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USE OF SIMULATION TOOLS FOR MANAGING PUBLIC BUILDINGS ENERGY DEMAND

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Abstract. *There are several ways to attempt to model a building and its heat gains from external sources as well as internal ones in order to evaluate a proper operation and also audit retrofit actions. These models apply different techniques varying from simple regression to more physically grounded models. A frequent hypothesis for all these models is that the input variables should be based on realistic data when they are available, otherwise the evaluation of energy consumption might be highly under or over estimated.*
In this paper, the use of Energy Plus as an energy consumption auditing and predicting tool is tested using as a case study the Administration Building of the University of São Paulo. The building energy consumption profiles are collected as well as the campus meteorological data. A parametric analysis for the simulated building models on Energy Plus is done to evaluate the influence of several parameters such as the building profile occupation.

***Keywords**: Building simulation, energy consumption, energy auditing*

1. INTRODUCTION

Managing adequately the building energy demands has always been a struggle for facility managers. The proper use of the energy in a building provides lower operational costs in two aspects. The first one is achieved by evaluating the energy end-uses (lighting, electrical equipments and HVAC) and implementing actions to reduce the amount of energy for one or more of these end-uses. The second one is related to the penalties imposed by electricity companies in Brazil and other countries due to the increase in the peak energy demand beyond a limit previously agreed in energy supply contract. If the facility manager could anticipate the energy demand profile and also the energy consumption of the building, he could implement actions to reduce one or both of them and, therefore, reduce the operational cost of the building.

The University of São Paulo (USP) started in 1997 a program to design and implement actions in order to reduce the energy consumption called PURE-USP (Permanent Program of Efficient Use of Energy) (Saidel et al., 2003). Among the several actions implemented by the program, an on-line measurement system for energy consumption that allows the development of building energy consumption profile database can be pointed out, which has become a very important tool for planning the retrofitting actions.

Since the beginning of the program, several retrofits have been implemented in air conditioning systems in use at the University. One of those retrofits was implemented at the University Administration Building. By analyzing its energy consumption breakdown, it was verified that the air conditioning system contributes with almost 29% of the total energy consumption in this building. Particularly in this campus, the University also has a meteorological station where the most important parameters have been registered (dry bulb temperature, relative humidity, solar radiation, etc.) for the last ten years, providing a reliable weather database.

1.1. Energy auditing and prediction

One of the major concerns for facility managers nowadays is how to evaluate and forecast the energy demands of a building, especially for those with air conditioning systems. The main drawback is caused by the variation in the energy consumption profile that these systems produce. These variations are due to changes in the external climate conditions, occupants' fluctuations along the day, and the internal loads installed in the building.

In order to better understand the complexities of the matter, some studies will be briefly presented.

2. LITERATURE REVIEW

Yik et al (2001) developed a model to predict the energy consumption for 23 commercial buildings and 16 hotels. Their research included an evaluation of several parameters such as floor area, air conditioning system type (air or water cooled), hotel grade and year when the building was built, etc. For simulating the buildings, three programs were used for specific tasks: one for cooling load simulation, one for detailed building heat transfer and one for air conditioning system simulation. The authors used the energy and cooling load profiles provided by the detailed simulation programs to feed a simpler model based on normalized cooling load profiles related to the gross floor area of the buildings studied in their research. The results show a very good correlation (average deviations of 2% between detailed simulation programs and proposed model). It should be pointed out that this methodology is based on the evaluation of energy and cooling load profiles calculated by detailed simulation programs and calibrated energy consumption profiles.

Chirarattanon & Taveekun (2004) tested a model for predicting energy consumption for buildings based on the Overall Thermal Transfer Value (OTTV). This building parameter is based on the thermal characteristics of the building (wall composition, glazing types, wall-window ratio, etc.). The OTTV values are then correlated with other parameters such as shading coefficients, lighting and equipment density in equation that are developed for different building occupations (hotels, commercial buildings, hospitals, etc.). The energy consumption of several buildings was audited as well as DOE-2 runs were performed in order to be used as reference for the proposed model. The proposed model has a fair correlation with the values evaluated in the auditing process and simulation. The model reproduces the behavior of the energy consumption profiles but it has poor prediction in several cases, especially for hotels and hospitals, and good predictions for department stores and commercial buildings.

Pan *et al.* (2006) presented a methodology for the calibration of building simulation models based on three different criteria. Among the steps of the calibration process, the authors performed several revaluations of the internal loads in order to decrease the uncertainty of the simulations. They pointed out that those revaluations are quite important to properly fit the models to the actual building profile. After the evaluation processes, the uncertainties for the two buildings energy consumption profiles remained around 5% and sometime even lower. The authors also emphasized that the definition of operating schedule of the internal gains was one of the most challenging tasks due to its intrinsic randomness.

Gugliermetti *et al.* (2004) showed that the climate data aspects can play an important role on forecasting the energy consumption in office buildings. The authors identified that the use of typical month day instead of annual weather tape can induce an over or under estimation of the building energy profiles.

Botsaris & Prebezanos (2004) presented a methodology for building energy auditing based on indexes such as index of thermal charge and index of energy disposition. These indexes can be used to predict the thermal behavior of the building and provide information for the building auditing and certification.

Pedrini *et al.* (2002) described a methodology for analyzing building energy performance and applied it to 15 buildings. The authors pointed out that the calibration of the models is done by visiting the site, studying the building plans and observing the building energy demand profile. The authors emphasized that, during the process, several inputs were not available. Therefore several assumptions had to be made. By the end of the process, the uncertainties dropped from an average of 130% to 10%.

Zhu (2006) explored the capabilities and limitations of a simulation tool called eQuest to perform energy evaluation of an office building. The author emphasized that the tool can provide important insights for the designer about the impact of different strategies for reducing energy consumption. The main drawback is that this kind of tool requires detailed information on the building constructive aspects, as well as its occupancy, lighting and equipment operation schedules.

Westphal & Lamberts (2005) presented a methodology for calibrating building simulation models through the definition of parameters that most affect the main electric end-uses of a building. In the used methodology, the authors suggested six stages for calibrating the model. A case study is presented, in which the annual electricity consumption predicted by Energy Plus simulation was only 1% lower than the actual value.

Having presented some methodologies for energy consumption prediction, the presented case study will be described and its methodology analyzed.

2. BUILDING SIMULATION

2.1. Building description

The Administration Building of the University of São Paulo has two blocks with 6 floors each (Fig. 01), with gross floor area of 3,000 m^2. Both blocks are oriented 43° northwest and most of the building occupancy occurs between 8:00 to 18:00. Building population is of almost 1,000 employees.

The building air conditioning system is composed by unitary window-type and split air conditioners spread along each floor and individually controlled by the users.

Several inspections were made in order to evaluate the different types of internal loads (lighting, computers and occupancy) and their schedules. As mentioned before, the uncertainty of such information is quite high and therefore some assumptions were made in this case study.

The schedule for lighting, equipment and people was assumed to have the same pattern of the energy demand profiles. These profiles were evaluated by the previously mentioned measurement system developed by PURE (see Fig. 2). Table 1 shows the maximum and minimum values assumed for the internal loads in this study as well for the dry bulb temperature evaluated from the weather database. Based on inspections and previous calculations, it was also possible to evaluate an end-use breakdown (see Tab. 2).

Figure 1. Front side of the University Administration building.

Table 1. Internal loads maximum and minimum values.

Internal Load	Minimum Value	Maximum Value
Occupancy	110 persons	1008 persons
Lighting	10 kW	82.8 kW
Electrical equipment	8 kW	57.6 kW

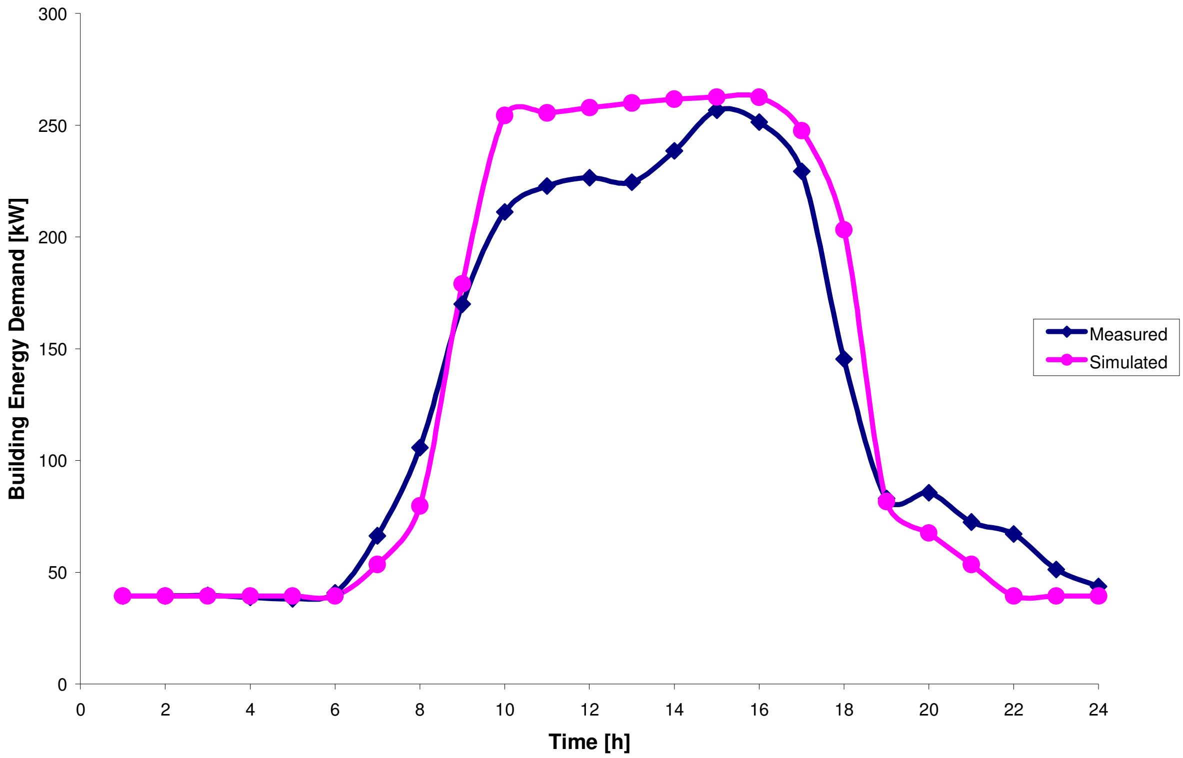

Figure 2. Typical building energy demand profile.

Table 2. End-use breakdown distribution.

End-use	Contribution
HVAC	45%
Lighting	30%
Electrical Equipments	21%
Others	4%

Another important assumption is the use of an average COP for the unitary air conditioners, since the equipment was acquired in different periods and it is impossible to impose a COP unless a full performance evaluation of each equipment is implemented.

For building simulation, it was used Energy Plus (US DOE 2005), a robust building simulation software that allows the user to implement the geometry and materials of the building as well as its internal loads and HVAC systems characteristics. It allows the user to set two kinds of simulation: a design day and annual simulation. For the later, a weather parameter profile should be provided in which the main parameters (dry/wet bulb temperature, direct/ diffuse solar radiation, wind speed/direction, etc.) are given in an hourly basis and the software can provide an annual profile of several outputs (cooling/heating loads, zone temperature, building energy consumption, etc.). For the design day simulation, the user should supply a group of parameters such as maximum and minimum dry bulb temperature, wet bulb temperature when the maximum dry bulb temperature occurs, wind speed and direction, etc. for a single day. The software will provide for such day the same outputs mentioned for the annual simulation.

For this study, the description of the building and its internal loads is kept as simple as possible in order to avoid an over-detailed modeling, which can be very time-consuming. It should be emphasized that the purpose of this research is to forecast, within a reasonable uncertainty, the energy profile of a building using a simulation tool with a set of parameters that briefly describes the building and the climate data. Therefore, the design day simulation option available in Energy Plus was used.

3. SIMULATION AND RESULTS

Using the data obtained by the energy demand measurement system, the energy consumption for each business day between January 1st and March 31st was evaluated providing a 54-day database. This period was chosen because it represents the highest outdoor temperature period in the year. Due to the high temperature and solar radiation profiles in this period, the air conditioning system will be working more often, allowing a more accurate evaluation of its influence on the building energy demand. For that period, the main climate parameters (dry bulb temperature, wet bulb temperature, wind speed/direction and solar radiation) were obtained from the campus meteorological station, which is managed by the Institute of Astronomy, Geophysics and Atmospheric Science of the University (IAG-USP). Table 3 shows minimum, maximum and average values for the main weather parameters between January 1st and March 31st.
The building characteristics (geometry, wall and window materials, lighting, equipment and occupancy schedules) were implemented in Energy Plus. Each day was simulated using the design day simulation option and the daily total energy consumption was compared with the actual available data. Comparison of simulated and actual data is shown in Fig. 3.

Table 3. Main weather parameters.

Parameter	Maximum	Average	Minimum
Dry bulb temperature [ºC]	33.2	27.0	18.4
Wet bulb temperature [ºC]	24.6	22.0	18.0
Global solar radiation [W/m^2]	1328.9	971.6	244.8
Wind speed [m/s]	4.1	2.4	1.5
Wind direction [º]	330	150	10

In order to enhance the result confidence, the influence of some input parameters and software settings on energy consumption prediction were also investigated. The first parameter analyzed was the solar radiation level. As a default setting for Energy Plus, it is assumed that the building experiences a clear sky condition where solar radiation profile achieves its highest values. This is not a common situation, and therefore the user can correct the solar radiation level by changing a program variable called *SkyClearness*. Nevertheless, this is not information readily available in advance for the facility manager.

In order to check the influence of that parameter, two sets of simulation runs were undertaken: in the first one this variable was kept equal to 1 (program default), and in the second one the *SkyClearness* was changed until the solar radiation profile became similar to the actual one. The adjusted *SkyClearness* values ranged from 0.18 to 0.80 for the considered period. By comparing the two sets, the building energy consumption evaluated with *SkyClearness* equal to 1 was 1.3% higher than that for adjusted *SkyClearness*. This difference is quite acceptable for the purposes of managing the facilities and might indicate that the solar radiation is a second-order input parameter for these purposes.

In this paper the influence of the other weather parameters is also evaluated using a series of simulation where each parameter is modified based on its uncertainty evaluated from the meteorological database. Table 3 presents those uncertainties and the uncertainty promoted by each parameter.

Based on uncertainty for each variable presented in Table 3, the total uncertainty due to the weather parameters is ±2.2%, which is much lower than the difference between the simulated and the actual energy consumption data.

The latter statement is reinforced by the results achieved when variations in the schedules for lighting, equipment and occupants are imposed. For the simulation sensivity analysis purposes, a variation range of ±20% was imposed for those schedules. This variation was set in the hourly value of each schedule while keeping the others unchanged. The weather parameters were also kept unchanged. The results of such analysis are presented in Table 4.

By analyzing Table 4, one can observe that the different results for the same variation for each schedule can be explained due to the different contribution of each internal load in the total building energy consumption profile. Besides that, the uncertainty caused by these variations is five to ten times higher than the ones produced by the weather parameters uncertainty, and it is of same order of the difference between actual and simulated energy consumption.

Another parameter that significantly influences energy consumption prediction is the COP value. Such parameter typically ranges from 2.0 to 3.0 for window-type air conditioners. For the present study an average value of 2.5 was assumed, and variations within the typical range may lead to prediction errors of 12 to 16%, similar to those for building schedules.

Table 3. Sensivity analysis results for building energy consumption for a variation on the weather parameters.

Weather parameter	**Uncertainty**	**Building Energy Consumption Variation**
Dry Bulb Temperature	±1.0ºC	±1.2%
Daily Range	±1.4ºC (*)	±1.2%
Relative Humidity	±5%	±0.8%
Global solar radiation	±20W/m^2	±1.2%

(*) Obs.: The uncertainty of the daily range is calculated based on the ±1.0ºC uncertainty of the maximum and minimum dry bulb temperature.

Table 4. Sensivity analysis results for building energy consumption for a ±20% variation on the internal loads values.

Internal Load	**Building Energy Consumption Variation**
Occupancy	±6.2%
Lighting	±12.4%
Electrical equipment	±10.6%

Based on this analysis, an uncertainty calculation was made and the result provided an uncertainty of ±13%, providing the limits for Fig. 3. It can be noticed that 80% of the database is included in a ±13% region which is a fair result, considering the uncertainties related to the parameters mentioned earlier. This result is similar to those reported in other works in literature. Nevertheless, by performing a regression analysis in the data points of Fig. 3, it was found a very low slope line (almost horizontal).

The explanation of such behavior is based on the user possibility of individually changing equipment setpoint in order to achieve its desired thermal comfort condition, or opening building windows. For days when the maximum dry bulb temperature is higher than 26ºC, Energy Plus underestimated the energy consumption because the total capacity of the air conditioning systems installed is bellow the capacity evaluated by the software as required for maintaining the temperature in the rooms. This behavior can be seen in Fig. 4 where the difference between the measured and the simulated energy demand is plotted against the maximum dry bulb temperature. This happens because the occupants bring additional fans or mobile air conditioners to the building, in order to promote a better thermal comfort condition. This increase in the energy consumption is quite difficult to evaluate because the equipment use is quite user dependent.

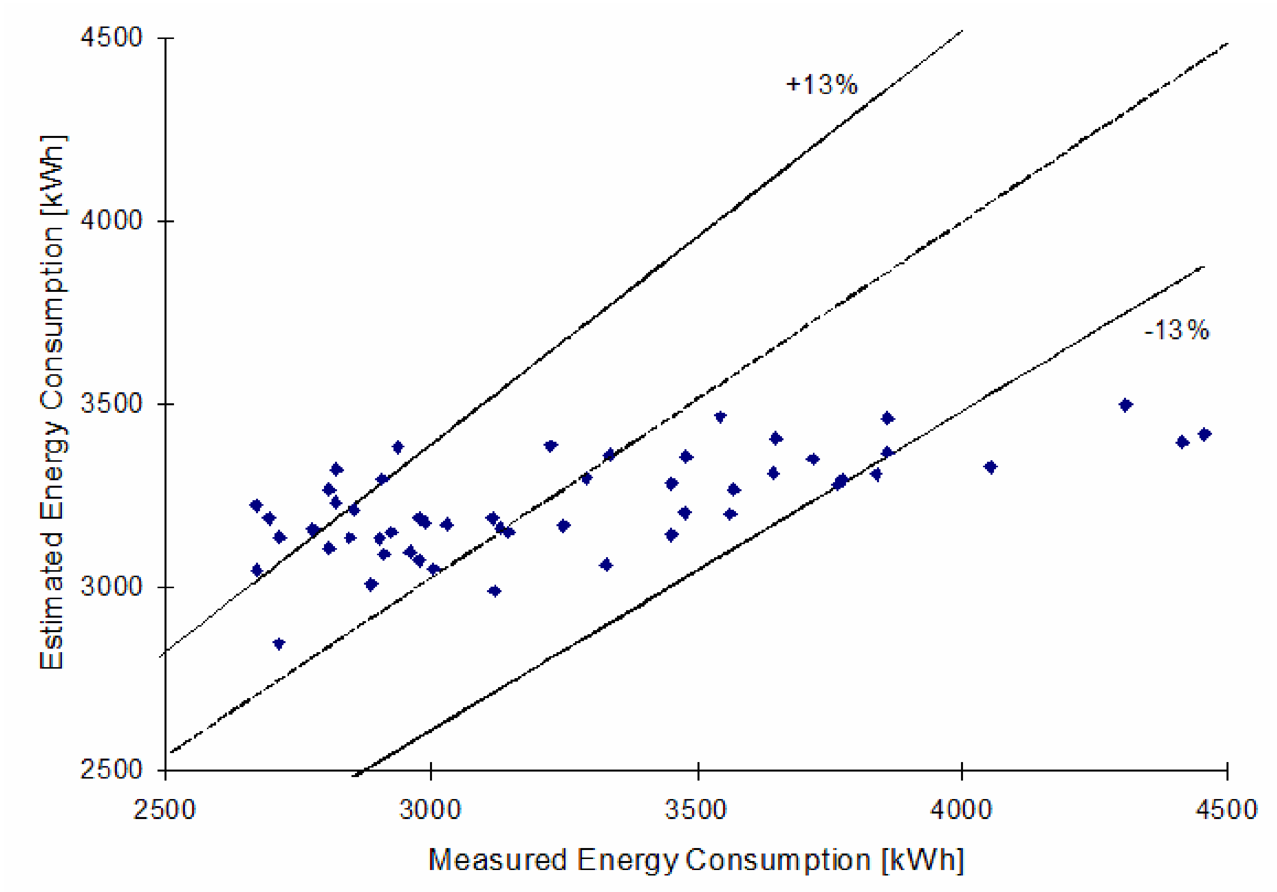

Figure 3. Comparison between simulated and measured daily energy consumption.

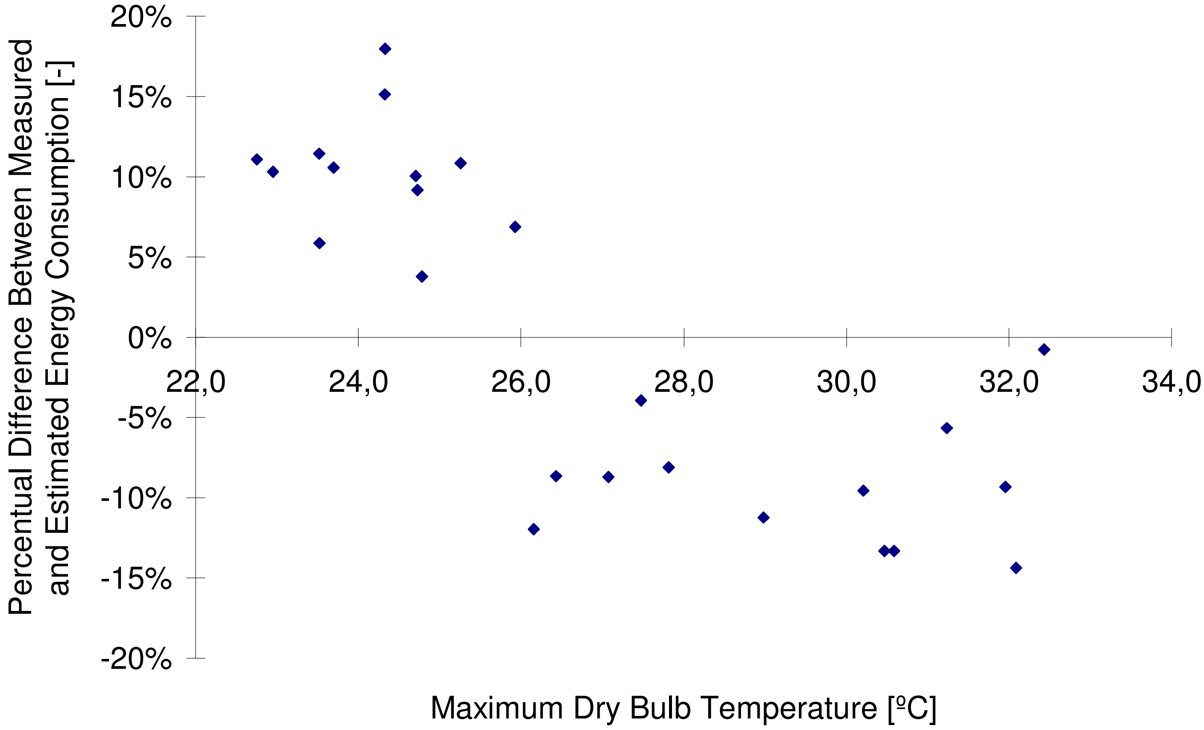

Figure 4. Difference between the measured and estimated energy consumption and the maximum dry bulb temperature.

During the days with maximum dry bulb temperature lower than 26ºC, there is an over estimation of energy consumption. This overestimation can be explained by the assumptions concerning to windows openings. During the simulation, it was adopted that the windows are closed all the time. Because the building envelope allows having a large heat gain (mainly solar radiation), Energy Plus evaluated a higher energy consumption due to the intense use of air conditioning systems caused by this closed window condition. In the actual building, the occupants can choose between using the air conditioning or open the windows. This choice is more frequent in the days that the maximum dry bulb temperature is around 23 to 24ºC. This behavior is quite difficult to take into account in Energy Plus, and therefore the higher differences found in the energy consumption evaluation occurred for colder days.

4. CONCLUSIONS

This paper analyzed the feasibility of using a detailed building HVAC design and simulation tool for forecasting the energy demand in an office building. The results of case study for the Administration Building of University of São Paulo presented an error range of ±13% for 80% of the tested database.

The major source of uncertainties are related to proper evaluation of lighting, equipment and occupancy schedules when one compares to the uncertainties produced by weather parameters. An adequate evaluation of the COP also plays a very significant role in the prediction of the energy consumption of a building.

It should also be pointed out that the occupant behavior in such building profile where the main air conditioning system are unitary equipments (window air conditioner and split systems) can also significantly affects the energy consumption profile, making its forecasting more difficult or inaccurate.

Nevertheless, after a proper calibration, the detailed simulation program would become a useful tool for forecasting the building energy demands. Moreover, it would also provide insights for the facility manager on opportunities for reducing the building energy consumption. In this sense, it should be stressed that the schedules of the internal loads must be periodically revaluated to assure an updated description of the building usage and, therefore, a more accurate evaluation of the energy demand.

This study is preliminary and several others should be followed to improve the methodologies to evaluate the energy consumption in air conditioned buildings in order to better predict the energy consumption profile.

5. ACKNOWLEDGEMENT

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