ENERGY EFFICIENCY IN AIR-CONDITIONED BUILDINGS OF THE TROPICAL HUMID CLIMATE

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ABSTRACT
Energy monitoring was done for 42 air-conditioned commercial buildings. They present high electrical consumption rates: 302KWh.m^2 per year. This is due to a poor thermal design of their envelopes, their exploitation and a poor energy efficiency of equipments due to a lack of standards. Presently, it is possible to save about 12.3%of the national electrical energy consumption ‘‘medium voltage’’, representing 23% of the energy consumption of air-conditioned commercial buildings, if we apply the recommended energy savings requirements. In the case of new buildings, it is vital to improve their thermal design, to select efficient energy equipments so as to avoid the actual waste of energy. It will then be necessary to strengthen our knowledge of the dynamicthermal behaviour of buildings in the tropical humid zones and also to contribute by establishing some energy standards and thermal oriented regulations for constructions.

Keywords*: energy efficiency, conditioned buildings, tropical humid climate, energy audits.*

NOMENCLATURE

Ce	Electric consumption of anair-conditioned building (kWh)
CV	Thermal contributions per unity of conditioned volume (W.m^{-3})
Dla	Douala
Fs	Wall’s solar factor (without dimension)
dif	diffus
glb	global
IR	Solar radiance (kWh.m^{-2})
K	Wall’s thermal transmission coefficient (W.m^{-2}.K^{-1})
R	average solar irradiation incident on the wall for the considered period (W.m^{-2})
ROM	ratio of the glazed surface by the wall’s one.
S	total area of outsides partitions (m^2),
Te	outside air temperature (°C)
Ti	indoors air temperature (°C)
V	Volume of building or the one of the considered part of building (m^3)
Ydé	Yaoundé

Subscripts

i	Wall’s identification
o	opaque
v	glass

1. INTRODUCTION

The mastery of energy in building aim a double objective: best as possible, answer to the comfort need while reducing energy consumption. So, national thermal standards (present in numerous countries) aim particularly to specify requirements or standard situations, so that thermal engineers could evaluate thermal characteristics of their projects with the same base. However, in west African countries and those of the center (except the Ivory Coast), this base is not defined. That is why, in Cameroon, construction engineers base their calculations during the design of new buildings, in knowledge linked to the thermal of building and the control of air-conditioned ambiances developed in moderate countries. Are those moderated conditions adapted to the tropical climate? What will be their incidence on real electric consumptions of buildings?

An analysis of energy audits realized in 42 buildings of tertiary activities of Cameroon (build in the 70, 80 and 90 decade), could help to answer questions above (table 1). These audits took place in the cities of Yaoundé (latitude 3°52', longitude 11°32') and Douala (latitude 04°01', longitude 09°44') where buildings represent about 75 % of the national average voltage electric consumption [1].

Table 1. Description of general characteristics of existing buildings

Cities	Types of building	Orientation	Type of walls	Wall's color	Roofing's type	Solar protection	Type of glass	ROM
Yaoundé	(CHE) hospital	E/O	Concrete Block	Clear	Tile	any	Double et Nacco	35 %
	SCB-CL Bank	E/O	Block of glass	Brown	Non-isolated tile	interior curtain	Simple	45 %
	SOFITEL hotel	E/O	Concrete Block	Brown	Isolated tile	Interior blind	Tinted	30 %
	Public (MINREX)	E/O	Concrete	beige	Tile/ sheet metal	Mediocre	Nacco	25 %
	Group of 17 public and private buildings of the tertiary activities	80% E/0 20% S/O	40% concrete block and 60% glass block	80% Brown and 20% beige	Tile/ sheet metal	40% interior curtain 80% any	30%simple 20% Nacco	50 % à 70%
Douala	General hospital	E/O	Concrete	beige	Tile	Any	Nacco	40 %
	(BICIC) Bank	E/O	Block of glass	Brown	Non-isolated tile	interior curtain	Tinted	80 %
	SAWA hotel	E/O	Concrete	Brown	Isolated tile	Solar-break	Simple	30 %
	Public (ONCPB)	E/O	Concrete and glass block	Beige	Tile/ sheet metal	Any	Simple and Nacco	70%
	Group of 17 public and private buildings of the tertiary activities	80% E/0 20% S/O	60% concrete block and 40% glass block	Beige and Brown	80% non-isolated tile 20% isolated	30% interior curtain 70% any	60% simple 40% Nacco	40% à 70%

2. APPROACH OF BUILDING'S FUNCTIONING

In order to show the role envelope in the building's energy consumption, we will present this approach of the building's thermal working in hot climate [2]. Because of simplified considerations, we choose the case of conditioned buildings with a light thermal inertia and maintained at the constant indoor temperature of (Ti). We consider only the conduction and radiation heat gains. In that case, the building's provided refrigeration power (*Pf*) for the heat compensation due to the envelope is a function of his global volume's coefficient of thermal contributions (CV). So we have:

$$Pf = CV \cdot V \tag{1}$$

$$CV = \frac{\left(\sum K_o \cdot S_o + \sum K_v \cdot S_v\right)\left(T_e - T_i\right)}{V} + \frac{\sum Ri \cdot Fsi \cdot Si}{V} \tag{2}$$

$\sum K_o \cdot S_o$: Conduction heat contributions through opaque partitions (W.°K^{-1})

$\sum K_v \cdot S_v$: Conduction heat contributions through the glazed partitions (W.°K^{-1})

We can also evaluate the average building's transmission coefficient per unity of area Km by the following relation:

$$Km = \frac{\sum K_o \cdot S_o + \sum \mathrm{K_v} \cdot S_v}{\sum S_i} \tag{3}$$

Let us introduce Km in the CV formulae shown above and knowing that (Σ Si = S), we will have:

$$CV = \left[Km \cdot (T_e - T_i) + \frac{\sum Ri \cdot Fsi \cdot Si}{S} \right] \cdot \frac{S}{V} \tag{4}$$

Fsi represents the heat flow rate due to sun which passes through the wall by the solar radiance receive by the aforesaid wall. For the opaque partition, Fsi = b.K/he, with « b » as the wall's absorption coefficient and « he » the convective heat exchange coefficient.

For a given transmission coefficient Km with the same solar factors, it is noticed that the building's form factor (S/V) have a considerable importance. So, CV will have a light value (and the provided refrigeration power too) if the building has a little partition area exposed to the solar radiation. In the same way, Fsi and the energy needs will be reduced with the improvement of the wall's solar protection (glazed area principally). Otherwise, the reduction of the ratio of the glazed surfaces by the opaque ones will reduce the CV coefficient and air conditioned needs.

3. IMPACT OF ENVELOPE ON ENERGY CONSUMPTIONS

3.1 Ratios of energy consumption

The cooling of the 42 audited buildings represents, based on the building, 60 % to 72 % of their global electric consumption (figure 1). The ratio of the electric consumption (kWh/m^2/year) of a building is an indicator allows us to situate the specific consumption compared to the other buildings considered as references. The specific consumption ratios found for the 42 studied buildings are high (302 kWh/m^2/year in average, for the buildings of less than three floors and 450 kWh/m^2/year for those with more than three), compared to the reference specific consumption 160 kWh/m^2/year [3].

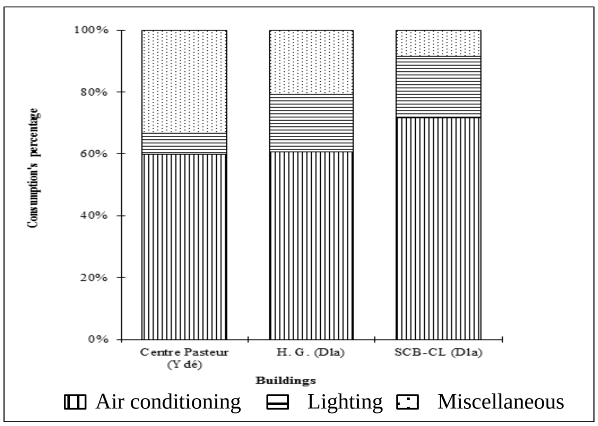

Figure 1: Yearly electrical consumption balance

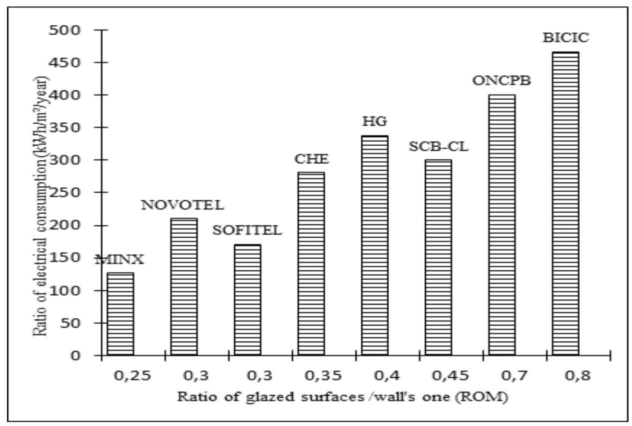

Figure 2: Influence of ROM on building's electrical consumption ratio

Let us design by ROM, the ratio of the glazed surfaces by the opaque's one. The figure 2 shows the influence of that coefficient on the electric consumption ratio in conditioned buildings. This confirm the fact that the building's envelope has an important impact on the thermal loads due to the building and therefore on the electric consumption.

3.2 Modal identification of energy system (building)

For an existing building, it is very difficult to schedule all the physical parameters used to build a model of building's thermal behavior. Here, an empirical approach is used. It consists to sum up the real energy consumptions of the building in order to define a model of energy behavior. With this model, if it is representative, the extrapolation of the building's thermal behavior will be possible.

The thermal evolution of the building (the thermal response) is a function of the outdoor climate solicitations. Specially, they are the solar radiance and the air's temperature. So, we will assume that there is a linear correlation between the energy consumption of a building and the climatic variables. For this model, we choose the easily accessible variables which are: the average monthly temperature of the outdoor air and the monthly global average irradiation on the horizontal surface.

In first approximation, we applied a simple regression of the building's monthly electric consumption (Ce) on the outdoor average temperature (figure 3) and the solar irradiation. Then, a multiple regression (r, correlation coefficient) of the building's energy consumption on the same outdoor temperature and the solar irradiation. In that case let us show an example of the "*Centre Pasteur*" of Yaoundé.

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$$Ce = (4763.47)Te + (4.3798)Ir - 87814.844 \quad (r = 0.70) \qquad (5)$$

The found correlation coefficients for the examined buildings are relatively high. They show the considerable influence of the outdoor climatic solicitations (which act on the building's envelope) on the energy consumption of buildings in tropical climate.

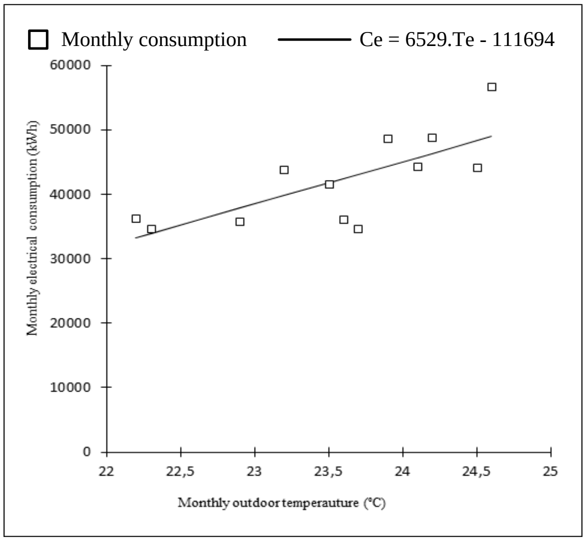

Figure 3: Correlation of electrical consumption and the outdoors's temperature

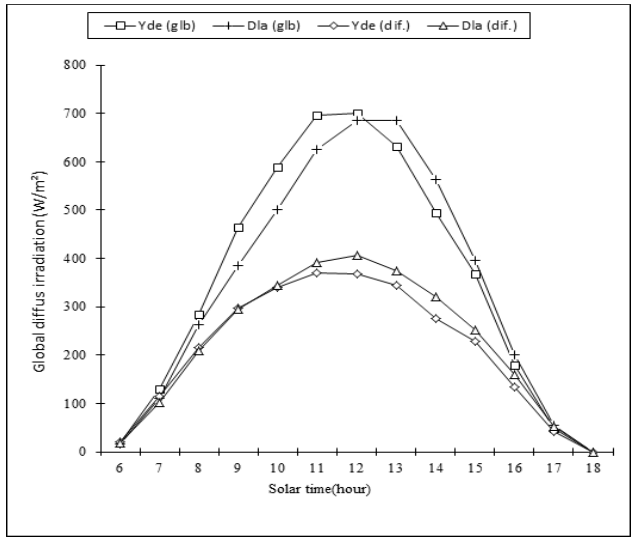

Figure4: Global diffuse irradiation of the hottest month

4. SYNTHESIS OF ENERGY AUDITS IN TERTIARY BUILDINGS

4.1 Envelope characteristics of existing building

The general characteristics of the 42 audited buildings in Douala and Yaoundé are (table 1):

- A modern architecture based on the European's models (building in concrete with glass);
- An arbitrary orientation, the East/West is the frequently one;
- A lack of the suitable solar protection of windows;
- A glazed surfaces higher than the opaque's one;
- The glass quality different from a building to another (lucid color, tinted or reflective). We even find some windows with adjustable gills (nacco) in some air-conditioned buildings.
- A dark color of outdoors's partition;
- The roofings and floors which are not thermally isolated, with a serious problems of tightness due to the weak slope of the tread although the high level of rain (4125 mm per year in Douala) and the worst position of the steambreak.

4.2 Indoor conditions

The temperature levels found in those buildings are relatively weak (18°C to 22°C) and the rate of humidity fluctuate from 55% to 80%. This might be due to the worst quality of regulation or possibly, the problem of the design efficiency. The installed refrigeration power is different from buildings to another. For example, the "*Centre Pasteur*" has an installed refrigeration power of 84,5 W/m^3 of the air-conditioned volume, the "*General Hospital*" 33,8 W/m^3, "*SCB-Credit Lyonnais"* 15 W/m^3.

Indeed, the refrigeration loads are evaluated according to the software developed for the moderated climate (Carrier, ASHRAE, AICVF) [4]**.** The reference outdoor conditions used for the thermal load's calculations in the above software are not adapted to our real conditions. So, those calculation methods consider that the direct solar flux is most important than the diffuse one. However, in humid tropical climate, the case of the Cameroon for example, the diffuse flux represents more than 50 % of the global solar flux. (Figure 4). While using the adequate data for the load calculations in the humid tropical climate, it will be possible to reduce the refrigeration power of 17 %. [4] [5]

4.3 Audits of air-conditioned systems in existing building [6]

60 % of the air-conditioned systems audited are the Windows types, most loud and greedy in energy. 30 % are the "split systems" and 10 %, the wardrobe system. The full air air-conditioning system, with constant air flows and single duct are those generally found in private buildings also called moderns one (bank, hotels, and office

buildings), build in the 90th decade; they have a high electric consumption rate. The fan's electric consumption becomes prohibitive in the case of high pressure systems audited. Since the years 2000, those systems are increasingly abandoned and the place is leaved to the centralized air-conditioning systems, more economics. Since 2006, the "INVERTER" system appears and is now used in many new buildings [7]. They adapt the compressor's speed according to the cooling load of the air-conditioned zone and therefore, reduce the energy consumption.

4.4 Energy efficiency of existing equipment

Energy equipment in audited buildings (centralized air-conditioning systems, single air-conditioning systems, splits systems, lighting systems, elevators, pumps, etc.) don't have improved energy specifications. The refrigeration efficiency (Copf) of installed air-conditioned equipment is not in conformity with the standards. This is due to the technology relatively old or maladjusted to the tropical conditions, the lack of standards and technical control in that field **[7]**. This situation is most complicated with the insufficiency of preventive maintenance and the worst quality of management, which reduce the refrigeration efficiency. Nevertheless, the introduction of INVERTER system mentioned above would permit in short term an improvement of 20 % of the refrigeration efficiency coefficient (COP) and a reduction of 30 % in electric consumption, compared to the traditional split systems [7].

4.5 Audits of electric consumption in those buildings

Electricity is the common used energy system in those buildings. In hospitals and hotels we find also gas and fuel. Transformers are commonly overestimated and permanently in charge even if they are not used. This is what increases the energy consumption due to the transformer loses. The asked power rarely reaches the rate 60% of the provided power and that is what explains the penalties commonly paid, for the non-reach guarantee of consumption; in fact there are some guarantee kWh which are not used, but are paid. With this aspect, it is easy to notice that the electrical design was not efficient.

The power factor is generally under 0.8. This causes the penalties paid for the worst power factor.

Energy consumption ratios are abnormally high compared to those of the reference buildings which are 302 kWh/m² for the buildings of less than three floors, and 450 kWh/m² for the buildings of more than three floors [6]. These data clearly explain the high consumption of electrical energy due to the air-conditioning system and implicitly, the lack of standards and politics of energy save at the national scale.

4.6 Measures of energy save

Requirements for the reduction of electric consumption in audited buildings have been identified [5] [8] [9]:

- Installation of programmable clocks, used for the command of air-conditioning systems and intermittent stops;
- Improvement of regulation (action on the required temperature and relative humidity);
- Increasing of the required temperature during inoccupation periods;
- Improvement of refrigeration systems performances[12];
- Canceling of conditioned air in elevators, laundry, launderette and kitchen;
- Stop of the heating devices in the air-conditioning systems;
- Stop providing new air during inoccupation periods;
- Reduction of the air renewal flow rate;
- Improvement of lamps and ballast energy efficiency;
- Reduction of the number of lamps and stop artificial lighting when natural lighting is sufficient;
- Cleaning of filters;
- Optimization of the provided power, amelioration of the power factor (installation of battery of capacitors).

On the 70500 MWh/year consumed by the 42 examined buildings, 21 300 MWh/year (30 % of the total consumption) might be saved by the application of the above identified requirements. Investigations need about 1, 2 millions of euros, with a time of return of investment less than two years. Applying all those requirements on all buildings of the tertiary activities with the same characteristics of our sample could bring the energy save potential at the value of about 84 MWh/year, which represents 23% of the total electric consumption for all buildings of the tertiary activities and 12.2 % of the average voltage electric consumption. Necessary investments are about 6 millions of euros; 53 % of these investments have a time of return on investments of 2 months and it concerns the project of improvement of actual working; 26% have a time of return of 17 months and 21 % a, 20 months.

4.7 Institutional environment and structure

Energy save requirements proposed above can be applied on all buildings of the tertiary activities in Cameroon. For that reason, it will be important to develop at the country scale, a national program of energy savings. Now, it is notice that the Cameroonian's institutional frame doesn't encourage the application of those requirements [7]. This climate is actually characterized by:

- A lack of standards or recommendations of energy efficiency in buildings and their equipment ;
- A lack of incitements to save energy. In fact, there aren't any laws or recommendations which encourage investments in energy save; rather the taxes laws discourage investments while granting 10 % per year of investments to heavy equipment [5], [10]**.**
- Really, there is not a politic of energy save on behalf of the energy supplier after his consumers to reduce energy consumption in order to manage supply and demand. For example, the pricing of the national company of electricity doesn't incite companies sufficiently to improve their power factor. [10]
- Deficiencies of permanent structures (governmental, quasi-public….) with a fundamental objective of energy save at the national scale (promotion, technical support, control…).

5. CONCLUSION

The Cameroonian tertiary buildings have been realized in absence of energy conservation restrictions. This is explained by an electric consumption relatively high. This situation is essentially due to the absence of standards and conventional criteria of thermal calculations of each building's components. Yet, 30% of the total consumption of those buildings might be saved by the application of identified requirements of energy save.

The presentation of the building's thermal functioning in hot climate permits to elucidate the influence of envelope on air-conditioning needs. The modal identification of building by the correlation of their electric consumption on the climatic parameters might help to characterize precisely, his thermal behavior. It has confirmed the link between the climatic solicitations and energy consumption of Cameroonians buildings and the importance of air-conditioning in their energy balance.

Therefore, it is necessary to deepen our knowledge about buildings thermal behavior in hot climate and contribute to the definition of energy standards and thermal recommendations for construction in tropical zones. These standards will precise all performance criteria of each energy components of building: envelope, lighting, air-conditioning, energy management etc.

The effective implementation of standard applied on new buildings (energy quality code of air-conditioned buildings) will contribute to the success of energy save program at the national scale, if the Cameroonian government improves the institutional environment by the adoption of the legal text on financial matters (taxes, custom, investments, politic of pricing).

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