USE OF SIMULATION TOOLS FOR MANAGING BUILDINGS ENERGY DEMAND

Alberto Hernandez Neto, Flávio Augusto Sanzovo Fiorelli

University of São Paulo, Escola Politécnica, Department of Mechanical Engineering.
Sao Paulo, Brazil
ahneto@usp.br, fiorelli@usp.br

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 retrofits actions. These models apply various 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 sensitivity analysis for the simulated building model 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.

INTRODUCTION

Managing adequately the building energy demand 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 this 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 that is 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 several actions implemented by the program, it can be pointed out an on-line measurement system for energy consumption that allows the development of building energy consumption profiles database, which has become a very important tool for planning the actions for retrofitting.

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, 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 hourly (dry bulb temperature, relative humidity, solar radiation, etc.) for the last ten years, providing a reliable weather database.

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 which have air conditioning systems. The main drawback is caused by the variation in the energy consumption profile that such systems produce. These variations are due to changes in the external climate conditions, occupant's fluctuations along the day, occupation schedule and the internal loads installed in the building.

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

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 the 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 by actual energy consumption profiles.

Chirarattananon & Taveekun (2004) tested a model for predicting energy consumption for buildings based on the Overall Thermal Transfer Value (OTTV). Such 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.) and for the different months of the year. 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 sometimes 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 a 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 building auditing and certification.

Pedrini *et al.* (2002) described a methodology for analyzing building energy performance and applied it into 15 commercial buildings. The authors pointed out that the calibration of the models is done by visiting the site, studying the building plants 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 drop 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 calibration of building simulation models through definition of the parameters that most affect the main electric end-uses of a building. In the used methodology, the authors suggested six stages for the calibration of the model. A case study is presented, in which the annual electricity consumption predicted by EnergyPlus simulation was only 1% lower than actual value.

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

BUILDING SIMULATION

Building description

The Administration Building of the University of São Paulo has two blocks with 6 floors each with a population of almost 1000 employees (Fig. 01) with gross floor area of 3.000 m^2. Both blocks are oriented 43º Northwest and most of the building occupancy occurs between 8:00 to 18:00.

Figure 1 Front side of the University Administration building.

The building air conditioning system is composed by unitary window-type 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 its 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, equipments 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 Fig. 3).

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

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

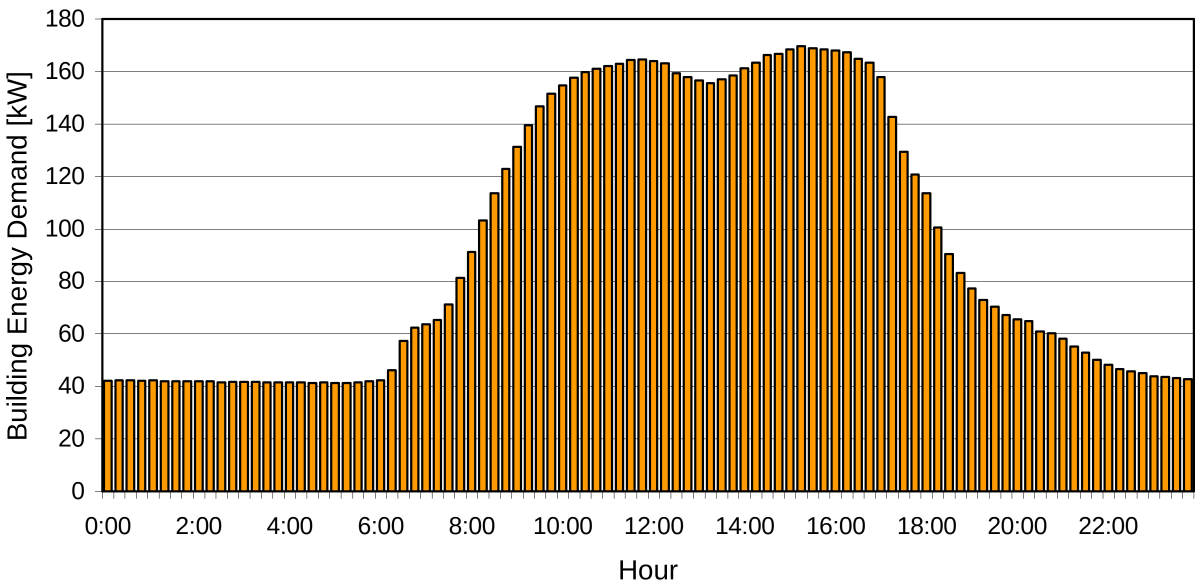

Figure 2. Typical building energy demand profile.

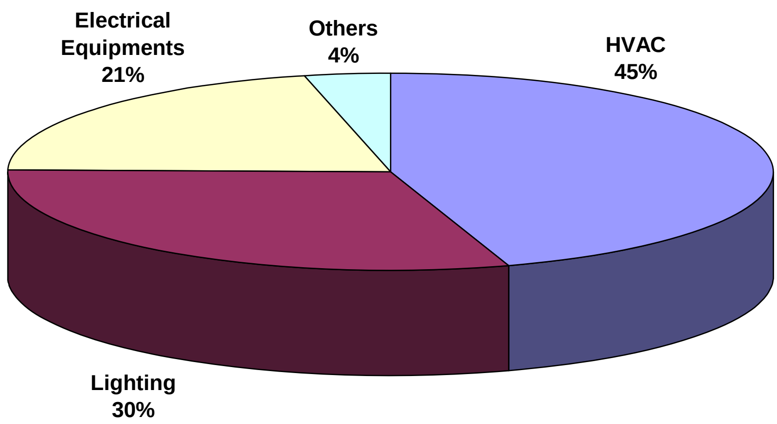

Figure 3. Building end-use breakdown.

EnergyPlus (US DOE 2005) is a robust building simulation model that allows the user to implement the geometry and materials of the building as well 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 one, a weather parameters profile should be provided where the main parameters (dry/wet bulb temperature, direct/ diffuse solar radiation, wind speed/direction, etc.) are given in hourly basis and the software can provide an annual profile of several outputs (cooling load, zone temperature, building energy consumption). 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 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 option for design day simulation available in EnergyPlus

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 54 days 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 to have a more accurate evaluation of its influence on the building energy demand. For such period, 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 2 shows minimum, maximum and average values for the main weather parameters between January 1st and March 31st.

Table 2 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

The building characteristics (geometry, wall and window materials, lighting, equipment and occupancy schedules) were implemented in EnergyPlus. Each day was simulated using the design day simulation option and the daily energy consumption was compared with the actual available data. Comparison of simulated and actual data is shown in Fig. 4.

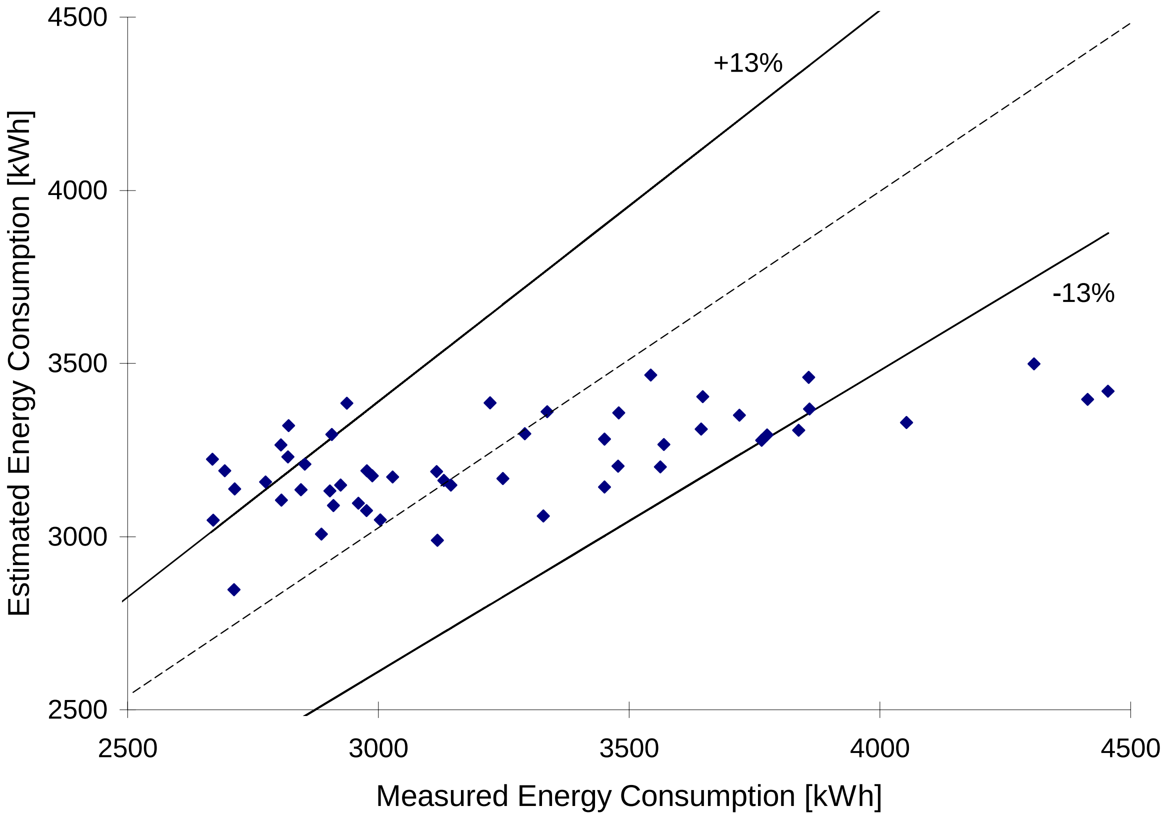

Figure 4. Comparison between simulated and measured daily energy consumption.

Based on Fig. 4, it can be noticed that 80% of the database is included in a ±13% region which is quite a good result, considering the uncertainties related to the parameters mentioned earlier. Such result is similar to those reported in other works in literature. In order to enhance result confidence, the influence of some input parameters and software settings on energy consumption prediction was investigated.

The first parameter analyzed was the solar radiation level. As a default setting for Energy Plus, it is assumed that the building experienced a clear sky condition where solar radiation profile achieves its highest values This is not a common situation, and therefore the user can correct solar radiation level by changing a program variable called *SkyClearness*. Nevertheless, this is not a typical information readily available in advance for the facility manager.

So, in order to check the influence of such parameter, two sets of simulation runs were undertaken: in the first one this variable was kept equal 1 (program default), and in the second one the *SkyClearness* was changed until the solar radiation profile became similar to actual one. The adjusted *SkyClearness* values ranged from 0.18 to 0.80 for the considered period. By comparing the two sets, building energy consumption evaluated with *SkyClearness* equal 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 solar radiation is a second-order input parameter for such purpose.

The latter statement is reinforced by higher errors achieved for variations in the schedules for lighting, equipment and occupants. For simulation sensivity analysis purposes, a variation of ±20% was imposed for those schedules. This variation was imposed 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 3.

By analyzing Table 3, 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.

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%.

Table 3. Sensitivity 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%

Observing in Fig. 4, one can notice a very low slope line (almost horizontal). The explanation of such behavior is based on the user possibility of individually changing equipment setpoint or opening building windows in order to achieve its desired thermal comfort condition.

In hotter days, EnergyPlus underestimated the energy consumption because the actual system capacity of the air conditioning systems is bellow the capacity that EnergyPlus evaluated as required to provide proper thermal comfort. In order to promote a better thermal comfort condition, the occupants are used to bring additional fans or mobile air conditioners to the building. Probably, this action is the main cause for the increase in the energy consumption, and it is quite difficult to be evaluated by EnergyPlus.

In colder days, there is an overestimation of energy consumption that can be explained by the windows openings consideration made in the simulations. It was adopted that the windows are closed all the time. Since the building envelope allows having a large heat gain (mainly solar radiation), EnergyPlus 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 opening the windows. This behavior is quite difficult to take into account in EnergyPlus simulations and is more critical when the maximum dry bulb temperature is around 23-24ºC. Therefore, the overestimation found in the energy consumption for colder days can be explained by this occupant's behavior.

CONCLUSIONS

This paper analyzed the feasibility of using a detailed building simulation tool for forecasting the energy demand in an office building. The results of a 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 sources of uncertainties are related to proper evaluation of lighting, equipments and occupancy schedules. 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's behavior in a building where the air conditioning equipment are mainly unitary systems (window-type air conditioners and split systems) can significantly affects the energy consumption profile, making its forecasting more difficult or inaccurate.

Nevertheless, after a proper calibration, the detailed simulation program can become a useful tool for forecasting the building energy demands. Moreover, it can also provide insights for the facility manager on opportunities for reducing the energy consumption of the building.

It should be pointed out that the schedules of the internal loads should be periodically revaluated to assure an updated description of the building usage and, therefore, a more accurate evaluation of the energy demand.

ACKNOWLEDGMENT

The authors would like to acknowledge the staff of Permanent Program of Efficient Use of Energy of University of São Paulo (PURE-USP) for providing the energy demand data, as well as the staff of the Institute of Astronomy, Geophysics and Atmospheric Science of the University of São Paulo (IAG-USP) for providing the weather database used in this paper.

REFERENCES

Saidel, M. A., et al. 2003. "Energy Efficiency and Alternative Energy Sources at the University of São Paulo". Proceedings of 17º International Congress of Mechanical Engineering, São Paulo, Brasil, November.

F.W.H. Yik, J. Burnett, I. Prescott. 2001. "Predicting air-conditioning energy consumption of a group of buildings using different heat rejection methods", Energy and Buildings, Vol. 33, pp 151-166.

S. Chirarattananon and J. Taveekun. 2004. "An OTTV-based energy estimation model for commercial buildings in Thailand. Energy and Buildings, Vol. 36, Issue 7, July, pp 680-689.

Y. Pan, Z. Huang, G. Wu, C. Chen. 2006. "The application of building energy simulation and calibration in two high rise commercial buildings in Shangai”. Buiding Simulation Conference, Australia, November.

F. Gugliermetti, G. Passerini, F. Bisegna. 2004. “Climate models for the assessment of office buildings energy performance”. Building and Environment, Vol. 39,pp 39 – 50.

Pantelis N. Botsaris and Spyridon Prebezanos. 2004. “A methodology for a thermal energy building audit. Building and Environment”, Vol. 39, pp 195 – 199.

Pedrini, F.S. Westphal, R. Lamberts. 2002. “A methodology for building energy modeling and calibration in warm climates”. Building and Environment, Vol. 37, pp 903 – 912.

Y. Zhu. 2006. “Applying computer-based simulation to energy auditing: A case study”. Energy and Buildings, Vol. 38, Issue 5, May, 2006, pp 421-428.

F. S. Westphal and R. Lamberts. 2005. Building Simulation Calibration Using Sensitivity Analysis, 9th International IBPSA Conference, August.

US Department of Energy, 2005. ENERGYPLUS™, Input Output Reference.