Original Article

Study of Dioxide Carbon Concentration and Indoor Air Quality in Some Buildings in the Equatorial Region of Cameroon (Yaounde)

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Abstract

Background and purpose: Elevated CO2 rate in a building affect the health of occupant. This document presents results of an experimental analysis conducted in 50 offices located in 12 buildings with different layer in Cameroon (Yaounde). This study took place in 2012, during the dry and the rainy seasons. The main goal is to show the influence of the building structure, the ventilation and the number of occupants on the CO2 concentration in buildings. The areas chosen were ventilated at 60%.

Materials and Methods: A questionnaire was distributed to occupants. The different values in terms of temperature, air speed, humidity, CO2 concentration and luminosity rate were measured simultaneously during working hours and without the occupants. The measurement took place while offices were naturally ventilated. Values obtained were analyzed and integrated.

Results: Painted buildings with glasses were more pollutant than those made with soil and wood. A mechanically controlled area was more comfortable but more pollutant than a naturally ventilated area.

Conclusion: The CO2 concentration changes exponentially when the number of people in a hall increased especially when there are smokers. For temperature ranged from 20.5°C to 28.8°C and the CO2 from 350ppm to 1450ppm, the average consumption of O2 by person varied between 0.0097cfm and 0.0162 cfm.

*[Kameni Nematchoua M. Tchinda R. Orosa J. *Roshan Gh. Study of Dioxide Carbon Concentration and Indoor Air Quality in Some Buildings in the Equatorial Region of Cameroon (Yaounde). 2014;2(1): 1-15] http://jhs.mazums.ac.ir*

Key words: CO2 Concentration, Indoor Air, Buildings, Equatorial Climate, Health

1. Introduction

Following the energetic crisis in the ninety nineties, buildings have been built with tighten envelops, counting on mechanic ventilation to reduce the energetic cost. Thanks to tighten envelops, a great part of the energy contribute to the ventilation (1). Buildings greatly contribute to emission of greenhouse gases in the atmosphere. More than 25% of emissions are generated by the architecture of the building, from the building structure, the maintenance, the heating, the lighting to the indoor fitting up. Consequences of climate change caused by green house gas in buildings resulted in an increase demand in sustainable buildings including a new strengthening of energetic efficiency of houses in different parts of the world (2). Human being produces carbon dioxide (CO_2) according to their normal metabolism. Consequently, CO_2 concentrations in buildings where people live are higher than the concentrations of outdoor air. The level of difference between indoor and outdoor concentration decreased as the ventilation rate of the building per occupant increased(3-4). In many buildings, the number of occupants and the ventilation were not stable, which did not allow to determine the exact CO_2 rate. The epidemiologic research showed that the indoor CO_2 concentrations were useful to predict human health and the performance of the human body (5). In fact, a high level of CO_2 can cause headache and changes in breath rhythms in houses. Consequently, in order to keep a good quality of indoor air, the indoor CO_2 concentration must be reduced to certain level (inferior to 1000ppm)(5). CO_2 is sometime used as a substitute to examine the quality of indoor air and the ventilation efficiency. Research made by Seppanen et al (6) showed that occupants of offices of buildings which had a greater difference between the indoor and outdoor CO_2 concentrations were generally sick due to the pollution rate of their buildings. Batagoda and Jayasinghe (7) showed that it was possible to reduce the CO_2 concentration by using material with low emission in the new building; this will also allow reducing the energy cost consumed by the buildings. In the past, in sub-Saharan Africa, no building standard was respected. Nowadays, as Africa faces its population mostly young, the design of its building changes completely. Many builders ignore the influence of the building on health and productivity of the occupants. This study aims at showing the influence of occupants and the layer of building on the CO_2 concentration. The adaptive approach consisted on the distribution of a questionnaire and to take simultaneously the temperature, the CO_2 rate, luminosity etc.

2. Materials and Methods

Field Study
2.1. Analysed cities

Cameroon is divided into three climatic zones: the Sudanese, the sudano–Sahelian and the equatorial regions. Cameroon is characterized by an equatorial climate with two main seasons of equal amplitudes. The study was conducted in the equatorial city of Yaounde. Yaounde is the Cameroon political capital and is located approximately at 300 km from the Atlantic coast and enjoys a sub-equatorial climate with four seasons; a large dry season from mid November to late March, a short raining season from April to mid June, a short dry season from mid June to mid August and a long raining season from mid August to mid November. Its altitude is between 600-800 m. The Yaounde city was built on several hills and enjoys a picturesque setting and a relatively fresh climate respects the coast regions. The maximum temperature is ranged between 30 °C and 35 °C and the minimum is 15 °C. It unfolds geographically between 3°52' N latitude and 11°32' E longitude. The Yaounde population was about 2.5 Million inhabitants in 2011 due to the early 90s rural exodus which makes super populations with a growth rate estimated at 7 % per year. As a consequence of this fast exodus, several suburbs were created in the western and north parts of the Yaounde city.

2.2. Materials

In this study, indoor air speed, indoor relative humidity, CO_2 concentration and indoor air temperature were measured by a thermo-anemometer (model C.A1226) and a CO_2 Monitor (model CO200). On the other hand, outdoor temperature, wind speed and relative humidity were collected from the national weather station. All these equipments were calibrated before used to ensure reliability and accuracy. The calibrate equipments give to correct measures of physical parameters of environment. Finally, the sampling accuracy of each device is showed in Table1.

Table 1. Characteristics of the measurement system

C0$_2$ Monitor	Function	Range	Resolution	Accuracy
	CO_2	0 to 9999ppm	1ppm	±(5%rdg+50ppm)
	Temperature	-10 to 60°C	0.1°	±0.6°C
(model CO200)		14 to 140°F	0.1°	±0.9°F
	Humidity	0.1to 99.9%	0.1%	±3 %(10 to 90%)
				±5 %(< 10% or >90%)
Digital thermometer	Temperature	-20°C to 0°C	1°C	±5.0% of rdg ±4 digits
		0°C to 400°C	1°C	±1.0% of rdg ±3 digits
		400°C to 1000°C	1°C	±2.0% of rdg
C.A 1226 Thermo-anemometer	Air velocity	0.15 to 3 m/s	0.01 m/s	±3% R + 0.1m/s
		3.1 to 30 m/s	0.1 m/s	± 1% R + 0.2m/s
	Temperature	-20 to +80 °C	0.1 °C	± 0.3% R + 0.25°C
	Air flow	0 to 99999 m^3/h	1 m^3/h	±3%R ± 0.03*surf.
Light Meter IM-1308	Light Meter	40.0 Lux to 300.0Klux	± 3%	±5%reading ±0.5% scale

2.3. Methodology

The number of samples was 12 buildings with different layers and structures. This study took place during the dry and the rainy seasons. 50 offices were chosen in these buildings. Concerned by solar radiation which influences the quality of indoor air, we choose buildings with the same orientation. The choice of buildings answers at several criteria, concerning the structure and the working of the buildings, as well as their environment. These are of buildings essentially occupied during work hours, it that facilitates the access during the investigation. But the essential criteria were the availability and the desire of people to participate in the investigation. This choice also rested on the inertia of the building. The offices chosen in the buildings have been selected in order to have the different orientations in facade as well as the different configurations of bureau (Individuals and collective). The indoor activity was sedentary. In all these buildings, large windows occupied more than half of the wall and were covered with curtains, preventing the solar radiation from entering inside. Doors were mostly made with wood. Oxygen rate consumed by person was given by the relation established by Persily (10).

2.3.1. Indoor air

It can be observed that, in Yaounde, indoor climate is favorable in terms of study and work. Particularly in the rainy season, the internal temperature decreases few times to 15 °C and it rarely reaches 31 °C in the dry season. The relative average humidity varies around 65 ± 30%, while the wind speed rarely reaches 0.47 m/s(13). These different characteristics can be explained by the fact that the Yaounde city is built on seven hills.

2.3.2. Field measurement of environmental parameters

The adaptive approach consisted on the distribution of a questionnaire and to take simultaneously physical measure was used. To analyze these effects, a sampling process with frequencies of 10-20 minutes was done during the working hours, particularly, from 8:00 a.m. to 17:00 a.m., and during the unoccupied period from 5:30 p.m to 6:00 a.m., in each season. Furthermore, measurement devices were installed at 7:00 a.m. in order to adapte them and the measurement itself started at 8:00 a.m. On the other hand, sampling devices were placed 1.1 m in height in accordance with the ASHRAE Standard 55 (8) and ISO 7730 (9) requirements. Furthermore, devices were placed far away from any heat source and as close as possible to employees to get the more realistic indices. Once obtained the temperature ,CO_2 concentration and relative humidity conditions in each of buildings, the comparison of averages has been carried out by means of the analysis of the variance of a factor (one way Anova) using the statistical software SPSS for a level of significance of 0.05 and a Tukey post hoc to define the homogeneity of coating.

2.3. 3. Occupants

The internal activity is sedentary. In this study, we first of all varied the number of occupant till 10 persons in each office by imposing natural ventilation followed by natural ventilation in order to study the influence of occupants on the indoor CO_2 concentration. After that, we studied these offices when occupants were out. The number of occupants was not predictable in buildings during working hours. Offices studied were more visited during working hours (from 8 am to 5pm). From 8 pm, the areas studied were unoccupied. It was forbidden to smoke during working hours and to enter the study hall with toxic tools.

2.3. 4. Buildings

The age of buildings studied varied from 5 to 35ans. There were two different types of buildings, those with local materials (wood, soil and stone) and imported materials (glass etc.) their heights varied from 3.8 to 4.4m and areas were ranged between 32 and 120m^2. All openings were closed. Windows were made with glasses and varied between 0.63 and 1.2 m^2. The windows were covered with curtains which did not allow solar radiation to enter the office.

2.3. 5. Subjective measurements

The questionnaires employed in this work were distributed before and in the afternoon. More of 1000 questionnaires were analyzed, these questionnaires were written in English and French language, which are the official languages of the country. The language preferences of the occupants were considered while distributing these questionnaires to them. They were constructed in accordance with ISO 7730 (9) and ISO 10551 standards (12). From these questionnaires, clothing and metabolic rate were assessed and, at the same time, it was also possible to know the sex, age, weight and size of each occupant. Finally, like in previous research works, thanks to the questionnaires, it was also possible to find out the thermal sensation, thermal preference and acceptance of the thermal environment in the occupied areas.

3. Results

In this study, workers have been subject to natural ventilation, then the artificial one. In the different offices, ages of individuals varied from 28 to 45 ans. All were considered as adults, their size varies from 1.55 to 1.82m and their weights from 62 to 102 kg. Activities in the buildings studied were sedentary (1 to 1.2 met) and the resistance for occupant clothes varied from 0.5 to 1.45clo with an average of 0.9clo for women and O.7clo for men. It has been proven that the type of ventilation, occupants and structure of the building had direct impacts on the CO_2 rate in offices. Table2 gives some characteristics of physical measures and questionnaires.

Table 2. Synthesis of measured data in Cities

City: Yaoundé

Coating	Glass	Wood	Earth	Stone	Plaster	Paint
Height[m]	4.30	3.80	3.80	3.90	4.40	3.90
Floor area [m^2]	120.00	66.50	32.00	68.5	71.50	49.00
Volume [m^3]	516.00	253.70	121.60	267.15	314.60	196.00
Clothing (Clo)						
Maximum	1.30	1.20	1.40	1.20	1.40	1.40
Minimum	0.36	0.55	0.30	0.47	0.75	0.65
Mean	0.74	0.81	0.55	0.87	0.85	0.72
Standard deviation	0.18	0.10	0.08	0.09	0.07	0.07
Metabolic rate (Met)						
Maximum	1.30	1.30	1.20	1.30	1.20	1.20
Minimum	1.00	1.00	1.00	1.00	1.00	1.00
Mean	1.05	1.05	1.00	1.02	1.02	1.00
Standard deviation	0.04	0.06	0.05	0.04	0.07	0.03
T_{in} (°C)						
Maximum	30.90	29.80	29.40	29.90	31.30	29.50
Minimum	24.90	20.50	21.50	22.90	24.90	22.00
Mean	25.90	24.80	24.50	25.80	22.70	23.50
Standard deviation	1.50	2.30	0.96	1.03	1.98	0.92
V_{in}(m/s)						
Maximum	0.25	0.27	0.33	0.31	0.30	0.31
Minimum	0.08	0.07	0.04	0.05	0.07	0.07
Mean	0.19	0.10	0.12	0.17	0.11	0.16
Standard deviation	0.03	0.03	0.05	0.02	0.04	0.04
RH_{in} (%)						
Maximum	77.30	78.50	80.50	74.80	74.40	76.50
Minimum	59.50	61.60	62.90	54.00	47.50	66.70
Mean	69.00	72.70	65.50	62.50	61.50	70.60
Standard deviation	2.50	3.20	1.75	2.90	1.80	1.55
[CO2$_{in}$](ppm)						
Maximum	1664.00	1433.00	1233.00	1220.00	1371.00	1771.00
Minimum	482.00	318.00	311.00	401.00	411.00	456.00
Mean	750.50	610.00	527.50	647.50	678.40	789.50
Standard deviation	28.50	21.56	19.05	15.77	20.17	21.10

3.1. CO$_2$ and influence of occupants

Figures 1 and 2 shows the CO$_2$ evolution according to the number of occupants in the natural and artificial ventilation. When offices were naturally ventilated, during unoccupied hours (from 0:00am to7:30am and from 6:00 pm to 0:00am), the CO$_2$ concentration varied from 350 to 640 ppm, and from 8 :00am to 6 :00ppm, CO$_2$ increased considerably from 350 to 1435ppm. It achieved a peak at 03:00pm. This increase in CO$_2$ can be easily explained by the fact that the different offices were occupied by workers during working hours. Their activities have an impact on the CO$_2$ concentration.

When these offices were naturally ventilated and employees enter progressively the hall of study from one to 6, now the resistance of their clothes from 0.6clo to 1.3clo, all subject to office and research, we noticed that the concentration of CO_2 increased from 109 to 235ppm by person. This variation not constant by person can affect the health of each occupant. When a group of 20 persons entered, we noticed that CO_2 increased considerably so that it is difficult to determine the amount of CO_2 brought by each person in these study halls. The average obtained during working hours was 513.5ppm, with a standard deviation of 29.5. Increase of CO2 in halls when occupants were in is a natural phenomenon for everybody, during breathing, absorbs oxygen and rejects CO2. However, the variation of the CO2 rate between individuals depends on the physical, psychological and health aspects. Smokers and other people having chest infections produce a higher CO2 rate than healthy persons.(14-16) .Then in the same areas of study, when we move to ventilation system, the different hall become more comfortable, but more pollutant (see figure2). During unoccupied hours, the CO2 varied from 350 to 800 ppm, whereas during working hours, when 8 people entered progressively, the maximum concentration obtained was 1670ppm.
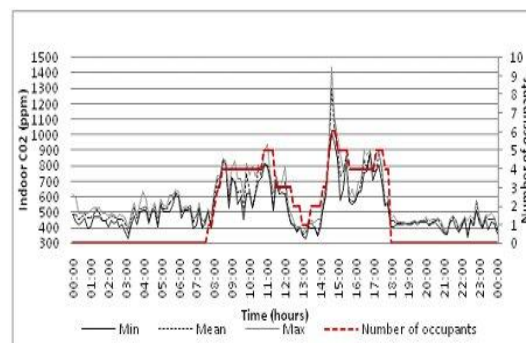
Fig 1. Indoor CO_2 concentration according to the number of occupants in natural ventilation
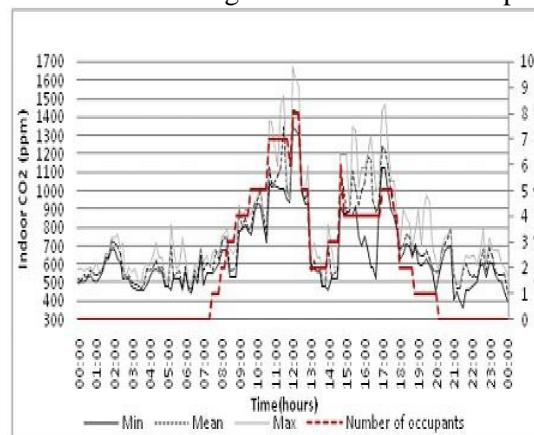

Fig 2. Indoor CO_2 concentration function of number of occupants in air conditioned

This value is considerable compared to offices naturally ventilated. The average value obtained from (8:00 to 18:00) was 555,5ppm with a standard deviation of 25.4. The pollution rate by each occupant in these conditions became difficult to evaluate. The increase can be due to the fact that the ventilation system used was slightly pollutant because when using fluid R22 (e.g. R32/125 (60/40), R32/125/134a/290 (20/55/20/5), etc.) and R502 (e.g. R32/125/143a (10/45/45), R125/143a (45/55), etc.), actually forbidden by the international community, the CO_2 concentration increases suddenly according to ventilation system used when passing from a natural area to an artificial.

3.2. CO_2 and Indoor Air Quality

In these offices naturally ventilated, the indoor climate was slightly acceptable but not acceptable in study and working conditions. During the dry season, temperature sometime achieved 31°C in the office. The consumption rate by individual greatly depended on the activity, the size and the weight of occupant. By applying all these elements to equations (1) to (2), we deduced that the average obtained in term of oxygen consumption by person was 0.0051L/s(0.01cfm), different values were ranged from 0.0046L/s to 0.0077L/s (0.0097cfm à0.0162cfm). These values were acceptable, compared to the range of oxygen absorption by person established in (10). From figures 3 to 5, we can see the CO_2 variation according to some

physical parameters measured. When the offices were subject to natural ventilation during the different seasons, we noticed a temperature ranged from 20.5°C to 28.8°C, the CO_2 varied from 350ppm to 1450ppm. The CO_2 average obtained for these different values was 513ppm; this corresponded to an average temperature of 25.25°C. The standard deviation was 13.5 for CO_2 C02 and 0.75 for temperature values. The humidity rate was not stable; it varied instantaneously according to hall studied and the season. The different humidity values varied from 42.0% to 83.5%. The standard deviation average was 318.5ppm and 1.75 respectively for CO_2 values and relative humidity. The correlation obtained between various humidity values was good (R=0.896). from different elements (temperature and relative humidity), we can certify that the quality of indoor air was not always comfortable or acceptable compared to ranges established by standard norms ASHRAE (8), for temperature ranged from 23°C to 26°C and humidity from 30% to 60% and in CIBSE (11), the comfort temperature was ranged between 22°C to 24 °C and humidity between 30 % and 60 %. The different ranges were established from works from the North America, Asia and Europe, sub-Saharan Africa which are to be explored. Figure 5 shows the different values of CO_2 ranged from 350 to 1600ppm according to the wind variation from 0.03m/s to 0.31m/s. the wind speed was unstable for it varied

according to seasons because of the various average values of wind obtained 0,08m/s and 0,11m/s respectively in dry and rainy seasons. Outdoor wind breaths such as monsoon (soft and humid) and harmatan (hot and dry wind) directly acted on the indoor comfort. The indoor air was till acceptable for workers used to their working places but not for visitors. Compared to the range established in ISO 7730 (9), which fixes the comfort air speed inferior to 0.25m/s, it was possible to assert that these offices were not always comfortable. For occupation densities of 5 m^2 by person, the air change rate varied from 1.1 to $1.9m^3.h^{-1}$. The instability of the indoor climate could be caused by the fact that during hot hours of the day, the building envelope got warm both with the outdoor air contact and the global solar radiation. The heat absorbed was partially stocked and propagated with hours by induction inside the building. During the night, the outdoor air and the phenomenon of heat transfer was inversed. The intensity of these phenomenons of heat transfer depends on the inertia and the heat insulation. After the analysis of questionnaires, we deduced that 63.8% of workers found their place acceptable, while 53.5% of occupants found it neutral during the two seasons. The different heat preferences varied according to seasons. In fact, during the rainy season, 63.5% preferred an unchanged place while in the dry season, 59.7% preferred a colder place.
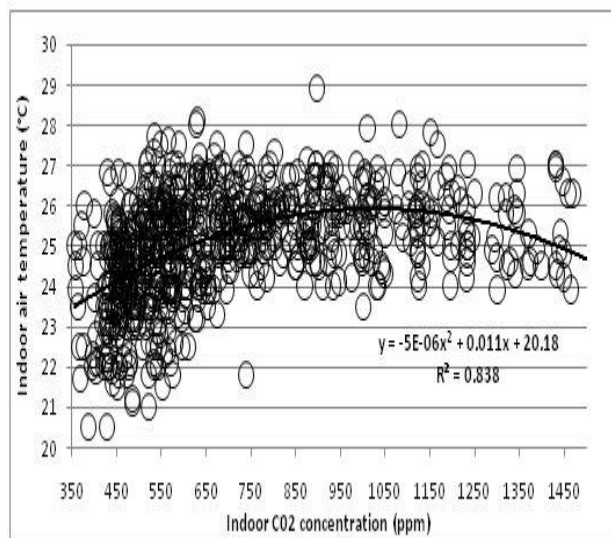

Fig 3. Variation of the air temperature in function of CO_2 concentration

For temperature ranged between 20 and 30°C and CO_2 from 350 to 1450 ppm, the following correlation was obtained:

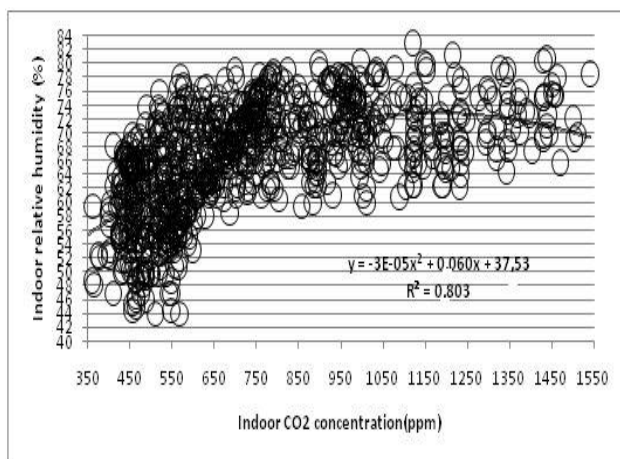$$T_a = -5.e^{(-6)}CO_2{}^2 + 0.011CO_2 + 20.18 , R^2 = 0.84 \ (1).$$

Fig 4. Variation of relative humidity according to CO_2 concentration

For relative humidity ranged between 40 and 85% and CO_2 from 350 to 1550 ppm, the following correlation was obtained:

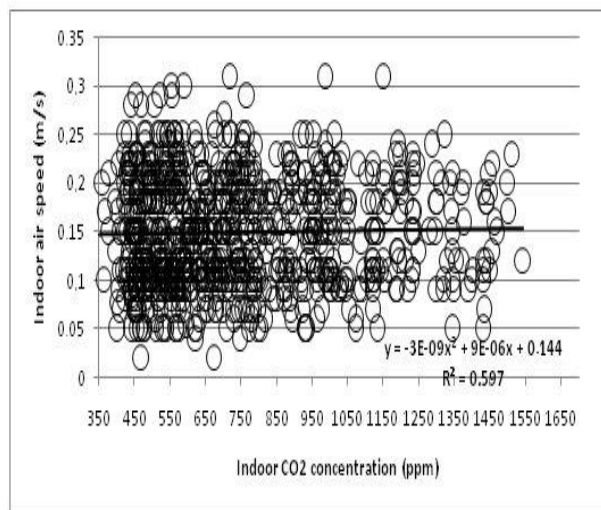$$Hr = -3.e^{(-5)}CO_2{}^2 + 0.06CO_2 + 37.53, R^2 = 0.81. \quad (2)$$

Fig 5. Variation of air speed according to CO_2 concentration

For air speed ranged between 0 and O.35m/s and CO_2 from 350 to 1650 ppm, the following correlation was obtained:

$$V_a = -3.e^{(-9)}CO_2{}^2 + 9.e^{(-6)}CO_2 + 0.144 , R^2 = 0.6. \quad (3)$$

It has been obtained a good correlation (R^2 =0.84) between air temperature and CO_2, between relative humidity and CO_2 (R^2 =0.81) , but also between air speed and CO_2 .The luminosity varied according to the different offices. During working hours, it varied from 77.5 to 242.6 lux. The average obtained during the two seasons in twelve buildings was 156 lux this remained insufficient compared to values prescribed by international norms which has to be superior to 350lux for office activities (14).This average is close to that obtained by Ogbonna(16).

3.3. CO_2 and building structure

The structure of the building influences the CO_2 concentration in buildings. In figure 6 and 7, we observed the evolution of the CO_2 during the dry season in naturally ventilated buildings. For average values of CO_2 of 400 to 850ppm, the average obtained in the different types of building with natural ventilation was 441,5ppm, with a standard ventilation of 12.5 and significant value of 0.45. As soon as the ventilation started for CO_2 average values from 350 to 980ppm, the average obtained was 519.6ppm with a standard deviation of 19.8 and significant value of 0.66 in different offices. The CO_2 average rate when passing from a naturally ventilated to an artificially ventilated area, varied from 482.5 to 551.5ppm (standard deviation(SD) of 12.6), in buildings with glasses; from 97.5 to 484ppm(SD=17.6), in buildings with wood; from 377.5 to 461ppm(SD=4.9), in buildings with soil; from 422,5 to 509.5ppm(SD=10.4), in buildings with stones; from 455 to 534ppm(SD=7.8), in buildings with plasters and from 513.5 to 578ppm(SD=8.6), in painted buildings. From these results, we could conclude that the concentration of CO_2 was not stable, it varied according to building. Among the six types of offices studied, CO_2 rate was higher in painted buildings, followed by buildings with glasses. This CO_2 rate was lower in buildings with soil and wood. These values confirm the results found by Ogbonna and Harris[16]. The different variations explain the influence of building materials on the CO_2 concentration [14-15].
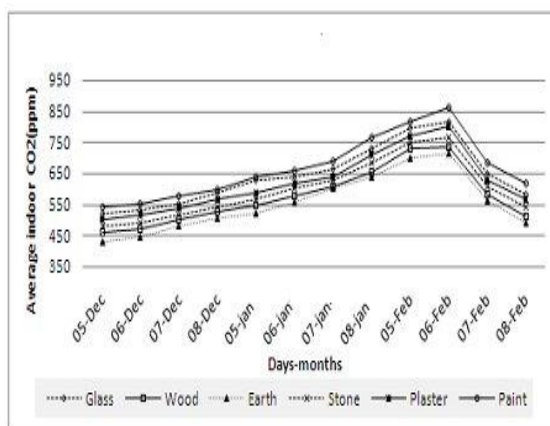

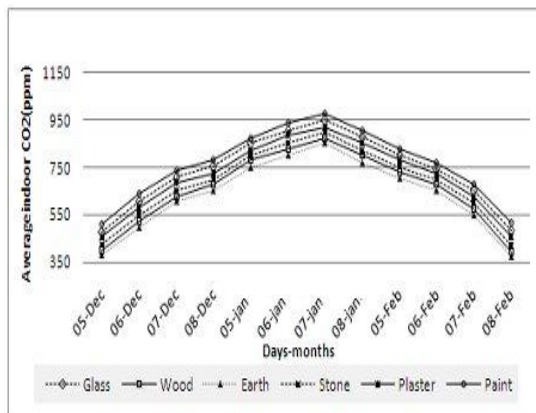**Fig 6**. Type of office & CO_2 Concentration during dry season in Natural ventilation (NV)

Fig. 7 Type of office & CO_2 Concentration during dry season in Air Conditioned (AC)

In rainy season (see figure figure8 and 9), average obtained are ranged from 370 to 750ppm(SD=13.9) and from 360 to 850ppm(SD=19.3), respectively in natural and ventilated area. Passing from one area to another, we noticed an increase of 20.1212 ppm(for a significant value(S.V) of 0.17) in buildings with glasses ; of 22.5015ppm(S.V=0.63) in building with wood; of 20.2301ppm(S.V=0.35) in buildings with soil; of 21.3319 ppm(S.V=0.48) in building with stone; of 22.5760ppm(S.V=0.78) in buildings with plaster and of 12.5071ppm(S.V=0.09) in

painted offices. From these results, we could conclude that the CO2 average concentration was higher in offices with wood and plaster and lower in painted buildings. When the outdoor CO2 concentration was analyzed, we found that these figures were grouped according to significant value of 0.97 with an average value of 850ppm and a standard deviation of 13.6. Moreover, buildings showed an average indoor CO2 of 730.5ppm and a standard deviation of 17.5 for a standard significance 0.59.
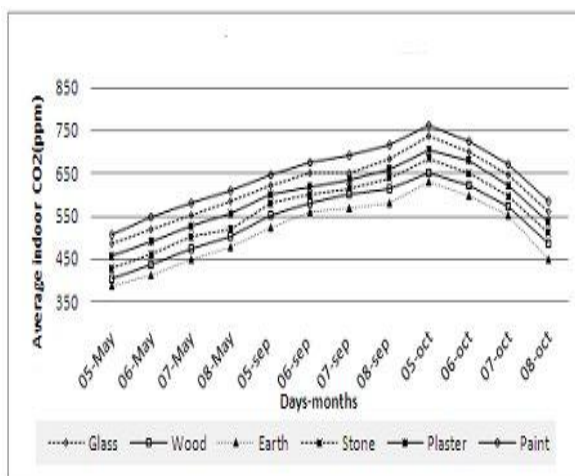

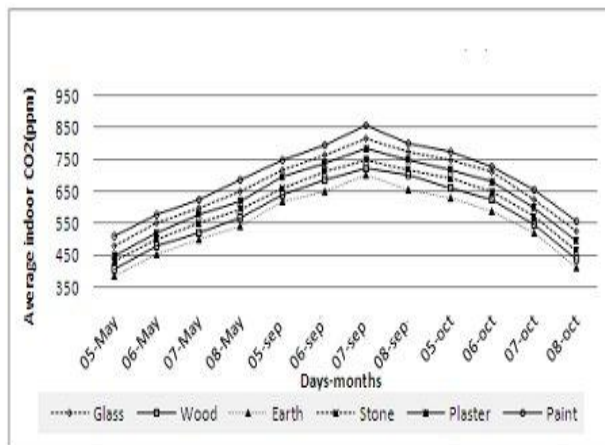**Fig 8**. Type of office & CO_2 Concentration during rainy season in Natural ventilation (NV)

Fig 9. Type of office & CO_2 Concentration during rainy season in Air Conditioned (AC)

Figure 10 shows the indoor and outdoor CO2 evolution. The different CO2 values varied from 350ppm to 1650ppm with an average of 1100ppm for outdoor CO2 and 995ppm for indoor CO2. The outdoor CO2 concentration was regularly superior to the indoor concentration. The more offices were visited, the more indoor concentration was considerable compared to the outdoor concentration.
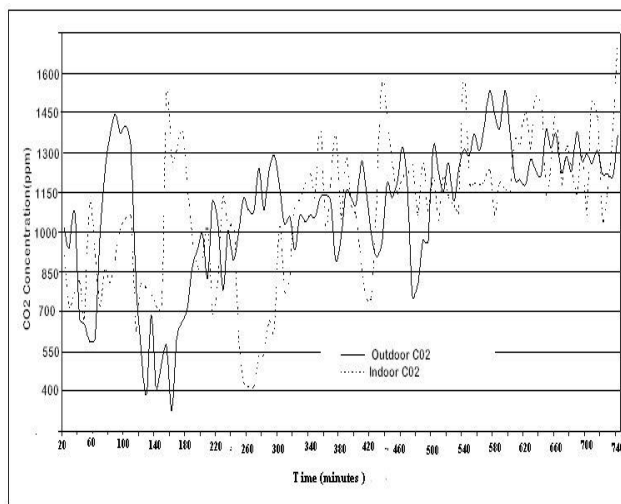

Fig 10. Outdoor and indoor CO_2

4. Discussion

The CO2 indoor concentration was very different compared to the outdoor concentration because of indoor activity of inhabitants and of the air conditioned. In general, the indoor air quality depends on its rate of pollution, its moisture level, and the quality of ventilation. However, depending on their effects, the indices that characterize indoor air quality can be classified into two categories (17): medical and odour indices. According to The World Health report 2002, indoor air quality is responsible for 2.7 % of the global burden of disease (15).

The more comfortable buildings were very often more pollutant. The higher level of CO2 in painted offices and office with glasses could be explained by the fact that the imported materials were made with the characteristics of the home country, when the materials were imported, they have been affected by the climate of its new area and sometime produced toxic and pollutant smells (13). Generally, when the outdoor temperature was inferior to the skin temperature (34 to 35°C), ventilation procured a feeling of thermal comfort. To make the maximum profit of the natural ventilation in sub-Saharan areas, buildings must be oriented perpendicular to the dominant winds and have large openings. This results is not surprising, it confirms the work of Jannot (18), in sub-Saharan areas. In this research, an experimental analysis was made in 12 buildings of different layers and with many offices, during two seasons. Results showed that the ventilation of an area, the structure of the buildings and occupants could impact the pollution rate of that area. Results from measuring instruments were not always on the same length with subjective answer of occupants, this is why it has been proven that areas commonly found acceptable were more often very pollutant. Occupants used to their offices hardly found their offices pollutant. We concluded that a natural ventilated area is less pollutant than an artificially control area. For oxygen consumption average of 0.01cfm by person, the different values were ranged from 0.0097cfm to 0.0162cfm. The increase in CO2 concentration was higher in naturally ventilated area. This concentration increased from 109 to 235ppm by person according to their working place and their activities. The human body been delicate, the indoor CO2 concentration was useful to predict individual health and their performance. Painted buildings and buildings with glasses were more pollutant whereas those with soil were less pollutant. Passing from a natural area to an air-conditioned area, the CO2 average rate increased from 20ppm to 100ppm according to the types of buildings. Architects and designers aware of this must encourage local material as far as building is concerned. Simple and non pollutant ventilation equipments such as fan-humidifier must be used to reduce the CO2 concentration in halls.

Acknowledgments

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