Comfort Levels for Office Environment Users

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ABSTRACT: The purpose of this study consists of verifying the efficiency of building façade materials and natural ventilation systems to control internal temperature in the office buildings of the city of Sao Paulo. It is assumed that such systems must achieve office environment users' standard comfort levels to be considered efficient, as well as maintain a reasonable relation between cost of implementation / performance, contribute to energy consumption reduction by minimizing the use of artificial air cooling systems and be easily operated by users and/or autonomous systems. For that, heat changes between building envelope, external environment and heating produced by internal environment occupants and/or equipment investigations were carried out with the objective of verifying in which period of the year optimum comfort levels can be reached through the means of natural ventilation, mechanical ventilation or cooling systems and how much energy has to be consumed with each alternative. Moreover, it pointed out how passive technologies can contribute to decreasing energy consumption in such circumstances. This approach has to also take into consideration data about air quality, in order to check diverse elements concerned to user comfort levels. This analysis evaluated different elements of building envelopes, such as window-wall ratio and components' thermal characteristics, in addition to different types of office floor programs and areas.

Keywords: energy consumption, comfort level, building material, natural ventilation, office building.

1. INTRODUCTION

The consumption of electricity in the urban centers has grown faster than the capability for increasing its production, creating one of the biggest urban infrastructure problems in Brazil.

There is an international trend towards reducing electricity consumption in the great urban centres. Many countries have created codes and regulations concerning energy efficiency, which intend to encourage this trend. In 1974, France founded the AIE – International Agency for Electricity, who was co-responsible, in a period of eight years, for more than a 25% reduction in the electricity consumption of new buildings [1].

Apart from the electricity rationing adopted by the federal government as an emergency solution for the immense energy crisis that hit the country in 2001, Brazil does not have thermo-energetic regulations that may insert the country in this global picture of resource optimization. This would be guaranteed by means of legislation forcing such directives.

According to data supplied by the Government Energy Agency [2], the commercial sector is responsible for 14% of the consumption of the electrical energy produced in the country. Moreover, this sector shows high potential of intervention from the architectural design team aiming the reduction of the user and building energy consumption [1]. Simple actions, like adjusting the project to the climate in which it is being carried out, are already capable of achieving huge results. This is the reason a number of architecture offices include themes like automation and auto-management systems in their project guidelines for the buildings, which tend to minimize the expenditure coming from the artificial air and light conditioning [3].

Such buildings have become widely known as “intelligent buildings”. However, quite often, despite using high-tech solutions for managing the systems, some of these buildings would be more efficient and economical if, apart from building automation, they used another approach called “intelligent architecture” [4]. This employs the use of passive technology elements which would contribute to improve thermal and lighting performance and, consequently, reduce or avoid unnecessary energy (or any other equivalent) consumption.

These passive technology elements should be adopted by the design team from the first sketches stage. They should take into consideration and benefit from all the characteristics of the local microclimate.

As described in many works [5, 6 and 7], this could be achieved by implementing correctly the solar chart, making use of the natural ventilation, inertia and thermal deadening. A conscious choice of finishing materials such as opaque envelopes, reflectors or glazing can be more efficient than many building automation systems on the market, so we suggest that all the possibilities for passive solutions should be tested before investing in the artificial ones.

2. THE CASE STUDY

The office tower studied, Dacon Building [8], is situated in an important commercial area in the City of São Paulo, Brazil. As shown in figure 01, it consists on a 25-storie high cylindrical-shaped tower, covered by a skin of glass, meaning a 100% window-wall ratio (WWR). This exposes the internal working environment to direct solar radiation the whole yearlong.

Figure 01: The Dacon Tower.

The study of this building was carried out based on a method of Post-Occupation Assessment [9], with emphasis on energy saving and environment comfort. It proposes an evaluation of the user's thermal comfort index inside the building; assessing their behavior, productivity and clothing, as well as the quality of the environment in relation to temperature, air speed, humidity and light levels. To achieve this, data was collected from two assessment sources: users and technical information. Based on the joint analysis of this data, it was possible to point out the positive and negative characteristics of the working environment.

The data was collected by means of non-structured interviews with the workers of one of the several companies located in the building, facility managers and the building administrator. This last one supplied technical data concerning the total monthly and yearly energy consumption, as well as the necessary information for calculating the energy consumption by end-users on each set of equipment, such as: air conditioning systems, artificial lighting, computers, lifts and water pumps. Physical measurements were carried out in the building, as well as the measurement of natural and artificial light levels in pre-established points in the office.

2.1. The user's perception

In addition to the building users' testimonies, the research carried out also included a critical analysis of their behavior, taking into consideration criteria which define thermal comfort, such as clothing and physical activities. The users' comments referring to thermal and spatial comfort in the environment are summed up as follows (see also Fig. 02):

Internal temperature is excessively high during the summer months, making the use of artificial air conditioning obligatory. The air conditioning is turned off only on rare occasions during the year.

Natural light is very intense close to the windows, causing visual discomfort to computer operators. As a solution for light-control, dark gray Venetian blinds were put up but mentioned as an aggravating factor for the discomfort due to the excessive heat that it dissipates. These Venetian binds are kept closed during great part of the day, making it necessary for the office to use only artificial lighting.

Some users also mentioned the fact that there was little artificial light to compensate for the lack of natural light and the lamps were not well positioned. This leads to shadows on the working tables and darkening of the computer screens.

The dark partitions were also mentioned as being unpleasant since it, according to the opinion of some users, makes the environment "less spacious".

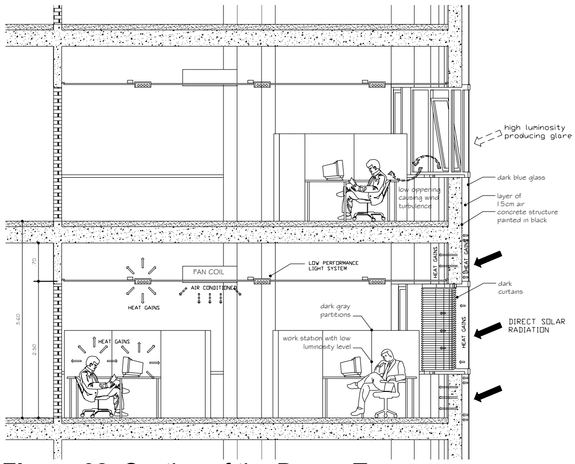

Figure 02: Section of the Dacon Tower.

By means of behavior observation it was possible to verify that, in general, the thermal resistance index of the building users' clothing would be at approximately 0.5 CLO [10] for both men and women. Activity levels were considered of a low metabolic rate as they carried out various light office activities (except for coffee and cleaning staff that would be carrying out medium metabolic rate activities).

2.2. Electric Energy Consumption

The analysis of all the elements supplied by the administration office and the primary data was of great importance as it allowed the tracing of the energetic consumption rate and the discovery of which agents cause the energetic deficiencies in the building. Once the results obtained from the analyses were ready and compared with data from studies already done on the subject, some statements can be made in relation to the energetic performance of the building:

- It was verified that the average annual consumption in the building is approximately 19,85kWh/m^2 per month, reaching 23.00kWh/m^2 in peak moments. Other researches showed average results of commercial buildings around 14.95kWh/m^2 [1 and 11]. Even the best results found in our research were above this value.
- It was seen that the consumption of the artificial air conditioning system represents up to 62% of the monthly expenditure, and studies conducted by PROCEL [12] showed that for a great part of the year it is much higher than 48%.
- Although the air conditioning is the highest consumer of electricity, there was confirmation to the fact that the lighting power density in these offices was 20.20W/m^2, also at a higher rate that was found in other studies (17.70W/m^2) [1 and 11].

2.3. Natural light levels verification

In order to carry out this stage, a digital light meter (luxmeter) was used. Three measurements were taken: one in the morning, one during lunchtime and one at the end of the afternoon. The internal measurements were accompanied by the variation in the quantity of external light, measured always at the beginning and at the end of each stage, on the top of the building. Measurements were taken at each meter as far as the partition on the opposite side, always maintaining the luxmeter at working area height. The amount of light was measured in the following variations: only natural light, only artificial light, and natural + artificial illumination combined. After these measurements the spots with deficient lighting were defined and an ideal *layout* for the light fixtures was drawn. The spots were rearranged in order to make the best use of it. According to the tabulation and analysis of the resultant numbers, the following conclusions are presented:

- The measurements up to a meter away from the windows showed excessive natural light, causing discomfort to the users. However, it was confirmed that the light level reduces very fast toward the interior of the room, to the point of insufficient office work levels at half way across the room. In the table 01 of the Interior Lighting Specification Brazilian Standards NBR-5413/92 [13], it is required from 500 to 1000lux for office activities and any natural lighting level below this minimum should be complemented with artificial lighting system.
- In the environments that it was possible to measure only the levels of artificial light, the Venetian blinds were closed and the analysis was done. The results showed that light was not distributed homogeneously, since differences higher than 50lux appeared from one spot to the other. This variation can be discerned clearly by the human eye, causing visual discomfort [13].

2.4. Diagnosis and partial conclusions

According to the analysis of the data collected in this case study; it was possible to identify the main negative aspects, both from the point of view of the user's comfort, and to the energetic performance of the building, as well as the causative agents.

It was confirmed that the architectonic project of the building is intimately linked to its thermal performance. Its shape (cylindrical) and its involving material (WWR 100%) increase the effects of the solar radiation that reaches the interior because of the intense radiation during the day (almost half of the building is subject to it all day) and the low thermal inertia of this type of material. Having *trombe* walls [14] also contributes in conducting the heat to internal environment.

The few openings for ventilation are located at a low level, causing turbulence and discomfort in the work plan. The windows do not allow night cooling because they are not motorized. This could delay the need for air conditioning the next morning and considerably reduce the energy consumption.

The lighting system was also confirmed as being inefficient: with high consumption and low efficiency. There was also no light shelf or other device to support the better use and diffusion of natural light to the interior of the building.

3. A SUSTAINABLE BUILDING PROTOTYPE

With the purpose of assessing the benefits of sustainable architecture concepts in office buildings, a prototype of a commercial building was developed for the same site of the building studied in this case. This "new project" made use of passive technologies and dynamic façades as important factors for environmental comfort from its conception. The tower volume considered the solar chart and predominant wind directions. Concerning the use of natural wind flows, it must be said that the adopted shape was strongly influenced by the possibility of using natural ventilation, so that the façade with the longest extension should receive orthogonal ventilation in relation to the predominant South Westerly wind direction (see Fig. 03).

While talking about the directives of the project, it is worth mentioning the position of the stair wells and elevators, positioned to serve as heat barriers on west and east façades, the two most exposed to solar radiation [7].

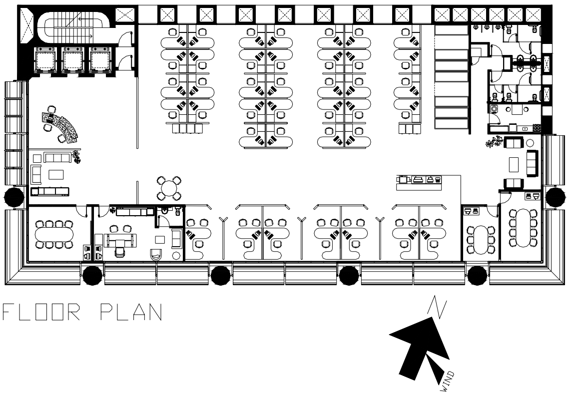

Figure 03: Floor plan.

As the solar radiation does not reach them in a homogeneous manner, the relation between opaque materials and openings was developed with different solutions for each façade orientation. Therefore, the South façade was conceived with 90% WWR, but with control of direct solar radiation in summer months. Horizontal louvers were positioned to bring natural light into the building around midday (see Fig. 04 below).

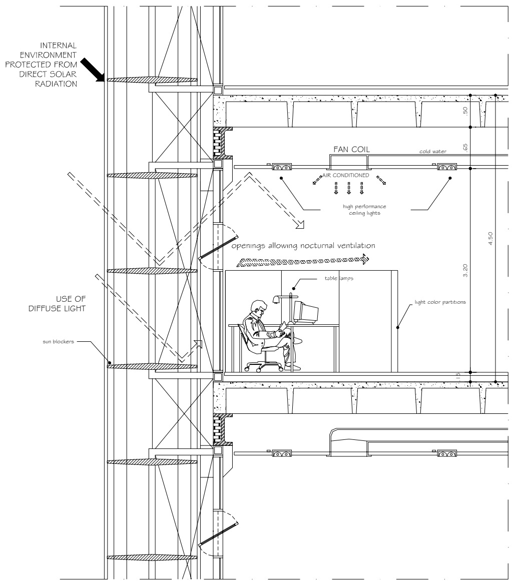

Figure 04: Section crossing South façade of the Prototype.

The East façade has a 60% WWR and is also protected by horizontal sun louvers. The North façade has only a 10% WWR due to the shape of its louvers functioning as both horizontal and vertical sun-protection, not permitting direct solar radiation into the internal environment during the hottest months of the year. Its openings are sufficient to allow for crossed ventilation in the building (see Fig. 05). The West façade (60% WWR) includes both horizontal and vertical sun breaks for protection against solar radiation right into early evening in the summer.

Apart from adopting a solution in the shape, the choice of thickness and material type would bring more inertia, delaying the transmission of external heat by conduction into the internal environment during the day. In order to achieve this, the façade facing north was composed of double walls (that are also used as technical vertical shafts), with an air entrance in the basement and opening at the top, functioning as "stacks" for the dissipation of heat.

The openings were situated on the upper part of the window, avoiding wind turbulence in the working area. They were also considered motorized and linked to a central independent or BMS control system. This would allow the opening and closing to be linked to the relation between internal and external temperature. E.g. when the outside temperature would be over 23^{o} C, the openings would be shut and the air conditioning system would be started. This temperature is considered the limit for a good rate of environmental comfort, under which people carrying out intellectual work can produce up to 85% of their capacity, but higher than this, production would fall considerably [10].

Automated control of the openings would also allow the use of night cooling for the internal areas of the building, in order to dissipate internal heat gained during the day. On the next day, there would be a reduction in the time span of the air-conditioning usage.

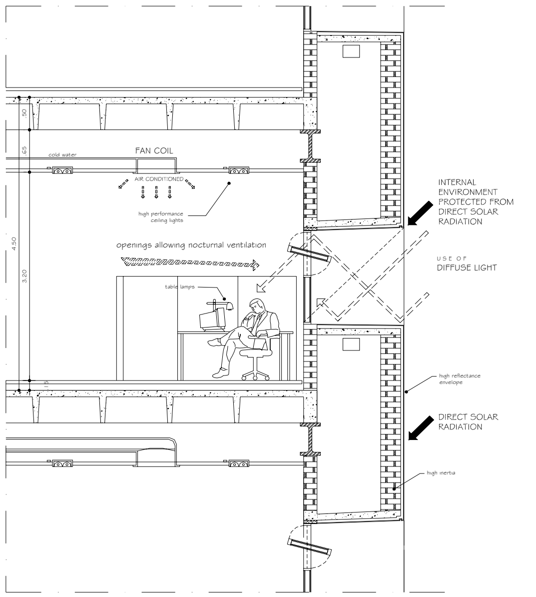

Figure 05: Section crossing North façade of the Prototype.

A transmission system for natural light was also thought of. The diffuse light would be enabled and optimized by using sun breaks and light shelves, increasing the natural light levels in the interior of the building and reducing the use of artificial lighting.

Only at this point did the active technology criteria interact with the project, permitting a reference to building automation. This would involve not only items related to environmental comfort, such as illumination and artificial temperature conditioning, but also presenting a sort of complexity, that would generate a synergy among all the parts of the building, such as the structured cabling, telecommunication, elevator control, electronic security, fire detection and alarm, as well as the electric and hydraulic management.

4. SIMULATION AND ANALYSIS OF THE RESULTS

This phase involved comparing the results obtained with our research / prototype with those that had been obtained in other studies. In order to do this, simulations of the heating changes were carried out using software [15] that could supply data on the external and internal environment temperatures. The latter indicated the combined effect between the internal air temperatures and the superficial environment ones, which have a great influence on the sensation of heat perceived by people. Again, 23°C was adopted as the limit-temperature for thermal comfort [10].

The variation in the environment temperatures were simulated for all months and the following conclusions were obtained:

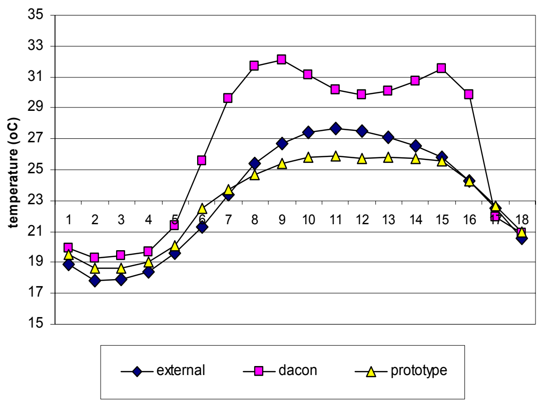

Figure 06: Temperature changes – January.

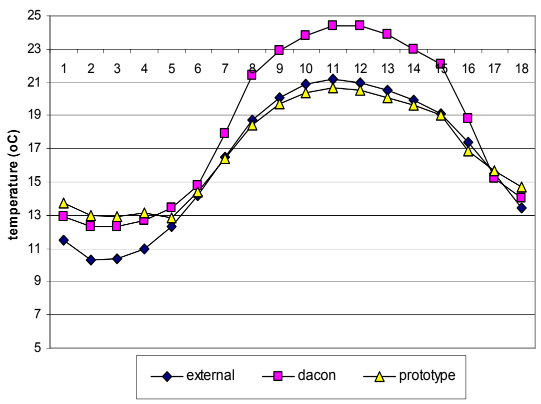

Figure 07: Temperature changes – July.

- For all the months assessed, as can be observed as an example given on figures 06 and 07 above, it was possible to conclude that the prototype's internal environment temperatures were always lower than those of the external air between 10a.m. and 5p.m. In this period of the day the solar radiation is more intense. Therefore, it is possible to say that either the external heat is blocked (appropriated thermal inertia and/ or thermal isolation of the materials used in the façade), or there is a correct dissipation of the heat with the use of natural ventilation.
- The same does not occur in the Dacon Tower simulation, where the low-inertia skin glass on the façades are not able to dissipate the heat absorbed from the external environment at the same speed in which it is acquired, increasing the need of air conditioning systems.
- Based on previous researches, the use of artificial air conditioning in most of the office buildings is necessary during the entire year. However, in this simulation, the need for using air conditioning only during the summer months was confirmed (when the external air temperature reaches levels higher than 23°C). Even so, the use of air conditioning would be necessary to reduce the internal temperature by a maximum of 4.5°C. On the other hand, the Dacon would need to cool almost 10°C in some peak hours.
- The study determined that in these circumstances the windows would be kept closed during the day and open at night, which would serve for delaying the need of operating the artificial air conditioning.

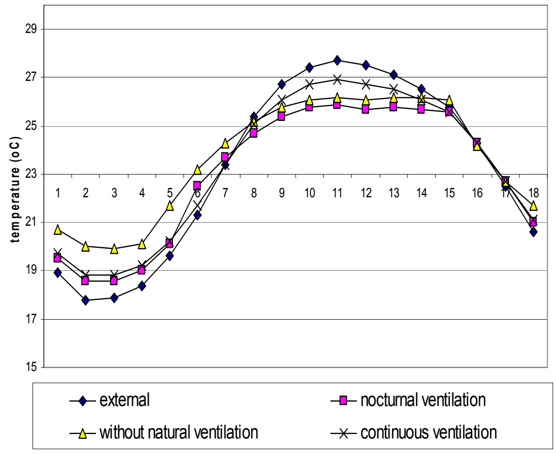

Figure 08: Ventilation mode.

The efficiency of this strategy was confirmed with the variation of the window operation modes during the month of January, the hottest in the year.

As demonstrated on Fig. 08 above, utilising night cooling strategy linked to closed openings during the day obtained the lowest temperatures. Even when compared with other schemes, such as continuous ventilation or closed openings during day and night.

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