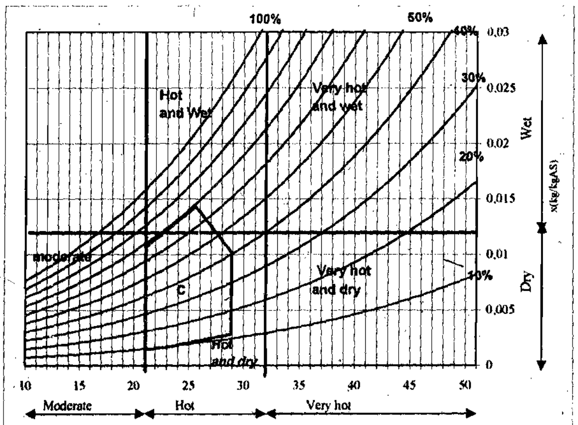


**Figure 1:** Diagram of the standard climates

**The Givoni bioclimatic chart**

Laid out starting from the psychometric diagram, the bioclimatic diagram was worked out by MILNE and GIVONI (Milne, et al., 1979). It specifies the zones of influence of certain ways of intervention on the climate effects, so as to obtain comfortable interior conditions (Fig. 2).

It includes:

(a) The comfort zone C, zone in which the natural conditions are enough to maintain comfort. This zone is characterized by a calm air, with speeds of air lower than 0.1 m/s;

(b) The zone V in which it would be necessary to ventilate naturally or artificially to have comfort. It will be allowed there wind speeds lower than 1.5 m/s;

(c) The influence zones of the principal architectural and technical devices:

(I) The zone I for which the dwelling must have a strong thermal inertia;

(II) The zone INV: it is that of the very strong thermal inertia associated with a good night ventilation;

(III) The zone RE: it is the zone of evaporation cooling;

(IV) The zones AC, DH and H which correspond to the zones requiring the air conditioning process (cooling, heating, humidification, dehumidification). These zones call upon more complex techniques of artificial air-conditioning.

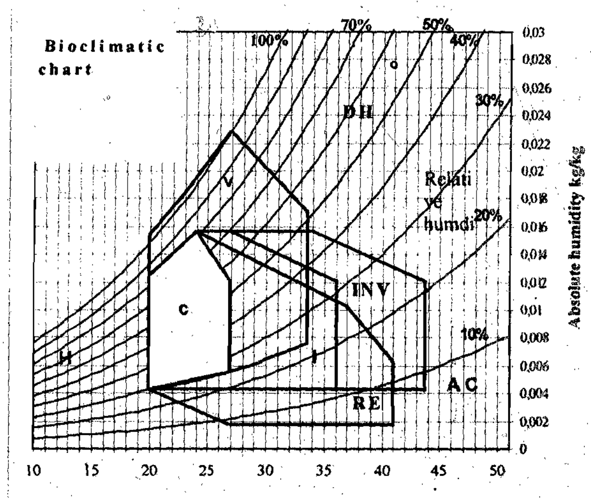


**Figure 2:** Givoni Bioclimatic chart

It should be noted that the zones other than the zone C correspond to zones of widened comfort, i.e. one obtains comfort due to artifices. Thus comfort is ensured in spite of unpleasant thermal stresses.

The establishment of this diagram holds account (Huet, et al., 1986):

(a) Conditions related to the occupants (acclimatized or non acclimatized persons);

(b) Conditions related to the non supposed air-conditioned buildings;

(c) Conditions related to the protection against solar radiation (efficiency of sunshade).

In its use, each climate is materialized by a whole of twelve segments, each one representing graphically one month climate. The coordinates of the extreme points of the segments are the monthly averages of the daily couple "temperature – relative humidity" Thus, at the maximum average temperature, one can correspond the minimal humidity of the same month and vice versa. Once the representation of the climate is carried out, one can read the suitable answers on the diagram, starting from the various zones.

On the assumption that the statements of an unspecified month, for a given area, are inside the comfort zone, then the climatic conditions, in the shade of a tent or a tree are comfortable. In the contrary case, when the external conditions are partially or completely apart from the ideal zone (zone C), it is necessary to have recourse to architectural devices which bring back the external conditions in the comfort zone.

The diagram thus gives the external limits for which an inert building, protected effectively from the solar radiation, with suitable ventilation would be comfortable.

One will choose the solution of a strong inertia or a very strong coupled inertia of night ventilation according to whether the average temperature of the extremes is in the comfort zone and the maximum temperature in zone I (Fig. 3) or in zone INV (Fig. 4) respectively.

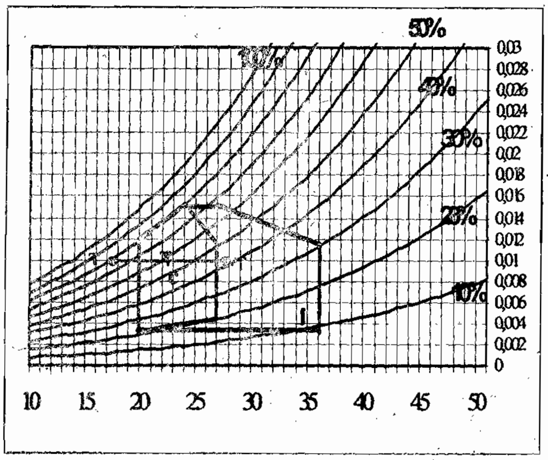


**Figure 3:** Extreme average temperature in zone I *INV*

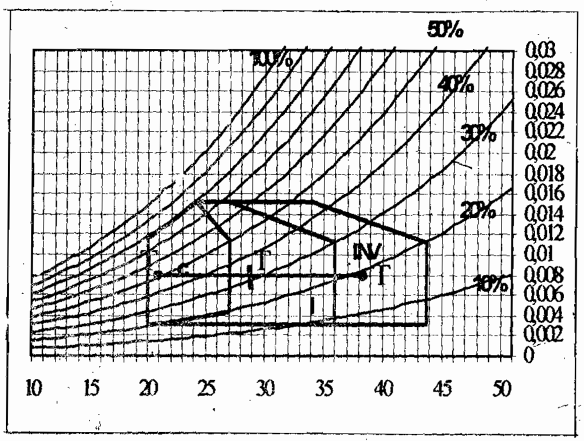


**Figure 4:** Extreme average temperature in zone

The solution of the very strong coupled inertia of night ventilation is adopted when the minima of the temperatures are in the comfort zone. One gives a detailed attention to solar protection and the mode of ventilation. Apart from night ventilation, ventilation during the hot hours can be only artificial (fans).

The roof of the buildings can be light and insulated rather than heavy. It must be well protected from the solar radiation. In the interior of the building, it is recommended to rather seek great heat-transferring surfaces than strong thicknesses of the partitions to evacuate heat more easily. These recommendations must be effective in the very hot and dry areas.

As for the influence zone of simple ventilation (zone V), it coincides with high temperatures and humidity. At this level, the feeling of comfort remains because of greatest cooling due to the air velocity. Indeed, heat accelerates the thermal loss of the body when air temperature is not higher than that of the skin and when the air is not saturated with water steam. The hot and very wet climates are in priority concerned.

In the zone RE called influence zone of evaporation cooling, one has recourse to humidification to reach the comfort conditions, the air humidification can cause its cooling until air is saturated of water. This type of cooling is possible in the hot and dry climates (desert climates in priority) where humidity is sufficiently low on a good part of the year. For these climates, the surrounding air is humidified and cooled after its passage through porous material maintained wet permanently. It is then introduced into the buildings where it mixes with the interior air in proportions such that one has comfort conditions.

When previously simple methods re... ineffective, zones of artificial air-conditioning (zones DH, H, AC), one has recourse to techniques of artificial air-conditioning. Those techniques bring back the interior conditions in the polygon of comfort corresponding to the local situation:

(a) Zone DH: zone of dehumidification (very hot and wet climates);

(b) Zone AC: zone of cooling or air conditioning (very hot and dry climates);

(c) Zone H: zone of heating (moderate climates, winter).

**The Mahoney tables**

Another tool for climatic design is the Mahoney tables (Huet, et al., 1986) which are more detailed and specific; they give recommended criteria for the development of the design of the building. To use that method, the building designer does not need to make preliminary hypothesis. It is enough to get a set of climatic data of a specific place and take note of them in tables. The comparison of those tables with the comfort zone, determined to a specific climate, allows the identification of groups of dominant climatic problems. After identifying those groups it is possible to get technical recommendations that should be taken into account during the design the design process. Recommended specifications for building orientation, spacing, air movement, building components and materials are indicated in the tables.

**Case study: bioclimatic diagrams and architectural recommendations in Côte d'Ivoire**

The works by G Lippsmeir and Côte d'Ivoire standardization (Bodou, 1998) allow subdividing Côte d'Ivoire in four great climatic zones:

(a) Equatorial or tropical wet climate, with ABIDJAN as reference town;

(b) Tropical climate of monsoon (climate of transition), with BOUAKE as reference town;

(c) Dry tropical climate, with KORHOGO as reference town;

(d) Altitude tropical climate, with MAN as reference town.

The case studies presented relate to climatic data recorded over ten years (Seka, 2001). The weather parameters are thus monthly averaged on ten years; statements being provided per decade.

**Case of ABIDJAN area**

The town of Abidjan, town of reference, selected arbitrarily in the zone with wet tropical climate, has 5.04° as latitude and –4.09° as longitude. This city presents two relatively hot periods (Bodou, 1998):

(a) From November to May, one records very hot days with a diurnal average temperature of 28°C;

(b) The period from June to October is much less hot with an average temperature of 25°C.

The relative humidity is very strong and annually oscillates around 80%.

During all the year, one records a weak pluviometry (below 50mm), with however a particular point from April to July.

Wind speeds are not very variable all the year. One record values ranging between 2 m/s and 2.5 m/s (Seka, 2001) all the year except, for January and December, where they go down appreciably below the lower limit. The zone thus is broken down in a regular way all the year by a wind of low intensity.

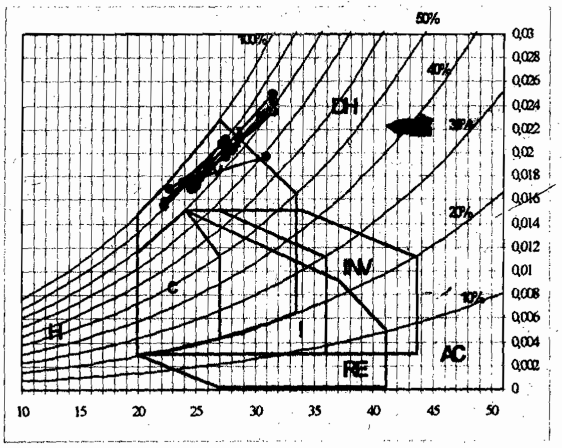


**Figure 5:** Bioclimatic chart of ABIDJAN zone

There is a hot and wet climate all the year. Very significant relative humidity is in major part between 80% and 90%. As shown in the bioclimatic chart (Fig.5), the plotted zone of relative humidity and temperature lie outside the comfort zone for the whole year. It was indicated that ventilation and dehumidification should be considered for this type of climate condition.

Ventilation is essential almost all the year particularly during March and from June to September. However, the maximum of temperatures during the other months being located in zone DH, it proves to be necessary to resort to mechanical ventilation, even with air-conditioning (air dehumidification) if mechanical ventilation must involve discomfort because o. high speeds of air that can be reached.

For the zone of Abidjan, dehumidification the day, replaced by natural or mechanical ventilation at night, except from June to September, where only ventilation is sufficient, is thus recommended.

Based on the Mahoney tables, the layout of the buildings should have their facades facing north and south. The shorter walls to face East - West axis. This is to minimise exposure to solar heat radiation of the building. The majority of fenestrations should also face North-South axis to maximise natural ventilation. Additionally, openings should be large (40 – 80 % of the wall area) and should be provided with protection from rain and sunlight. Room should be single banked to provide good air circulation within the building and walls should be built of light material with short time lag and low thermal capacity. Roofs should be of light materials with reflective surface and properly insulated. Wide overhangs are required to protect the interior from direct solar radiation and heavy rains. Adequate rainwater drainage is also recommended.

### Case of BOUAKE area

Reference town Bouaké, selected arbitrarily in the zone with tropical climate of monsoon, has latitude of 7.28° and a longitude of –4.9° (Bodou, 1998). The zone of tropical climate of monsoon presents also two hot periods:

(a) From November to April, the daily average temperature is approximately 27°C;

(b) From June to December, this temperature drops to around 25°C;

The humidity is relatively strong there from May to October with a significant fall from November to April, interval of time during which comes the harmattan (air much drier).

During all the year, one records a weak pluviometry on average, very variable and reaching the value of 70 mm in August.

One identifies two types of wind in this intertropical zone:

(a) The "harmattan" (dry wind) which blows from the North towards the East during November;

(b) The monsoon (on-shore breeze) which blows from the South towards the West during the other months.

Wind speeds are not very variable all the year.

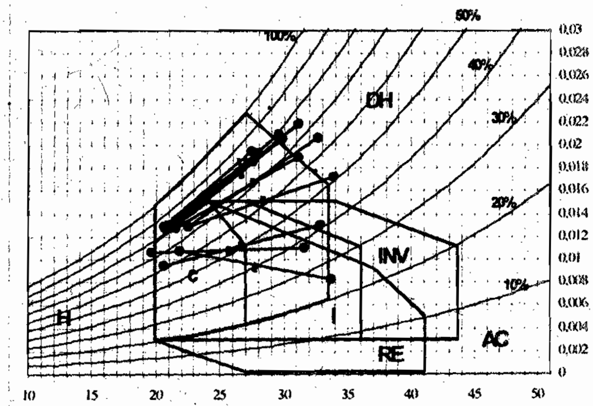


**Figure 6:** Bioclimatic diagram of BOUAKE zone

The distribution of the extremes of temperatures in the Givoni chart (Fig. 6) recommends ventilation. This ventilation will be primarily natural. However, the maximum temperatures from March to June and October to November indicate to resort to mechanical ventilation or air-conditioning.

The external conditions from December to June recommend strong inertia. One will thus be able to avoid the heating of the interior mass of the building during the day and to store heat to heat the nights.This solution will be associated with good natural ventilation the days as well as the nights.

Based on the Mahoney tables, the recommendations are almost the same (case of Abidjan). But here the openings should be medium (25 – 40 % of the wall area). The walls should be built of material with long time lag. This implies that wall materials should be able to store heat which can be transmitted to the interior of the building at a later period of time.

### Case of KORHOGO area

The town of Korhogo in zone of dry tropical climate has 9.13° latitude and –5.75° longitude (Bodou, 1998).

The days are very hot except in August when the diurnal temperature goes down appreciably below 30°C. The nights are on the other hand cold (temperature close to 20°C) with a characteristic from November to January when the night temperature ranges between 20 and 17°C.

Humidity is strong around July. It remains relatively weak the other months of the year with bare minimal value during the harmattan (December to March). In this zone, there is an abundant pluviometry around August (great rainy season). The period going from November to April is with drier atmosphere, the other months being rainy inter seasons. The wind speeds (harmattan and on-shore breeze) are low all the year.

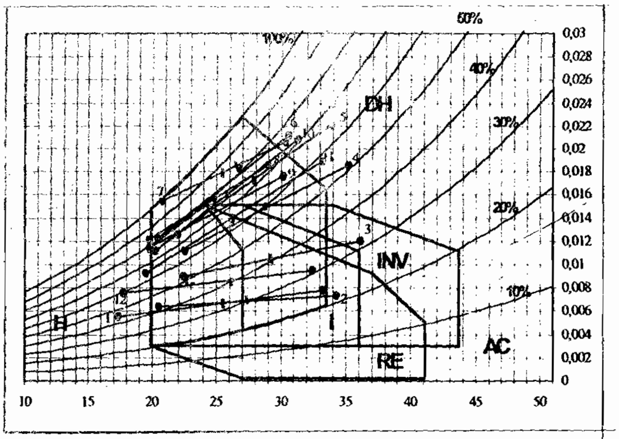


**Figure 7:** Bioclimatic diagram of KORHOGO zone

The Givoni chart (Fig. 7) associated with this zone indicates large characteristic features:

(a) Ventilation is required all the year and the solution of strong inertia is required to prevent the reheating of the interior mass of the habitat the day and to ensure the cold nights, particularly during December and January;

(b) The ventilation which must be necessarily mechanical the very hot and wet days from April to July and from October to November, will have to be replaced by a natural ventilation the nights;

(c) During February, August, March and September, ventilation could be natural all day long. In February and March which are rather hot and dry, cooling by process of the evaporation cooling would be of an additional contribution to make the environment comfortable;

(d) The solution of strong inertia seems to be essential because of the very strong diurnal temperatures in March. However, one could stick to a strong inertia while taking care to ensure the insulation and the protection of the building for the other months, where the strong diurnal amplitudes will tend to support the absorption of heat by the building;

(e) One must remind that for the zone with standard dry tropical climate of that of Korhogo, the architectural solution with strong inertia for which it will be necessary to ventilate or air-condition (to dehumidify or cool the air) at certain times of the year is recommended.

**Case of MAN area**

The altitude tropical zone, for which Man was taken arbitrarily as reference town, remains very wet a good part of the year, with an average relative humidity of 80%, with 7.02° of latitude and -7.55° of longitude (Bodou, 1998).

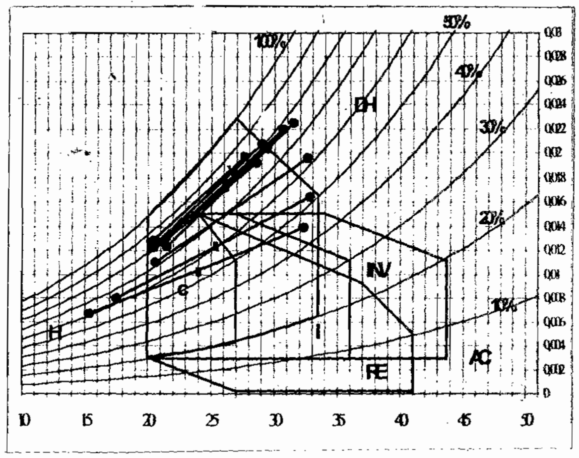


**Figure 8:** Bioclimatic diagram of MAN zone

The analysis of Givoni chart (Fig. 8) shows that ventilation is essential to ensure comfort all the year.

Over a period of five months (from March to June and October), one must have an alternation between mechanical ventilation the day and the natural ventilation at night. This natural ventilation continues from July to September to ensure comfort the day as well as the night.

Taking into account the strong diurnal amplitudes and the cold nights from November to February, architecture will have to adopt the solution of strong inertia in order to avoid the reheating of the mass of the building and to ensure the heating of the cold nights.

The heat insulation will have to be carried out so that the solution of strong inertia does not compromise the comfort of the more lenient periods; in addition, the solar protection of the building must be carried out so as to avoid the direct sunning.

**CONCLUSION**

It comes out from all that precedes that certain climatic parameters (temperature, humidity, wind speed), have a dominating incidence on thermal comfort. The realization of bioclimatic comfort requires an adequate combination of these parameters for the architectural design.

The use of the Givoni chart emphasizes clearly the possibilities, the zones and the modes of bioclimatic intervention to reach thermal comfort.

In Côte d'Ivoire, mechanical and natural ventilations are essential all the year and this, whatever the climatic zone. However, in the areas with extreme climates such as Abidjan, air-conditioning is necessary because of high speeds reached during mechanical ventilation. In order to minimise heat gains from solar radiation the main facades of the buildings should be oriented to face the north and south for all the regions. This orientation also provides better air circulation and lowers the operative temperature within the building. Sun shading device over windows is also a significant building component to be considered in providing protection from radiant solar heat gain. The walls must be of light construction in the Southern area and have strong inertia in the central and northern areas.

On the other hand, the insulation and solar protection must be perfectly assured, particularly in the zones of high altitudes (Man).

Lastly, the climate, much hotter and drier in Korhogo area, has revealed the necessity of resorting, at certain moments of the year, to the evaporation cooling, instead of air-conditioning.

In this paper the general climate design recommendations as developed aims to provide a set of targets which should encourage individual design solutions. We hope that it would provide appropriate information to help make better use of energy and materials in building design in Côte d'Ivoire, improving so human comfort.

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