AN USER-FRIENDLY COMPUTER PROGRAM TO PREDICT IN EARLY STAGES OF PROJECT THE THERMAL COMFORT AND ENERGY EFFICIENCY OF BUILDINGS UNDER TROPICAL CLIMATE CONDITIONS

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ABSTRACT

In a building, energy consumption and user's comfort are directly related to its thermal performance. In early stages of building design, architects do not have enough input data to perform precise calculations. Anyway, due to the importance of the initial concepts on the building future behavior, it is important to carry out that evaluation. In fact, it is possible to achieve a ranking of good project solutions following a parametric study approach. Expert rules can be extracted from the tabulated results of a great number of simulations over a standard digital prototype and under various project conditions. A simplified prediction computer program can then be developed to integrate both those expert rules and a multicriteria ranking strategy to allow architects reasonably estimate which are the best design concepts among diverse study configurations. This work describes the efforts that are being taken to develop such user-friendly computer program to be utilized mainly for tropical climate simulations. Firstly, the necessary steps to develop the code are exposed. Then, the reference virtual building, some simulations, their results and sample expert rules found are presented. Finally, some considerations of the methodology to rank the project alternatives are discussed.

KEYWORDS

thermal comfort, tropical climate, parametric study

INTRODUCTION

In a building, it is well known that the thermal performance, energy efficiency and user's comfort are closely related. Despite that, in the first stages of a project, it is very difficult for an architect to predict the future behavior of a building concerning these parameters, mainly because architects tend to design buildings following a "whole-building to smaller-detail" approach (Ellis et al, 2001). This means that at the initial stages of the design process, only general solutions are taken into consideration (Shaviv et al, 1996), and no detailed specification is available, like building materials or fenestration type. Such lack of precise information also limits the utilization of computer programs capable of evaluating and simulating the building's future performance because the great majority of them require detailed inputs to perform the calculations. Another problem is that architects generally have difficulties to deal with those applications because they are aimed to the researcher or to the thermal engineer. Unfortunately, it is at this conceptual phase that the impact of design choices on the energy performance of the building is more important. So, the development of an user-friendly tool capable of evaluating the impact of the initial design alternatives is very important.

It is clear that, due to the uncertainties of the design at this conceptual stage, the inputs must be as simple as the choices taken at this project's phase, i.e., building orientation, simplified geometry, gross window area, etc. With these simplified inputs, one way of assessing the building performance is making the computer program estimate it through what we can call "expert rules". Those rules are not capable of calculating the absolute values of data like the interior temperatures or illuminating levels, but are capable of describing the global behavior of the building for various project conditions like fenestration area, wind speed and direction, and so on. The target is then not to predict numerically the future performance of the building, but to evaluate the quality of the building performance when this performance is compared to other project configurations. In that way, by comparing the initial design studies, the architect is capable of, at least, avoid the worst alternatives.

THE COMPUTER CODE DEVELOPMENT SCHEME

To develop this prediction tool, three main tasks must be accomplished.

Firstly, it is necessary to establish the input parameters. This means choosing the input data that can be extracted from the architects' initial design schemes. In our point of view, this means the following building parameters: Building orientation; Building situation (altitude, latitude and longitude); Building exterior dimensions (width, depth and height); Simplified exterior walls compositions; Simplified wind speed and direction (mean monthly values); Simplified building typology (with one or two principal facades); Total window area in the main facade (in percentage); Type of solar protection in the main facade;

The second task is to find out what is the behavior of the building when we consider the variation of one or more of the input parameters. In other words, discover the "expert rules" that will enable to qualify the various project alternatives the architect has in mind. To obtain these expert rules, we can study buildings with multiple configurations and then discover the "hidden" rules of design. This can be done by means of computer simulation, and examples already exist in the literature (Gratia et al, 2002., Lam et al, 1997). Unfortunately, there is a known problem with this type of knowledge-based prediction tool we want to develop: they suffer from the inherent over-simplicity of the rules, mainly because these last ones are derived from a limited number of examined standard cases (Shaviv et al, 1996). Clearly, the predictions will be as different of the real building behavior as the project is different from the virtual prototype that was used for the simulations. To avoid this problem, the code developer and the user must accept that such tool is appropriate to be utilized only for certain project configurations, i.e., configurations similar to that one used in establishing the expert rules themselves. In other words, the code is a less generic tool but the precision of the results is guaranteed. In our study, that precision is achieved by limiting: Type of climate (tropical humid) and summer condition; Building typology (medium multi-story office building); Limited number of exterior wall compositions. Considering that, one can perform the simulations over a standard digital prototype under various project conditions with a "research" simulating tool and tabulate the results. In our case, the TRNSYS computer program is used for calculating the thermal performance, RADLITE (Castro, 1996) for the daylighting simulations and COMIS and a proprietary code based on the AIDA (Liddament, 1996) named AEOLUS for the ventilation/infiltration prediction (Bastos, 2000).

The last main task is to enumerate what we want as output results and how to evaluate those results to qualify the various chosen project configurations. Our main goal is to develop a prediction tool capable to evaluate thermal comfort, natural light availability and global energy consumption. So, these three parameters reflect the qualities and therefore the desired outputs of our code. Unfortunately, these three factors are sometimes conflicting. In the majority of the situations, to provide natural light inside the building also means to allow high heat gains, for example. Discover what are the best project designs can then be taken as a decision making process, where all these conflicting factors have to be considered. Multicriteria decision-making procedures are widely applied today to ensure a rigorous analysis of this type of process. These procedures are applied for the evaluation and ranking of various alternatives and it is demonstrated that this approach is realistic and produces reliable results. The ELECTRE III (ELimination Et Choix Traduisant la REalité) is a multicriteria decision-making method (Roy, 1977) and is the one we have chosen to integrate the computer code.

SAMPLE SIMULATIONS AND KNOWLEDGE-BASED RULES

We established a reference virtual building that was submitted to all the simulations, having the following characteristics:

(i) typology: a medium-size multi-story office building, presenting a strong bilateral configuration, i.e., the office rooms taking one half of the floor and the service areas taking the other half. These service areas comprise a corridor, stairs, bathrooms and elevators shaft. The office floor surface takes $240m^2$ from a total floor area of 384 m^2.
(ii) weather: the building is considered situated in a tropical humid area.
(iii) materials: wall compositions were chosen among the most used by the Brazilian construction industry for that type of building. Single panel windows were considered for the same reason.
(iv) occupation: the offices were considered occupied from 07:00h to 19:00h on workdays, from 07:00h to 12:00h on Saturdays and not occupied on Sundays.

With the reference virtual building well established a digital prototype having its characteristics was created using PREBID. That allowed us to generate TRNSYS Type 56 building description files in order to perform the thermal simulations. The floor was divided in six thermal zones, as seen in figure 1: left and right offices (ZONES 1 AND 2), corridor (ZONE 3), stairs (ZONE 4), bathrooms (ZONE 5) and elevator shaft (ZONE 6).

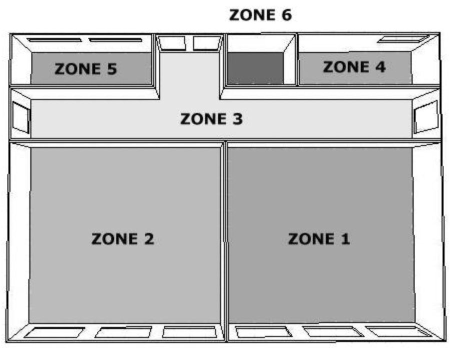

Figure 1. Thermal zones

TRNSYS type 54 was utilized to generate a full year of weather data, based on Rio de Janeiro's monthly mean temperature, humidity and global horizontal solar radiation.

Initially, we verified if artificial cooling was needed to achieve thermal comfort. A group of simulations was carried out varying the building orientation from 0 to 345 degrees with a 15 degrees step. All simulations utilized the period of 21/january to 19/february as having the summer typical conditions. Wind velocity and direction were considered fixed concerning the main facade, and taken from measured monthly mean data. Air renewals inside the various zones were considered as being 10 volumes/hour to a condition of windows opened 24 hours/day. An interior air velocity of 1.5 m/s was utilized to allow TRNSYS type 57 calculate the PPD comfort indexes. Window-to-wall ratio was fixed in 50% for the office zones. For the best thermal situation found, i.e., with the building main facade pointing south, the simulation results show that under these conditions it is not possible to achieve thermal comfort during the occupation times. The calculated PPD is over 10% for the entire day period (the acceptable comfort limit condition). So, mechanical cooling is needed if thermal comfort is intended for the building occupants. Under these conditions, an approach to optimize the building design can be to minimize the cooling loads and consequently, minimize energy consumption.

Due to the necessity of mechanical cooling to achieve comfort, other series of simulations were performed now taking account the air-conditioning of the office spaces (zones 1 and 2). By varying the building orientation (from 0 to 345 degrees with a step of 15 degrees - 0=north, 90=east) and the angle between a normal to the facade and the wind direction (from 0 to 345 degrees with a step of 15 degrees - 0=north, 90=east) we were capable of representing the different scenarios or project alternatives. The PREBID description files were changed to consider a set temperature of 25^{o}C for the cooling apparatus and the new ventilation and infiltration profiles, as the windows of the offices (50% of the facade area) were now considered closed to optimize air conditioning. The other windows were considered opened all times. COMIS and AEOLUS were utilized to calculate for each scenario the air infiltration and natural ventilation. The simulation period of 21/january to 19/february was maintained. Wind velocity was considered fixed at 3.0 m/s. The entering air in the office rooms due to the air-conditioning ventilation resulted in a 5 volumes/hour renewal. A total number of 576 simulations were performed and allowed us to obtain the following “laws” related to the building behavior:

(i) the energy necessary to cool the office areas related to the building azimuth (orientation).
(ii) the energy necessary to cool the office areas related to the wind direction.

The data obtained as results for all the project configurations were the total cooling energy consumption during the simulated period (21/jan-19/fev). All data were then tabulated and normalized by dividing each result by the maximum value of the series in order to homogenize the different units and scales involved. The results of the simulations that studied the influence of building orientation in the total cooling energy consumption showed that this last one follows practically the same profile independently of the other parameter values. In other terms, by varying only the building orientation, the energy necessary to cool the offices varies as presented in figure 2, independently of the wind direction. In the same way, another group of simulations studied the influence of wind direction in total cooling energy consumption. After normalizing the results, we could also perceive that by varying the wind direction, the energy profile followed the curve presented in figure 3.

A third group comprising 24 simulations studied the influence of building orientation in natural light availability, this last parameter being considered as the daily mean illuminating levels taken in a point located 0.8 meters high and 2,5 meters from the window surface, over a line crossing the middle of the room. The RADLITE code was utilized for the illuminating level calculations. A partial overcast sky (no direct solar radiation was considered striking the studied point). After normalizing the results, the profile shown in figure 4 was found.

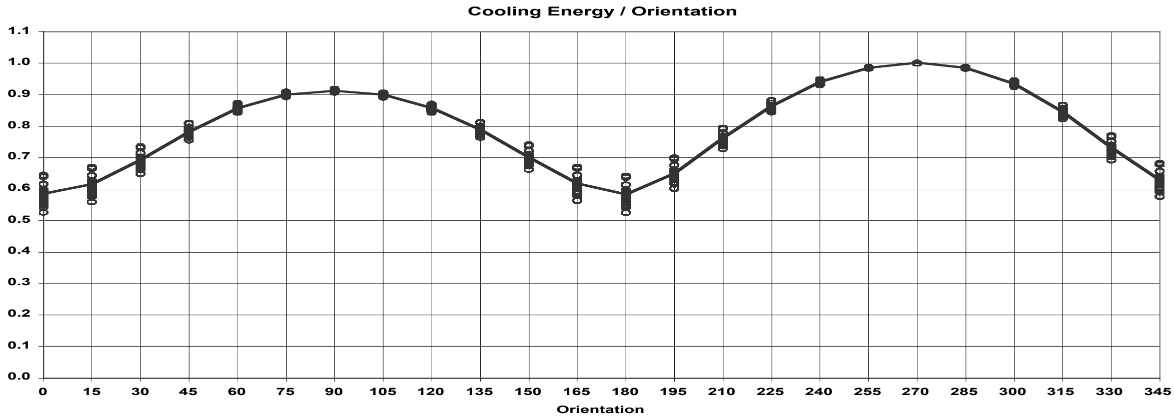

Figure 2. Energy necessary to cool the offices for various building orientations

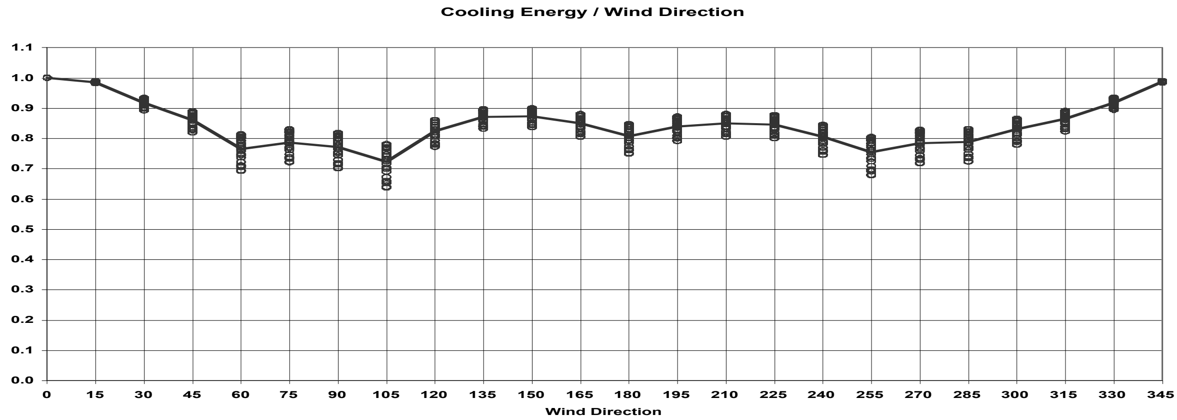

Figure 3. Energy necessary to cool the offices for various wind directions

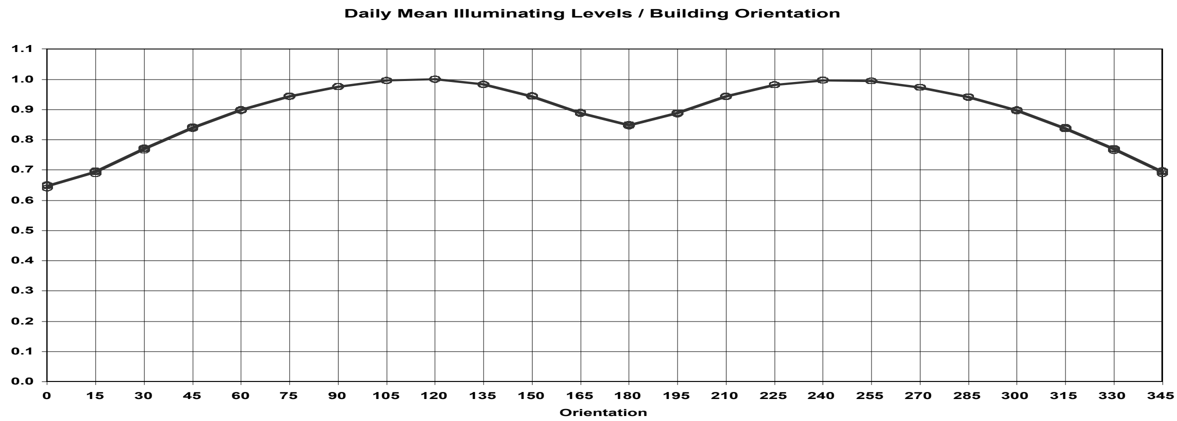

Figure 4. Daily mean illuminating levels for various building orientations

DISCUSSION

The simulation results indicate the following "expert rules" and conclusions:

(i) For this type of office building configuration, considering the utilization of standard Brazilian construction materials, under summer hot-humid climate conditions and not using solar protection devices, it is not probable to achieve thermal comfort by natural means only. So, air-conditioning is a necessity, and in this case, any optimization approach must then be done by means of lowering the energy consumption.

(ii) The relative variations of energy consumption to two parameters, i.e., building orientation and wind direction, follow each one general profiles that are independent of the other parameter. These profiles are described in figure 2 and 3.

(iii) The relative variation of daylight availability to building orientation follows one general profile that is described in figure 4.

Considering these “expert rules”, the task of ranking different project scenarios is theoretically simple. To obtain a “thermal performance index” concerning the cooling energy, it is sufficient to extract from each profile the relative value and perform an interpolation. We can note that worst situation (greatest energy consumption) is a scenario where the building has o orientation of 270 degrees and the wind strikes the main facade at an angle of 0 degrees. In this case, the performance index is equal to 1, all other configurations presenting smaller values. As our strategy is to diminish energy demands, this is the worst situation. Natural light availability can be extract directly from figure 4. In this case, our strategy is to maximize the use of daylight. Following this approach, if one considers diverse scenarios, the best solution is exactly that one which presents the smallest “thermal performance index” and the greatest “daylight index”. It is clear that these two criteria present conflicting results and so a method like ELECTRE III must be used to solve the ranking problem. This is the final goal of our computer code where the criteria are thermal comfort, natural light availability and global energy consumption.

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