A METHODOLOGY TO ANALYSE THE THERMAL LOADS OF NON-RESIDENTIAL BUILDINGS BASED ON SIMPLIFIED WEATHER DATA

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ABSTRACT

This paper presents a methodology to analyse the thermal loads of non-residential buildings based on simplified weather data, which are available for 206 Brazilian locations. These data include monthly average of maximum and minimum temperatures, atmospheric pressure, cloud cover and relative humidity. For each month, two typical days are used to estimate the cooling and heating loads. The Transfer Function Method was used to run load calculations and the validation was evaluated according to ASHRAE Standard 140. The methodology showed good results for cases with low mass envelope but revealed limitation to represent thermal inertia influence on the annual cooling and heating loads.

INTRODUCTION

Air-conditioners are responsible for 48% of the electric energy consumption of public and commercial buildings in Brazil (Geller, 1992). More efficient systems are obtained through good building planning and even automate and complex control systems. Nowadays, computer simulation tools are helping designers to analyse benefits due to efficient alternatives.

The dissemination of building simulation in Brazil has not been fully successful due to the lack of weather files. There are TRY files (Test Reference Year) for 14 Brazilian cities only (Goulart et al., 1998), but the Brazilian National Institute of Meteorology has published a database of simplified weather data for 206 locations scattered in the Brazilian territory (INMET, 1992). This paper presents a methodology to predict the annual cooling and heating load for non-residential buildings based on such simplified weather data.

Alvarez et al. (1985) present a similar procedure with results very close to those predicted by a specific hourly simulation tool. Simplified tools could help architects and engineers during early stages of design of energy efficient buildings.

With the same purpose, Signor et al. (2001) developed simplified equations, which can be used to run very simplified analysis about the influence of some building design variables on the annual electricity consumption. But those equations did not provide any information about building thermal loads.

This work is focused in the generation of a daily profile of external temperature. Using monthly averages of maximum and minimum temperatures, relative humidity, atmospheric pressure and cloud cover for each month, two typical days are generated, i.e., one having the highest cooling load and another having the lowest cooling load, or highest heating load, of the month. This method could help in thermal analysis of buildings and in the cooling or heating systems sizing procedure. In a next step, the method will be adopted to evaluate quick estimates of annual electricity consumption of air-conditioned buildings.

METHODOLOGY

Weather data

The main goal of this research is to generate a methodology to estimate the annual cooling and heating loads of buildings based on simplified weather data. Instead of files with hourly data, monthly average values of temperature, relative humidity, pressure and cloud cover are used. This sort of data was published by the Brazilian National Institute of Meteorology for 206 locations (INMET, 1992).

Dry bulb temperature (DBT)

First step of the methodology development was tried over cooling load calculation.

Primarily, it was thought that the monthly cooling load could be estimated by a typical day total cooling load times the number of days a month. However, the use of one typical day for each month could not provide a good representation of the total cooling load for mid season months (such as April, May, September and October, in Brazil), which register significant variations of temperature from one day to the next day. For example, this variation may be more easily detected in Florianópolis, which is located at latitude 27°40' S, than in Belém, which is located at latitude 01°23' S. In a large part of this country, mainly in southern regions, the use of air conditioner in just some days in a month is a common practice. In other days, natural ventilation is the main choice.

Seeking a better representation of monthly temperature variation, two typical days were adopted in the cooling load calculation: one with the peak cooling load, named as "peak day", and another with the lowest cooling load profile, named as "base day".

In the electric energy consumption calculation for the systems, only the days with the "on" condition is considered, which correspond to those days when the peak cooling load is higher than zero, as showed in figure 1. Consequently, in the monthly cooling load calculation, only the cooling load of those days under shaded portion of the graph in figure 1 will be considered.

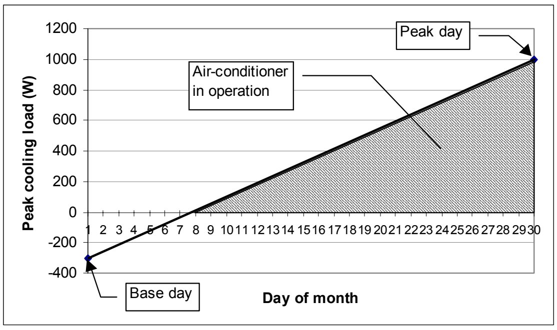

Figure 1. Days with air conditioning systems running in a generic month, between two typical days.

The cooling load calculation is carried out for the two typical days, considering the same buildings characteristics, such as schedules, internal loads and systems sizes, for both days.

The extreme values of temperature for the typical days are statistically generated. The maximum and minimum temperatures of the "peak day" correspond to the values that 95% of the days in that month would be equal or less than that. Equations 1 and 2 are used to calculate these values.

$$T_{peak\,max} = 1.645 \times S_{max} + \overline{T}_{max} \quad [1]$$

$$T_{peak\,min} = 1.645 \times S_{min} + \overline{T}_{min} \quad [2]$$

Where $T_{peak\ max}$ and $T_{peak\ min}$ correspond to the maximum and minimum temperatures of the "peak day", respectively. S_{max} and S_{min} are the standard deviations of daily maximum and minimum temperatures for each month. $\overline{T}_{max}$ and $\overline{T}_{min}$ are the averages of daily maximum and minimum temperatures.

In a similar way, the extreme temperatures for the base day are calculated for a frequency of occurrence of 5%, as represented in equations 3 and 4.

$$T_{base\,max} = -1.645 \times S_{max} + \overline{T}_{max} \quad [3]$$

$$T_{base\,min} = -1.645 \times S_{min} + \overline{T}_{min} \quad [4]$$

In equations above, values 1.645 and –1.645 correspond to z variable in the normal distribution where there is probability of 95% and 5% of the values to be equal or less than that.

The simplified database of weather data used in this work does not present standard deviations for monthly maximum and minimum temperatures. Although these values could be calculated from TRY files available for 14 Brazilian cities, it was necessary to find a correlation with others variables in the simplified database, in order to estimate the values for others 188 cities (206 – 14 = 188).

The analysis started seeking a correlation between standard deviation of daily maximum temperatures and monthly average daily range, monthly average temperature and absolute daily range. It was not detected any correlation.

But it was observed a correlation between the average of standard deviation of daily maximum temperatures of each month (28, 30 or 31 values) and the standard deviation of monthly maximum temperatures of the year (12 values). This means that: if the daily maximum temperatures present large variations in a same month, probably it will present the same pattern of variation from one month to another month. As example, table 1 presents these temperature data for Florianópolis city.

Table 1. Temperature data for Florianópolis city.

Month	$\overline{T}_{min}$	$\overline{T}_{max}$	$S_{(Tmin)}$	$S_{(Tmax)}$
Jan.	21.6	29.3	1.8	3.50
Feb.	21.2	28.2	1.7	2.46
Mar.	21.4	28.2	2.1	3.15
Apr.	17.2	26.9	2.5	1.66
May.	14.7	24.3	2.6	2.19
Jun.	12.5	22.5	3.9	2.95
Jul.	13.8	22.2	3.1	3.64
Aug.	13.7	21.2	3.9	2.75
Sep.	16.4	22.7	1.9	2.77
Oct.	16.9	23.3	2.2	3.04
Nov.	18.0	25.2	2.4	2.67
Dec.	19.1	26.8	2.3	2.86
Standard Deviation	3.16[a]	2.75[b]		
Average			2.53[c]	2.80[d]

Notes:
a. corresponds to $S_{(\overline{T}_{min})}$.
b. corresponds to $S_{(\overline{T}_{max})}$.
c. corresponds to $\overline{S}_{(Tmin)}$.
d. corresponds to $\overline{S}_{(Tmax)}$.

Figure 2 shows the correlation between average of standard deviations of daily maximum temperatures ($\overline{S}_{(Tmax)}$) and the standard deviation of monthly maximum temperatures ($S_{(\overline{T}_{max})}$) with R^2 equal to 0.7538.

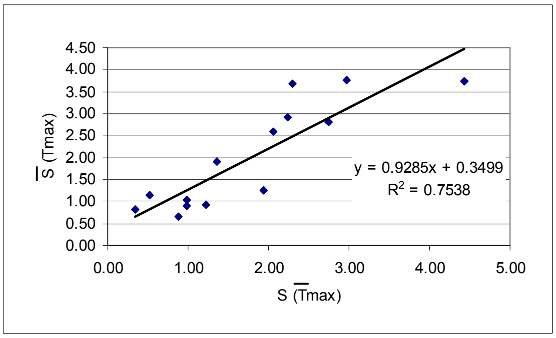

Figure 2. Correlation between the average of standard deviation of daily maximum temperatures ($\overline{S}_{(Tmax)}$) and the standard deviation of the average of monthly maximum temperatures ($S_{(\overline{T}_{max})}$), for 14 Brazilian cities.

The same correlation was extended to minimum temperatures, which presented R^2 equal to 0.8513 (Figure 3).

The equations did not present good correlations, but the hypothesis cannot be discarded without a validation of the method. There is a low quantity of values in the sample (only 14), which does not permit a rigorous conclusion.

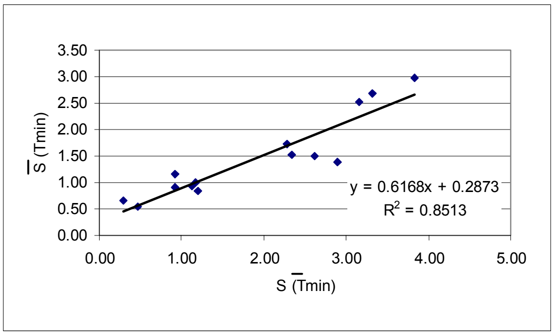

Figure 3. Correlation between the average of standard deviation of daily minimum temperatures ($\overline{S}_{(Tmin)}$) and the standard deviation of the average of monthly minimum temperatures ($S_{(\overline{T}_{min})}$), for 14 Brazilian cities.

The average of standard deviation of maximum temperatures ($\overline{S}_{(T\,max)}$) is calculated with equation 5, and in a similar way to minimum temperatures according to equation 6.

$$\overline{S}_{(T\,max)} = 0.9285 \times S_{(\overline{T}\,max)} + 0.3499 \quad [5]$$

$$\overline{S}_{(T\,min)} = 0.6168 \times S_{(\overline{T}\,min)} + 0.2873 \quad [6]$$

Using equations 5 and 6 to calculate the average standard deviation for each city, equations 1 to 4 can be adjusted to equations 7 to 10.

$$T_{peak\,max} = 1.645 \times \overline{S}_{(T\,max)} + \overline{T}_{max} \quad [7]$$

$$T_{peak\,min} = 1.645 \times \overline{S}_{(T\,min)} + \overline{T}_{min} \quad [8]$$

$$T_{base\,max} = -1.645 \times \overline{S}_{(T\,max)} + \overline{T}_{max} \quad [9]$$

$$T_{base\,min} = -1.645 \times \overline{S}_{(T\,min)} + \overline{T}_{min} \quad [10]$$

The daily pattern of external temperature (Dry Bulb Temperature – DBT) is generated from the percentage of daily range for each hour of the typical day, multiplied to the monthly temperature range plus the average of daily minimum temperatures.

Solar radiation and cloud cover

Solar radiation over the building envelope was modelled according to the solar radiation algorithm presented in ASHRAE (1997). In that method, global radiation achieving a particular surface can be calculated from latitude, longitude, surface azimuth and slope, and hour of the day. Values estimated by this method correspond to a typical day for each month and a clear sky condition.

In order to represent others conditions than clear sky, monthly average values for cloud cover (INMET, 1992) were adopted and multiplied to hourly global radiation values for the day with lowest cooling load (base day).

Table 2 presents cloud cover numbers for the 14 Brazilian cities that have TRY files and simplified weather data available. A cloud cover of 0 means a clear sky and 1 means complete overcast sky.

Table 2. Average cloud cover numbers for 14 Brazilian cities (INMET, 1992).

City	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	year
Belém	7,3	8,1	8,0	7,9	7,1	6,0	5,5	5,3	5,8	5,9	6,5	6,6	6,6
Brasília	7,0	7,0	7,0	6,0	5,0	3,0	3,0	3,0	4,0	7,0	8,0	8,0	6,0
Curitiba	7,3	7,3	7,3	6,7	6,1	5,7	6,0	7,6	7,3	7,7	7,4	7,7	7,0
Floriano-polis	6,7	6,6	6,1	5,7	5,1	5,2	5,4	6,1	6,7	6,9	6,8	6,8	6,2
Fortaleza	6,0	6,0	7,0	7,0	6,0	5,0	4,0	4,0	4,0	4,0	5,0	5,0	5,3
Maceió	5,9	6,0	6,3	6,8	6,8	6,8	6,8	6,3	6,2	5,5	5,5	5,6	6,2
Natal	5,0	6,0	6,0	6,0	6,0	6,0	6,0	5,0	5,0	5,0	4,0	5,0	5,4
Porto Alegre	5,3	5,1	5,5	5,1	5,5	5,8	5,7	5,8	6,0	5,6	5,4	5,8	6,0
Recife	6,1	6,3	6,3	6,7	6,7	6,7	6,5	6,4	6,1	5,7	5,5	5,9	6,2
Rio de Janeiro	6,0	5,0	5,0	6,0	5,0	4,0	4,0	5,0	6,0	7,0	7,0	7,0	6,0
Salvador	5,0	5,2	5,3	5,9	4,6	3,7	3,3	3,1	3,9	5,8	6,4	6,4	5,1
São Luís	7,2	7,8	7,9	7,7	6,9	5,7	5,3	4,7	4,6	4,9	5,1	5,8	6,1
São Paulo	8,1	7,5	7,7	7,4	6,6	6,2	6,1	6,2	7,2	7,7	7,7	8,2	7,2
Vitória	5,0	4,0	5,0	5,0	4,0	4,0	5,0	4,0	6,0	7,0	7,0	6,0	5,0

Cooling load calculation

In order to test the method, such a procedure was converted to a computer code and the Transfer Function Method (ASHRAE, 1997) was used to evaluate the cooling load calculation. This method has been chosen as less time-consuming, while presents satisfactory results, compared to more detailed methods, such as Heat Balance.

The TFM applies a first series of weighting factors to the heat flow transmitted by conduction through opaque surfaces in order to represent the thermal inertia. A second series of response factors is applied to the radiant portion of heat gains and cooling loads, simulating the thermal storage in building envelope. The ASHRAE Handbook of Fundamentals (ASHRAE, 1997) presents these transfer function coefficients for 41 representative walls assemblies and 42 roofs, covering a large variety of insulating and mass values.

Heating load calculation

Considering the procedure described above and the application of TFM to calculate the cooling loads for a specific building, negative cooling loads were computed as heating load.

Monthly and annual cooling and heating load are estimated as presented below.

Monthly and annual cooling and heating load

If the maximum hourly cooling load for the "base day" in a month is positive, it is assumed that the air conditioner will be turned on all days of that month. But if the "base day" presents a maximum cooling load with negative signal (heating load) in a month, it means that in some days the cooling system will not operate (as showed in Figure 1), i.e., only the heating system or ventilation will be turned on in that period. The number of days that the air conditioner is not running (*DaysOFF*), when the maximum cooling load of the "base day" is negative, may be calculated using equation 11.

$$\mathrm{DaysOFF} = \left| \frac{\mathrm{MaxCoolingBase}}{\left(\dfrac{\mathrm{MaxCoolingPeak} - \mathrm{MaxCoolingBase}}{\mathrm{nDays}} \right)} \right| \qquad [11]$$

Where *MaxCoolingBase* is the peak cooling load for the "base day", *MaxCoolingPeak* is the peak cooling load for the "peak day" and *nDays* is the number of days in the month.

The monthly cooling load (*MonthlyCooling*) is estimated applying equation 12, assuming that if the maximum cooling load for the "base day" is negative, the total cooling load for that day will be zero. The annual cooling load is the sum of cooling load for all months.

$$\mathrm{MonthlyCooling} = \frac{(\mathrm{CoolingPeak} + \mathrm{CoolingBase})}{2} \times (\mathrm{nDays} - \mathrm{DaysOFF}) \qquad [12]$$

Where *CoolingPeak* is the integrated cooling load for 24 hours of the "peak day" and *CoolingBase* is the integrated cooling load for 24 hours of the "base day".

The same procedure is adopted for heating loads, considering negative loads instead of positive loads in the calculation of number of days when the heating system is turned off (*DaysOFF*), and in the calculation of monthly heating loads.

VALIDATION

Jensen (1995) defines validation as "a rigorous testing of a program comprising its theoretical basis, software implementation and user interface under a range of conditions typical for the expected use of the program".

The validation should involve a literature revision, code check, analytical verification, comparison between models, sensitivity analysis and empirical validation (Jensen, 1995). The last one should be the most acceptable procedure, which is the verification of simulated outputs front of measured data in a prototype with the same characteristics of the virtual model. However, sometimes such procedure can not be evaluated, because some building variables are not measurable.

This difficulty in performing empirical validations has lead NREL (National Renewable Energy Laboratory) to develop a validation method called as BESTEST (Judkoff and Neymark, 1998), published in 1995. The BESTEST method was developed to help in test and detection of bugs and errors in building simulation programmes. Actually, the method does not give the results that each programme should provide, but gives a database with outputs from European and North American software, recognised as State of Art in the building performance subject.

According to Judkoff and Neymark (1998), a software validation can be made by 3 ways: analytical verification, from a known numerical solution; empirical validation, from measured data in a real model; and comparative test, i.e., between different programmes or versions of a same programme. The last cited way is the method adopted in BESTEST.

BESTEST/ASHRAE Standard 140

The methodology presented in this paper was written in a programming language and was tested according to BESTEST method, described in ASHRAE Standard 140 (ASHRAE, 2001). The Standard 140 has 40 cases, all of them with major sensitivity to envelope dependent loads. The tested variables include: thermal mass, direct solar radiation, windows shading, sunspaces, ground effect, night ventilation and systems set point. The weather file used is a TMY2 for the city of Denver, Colorado (USA).

The TMY2 file provided with ASHRAE Standard 140 was compiled in a digital worksheet so that the same pattern of simplified weather data was used to run the cases suggested in that standard. The BESTEST methodology was designed to be applied to any kind of building simulation software. Nevertheless, some cases cannot be simulated in simplified tools, as the one presented here.

Cases 600 through 650 are considered low mass cases and utilize lightweight walls, floor and roof. Cases 900 through 950 are considered high mass cases and utilize masonry walls and concrete slab floor.

The base case (Case 600) is a 48 m² floor area, single story, low mass building with rectangular-prism geometry and 12 m² of south-facing window. It has infiltration rate of 0.5 ACH and internal gains of 200 W, both 24 hours per day for the full year. The heating and cooling set points are 20°C and 27°C, respectively.

Solar absorptance of external surface is 0.6 and the envelope density is 43 kg/m² (of floor area). All low mass cases adopt the same envelope properties. High mass envelope density is 214 kg/m², with the same transmittance of low mass envelope.

Mechanical system is modelled as a 100% convective air system with non-proportional thermostat type, which senses only the air temperature, and no latent heat extraction. As the intent of the system is to produce only pure heating loads and sensible cooling loads, all equipment is 100% efficient and its capacity is effectively infinite (1,000 kW).

Table 3 presents the BESTEST cases that could be simulated by the method presented in this paper. Cases that test window shading, two zones with a sunspace and free-floating temperature were not simulated.

Table 3. BESTEST cases simulated in the methodolgy proposed.

Case code		Main Characteristic
Low mass	High mass	
600	900	Base case
620	920	East/West window orientation
640	940	Thermostat setback
650	950	Night ventilation

RESULTS OF VALIDATION

Results from ASHRAE Standard 140 are presented in this section. The methodology under analysis was named “Test”. Output data from all software available in BESTEST were transcript here also.

Low mass cases

Figure 4 shows annual heating loads for low mass cases. Case 650 was suppressed in that graph since it has heating system off 24 hours per day for the full year. Simulation of Case 600 in the Test methodology presented good agreement with other software tested. But Case 620 presented annual heating load 15% higher than maximum heating load output of other software (DOE2). This case has 6 m² of window area on façades east and west instead of 12 m² on south facing wall, as Case 600. The higher difference between cases 620-600 for the Test software than other software suggests a fragility of the method in the representation of solar gain through glazing surfaces.

As the Test methodology uses only two typical days for monthly heating load calculation, the thermostat setback for heating condition during firsts 7 hours of the day did not reflect a reduction in the annual heating load (Case 640).

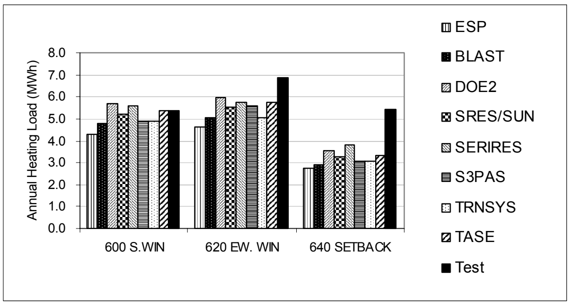

Figure 4. Low mass annual heating loads (MWh)

The annual cooling load estimated by the Test methodology presented good agreement with other software in BESTEST suite (Figure 5). Only Case 620 (windows on the east and west facing walls) presented annual cooling load value outside the range of the other tested programs, with 10% higher than maximum result.

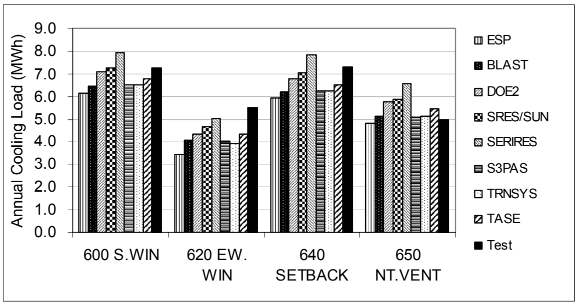

Figure 5. Low mass annual cooling load (MWh)

Both peak heating load and peak cooling load were well estimated by the Test methodology as shown in figures 6 and 7. Cases 600, 640 and 650 presented peak heating loads lower than minimum values of BESTEST collection. But these differences were less than 10%.

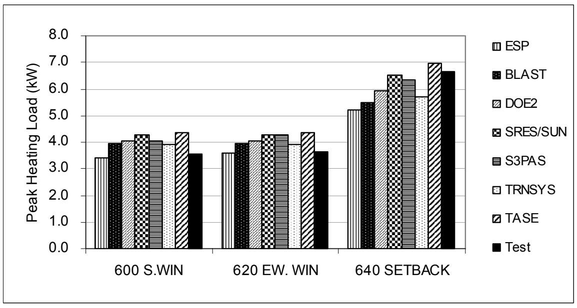

Figure 6. Low mass peak heating load (kW)

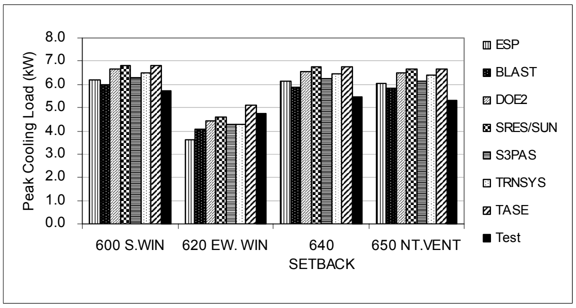

Figure 7. Low mass peak cooling load (kW)

High mass cases

Running the high mass BESTEST cases the methodology presented in this paper revealed a fragility to represent the influence of thermal mass in annual heating and cooling loads.

Figure 8 shows annual heating loads for high mass cases with results 153% (Case 920) to 367% (Case 940) higher than maximum verified between other software in BESTEST suite.

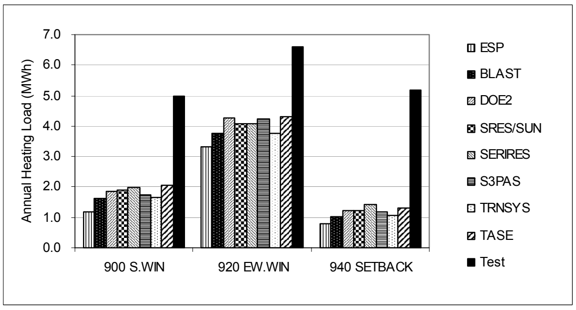

Figure 8. High mass annual heating load (MWh)

Figure 9 shows annual cooling loads for high mass cases with results 172% (Case 920) to 446% (Case 940) higher than maximum verified between other software in BESTEST suite. These significant differences detected in annual loads can be attributed to the use of two typical days in the prediction of monthly cooling and heating loads.

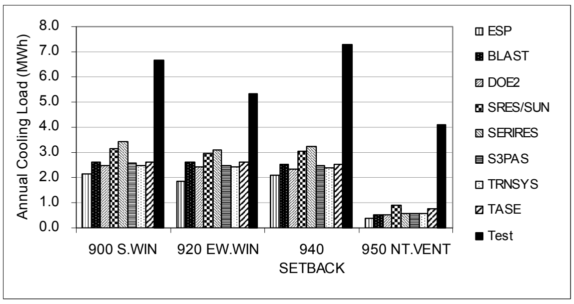

Figure 9. High mass annual cooling load (MWh)

As expected, high mass envelope provides attenuation and time lag in peak heating load and peak cooling load (Figures 10 and 11). Nevertheless, the integrated heating and cooling load for the typical days of high mass cases and low mass cases are the same. This result occurs due to the iterations used to solve TFM calculations, which are run over the same daily pattern of temperature and solar radiation. Consequently, the cooling load of hour 24 affects the cooling load of hour 1 of the same day and not of a next day with different pattern of climatic variables.

Peak heating loads for high mass cases are presented in Figure 10. The Test methodology have provided results within the range of other software tested in BESTEST.

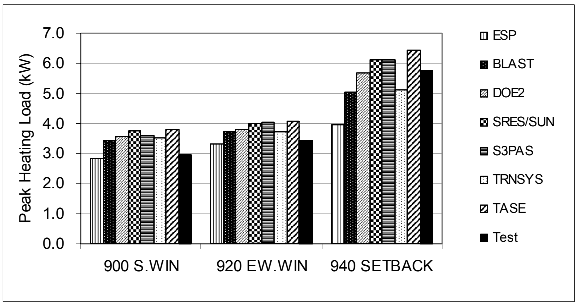

Figure 10. High mass peak heating load (kW)

Peak cooling loads for high mass cases are presented in Figure 11. In these cases, the Test methodology have given results higher than other software tested in BESTEST. Differences between Test results and maximum BESTEST results are between 13% (Case 900 – base case) and 45% (Case 950 – night ventilation).

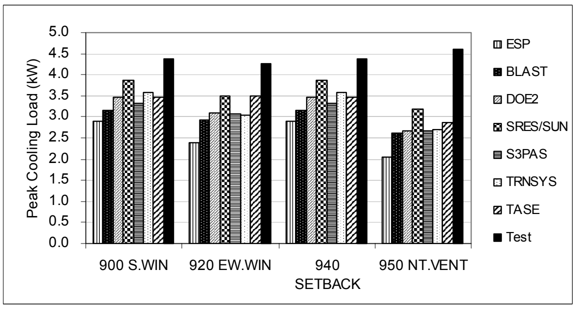

Figure 11. High mass peak cooling load (kW)

The disagreement presented by high mass cases could be minimized by utilization of more than two typical days. Possibly the generation of intermediate days between "peak day" and "base day", even by linear interpolation, should hide the effect of cooling loads of the typical days is being applied over the same climatic days.

Furthermore, Brazilian climates are not so severe as the climate of Denver, Colorado, available in the ASHRAE Standard 140. The test methodology revealed limitations to represent thermal mass influence on annual loads using a weather file with large variations of temperature from one day to another and high temperature daily ranges. Probably the Test methodology would present better result if simulated with Brazilian climates.

In a next step, the BESTEST cases will be simulated in the Test methodology using Brazilian climates, and in DOE-2.1E using TRY files available for some Brazilian cities. These simulations will help in the correction of high mass envelope influence on annual loads and peak cooling load.

Solar radiation

The methodology used to estimate annual incident solar radiation has presented results with good agreement to other tested software, as shown in Figure 12. But these tests could not detect if the adoption of clear sky for "peak day" and partially cloudy sky for "base day" is affecting the peak cooling and heating loads.

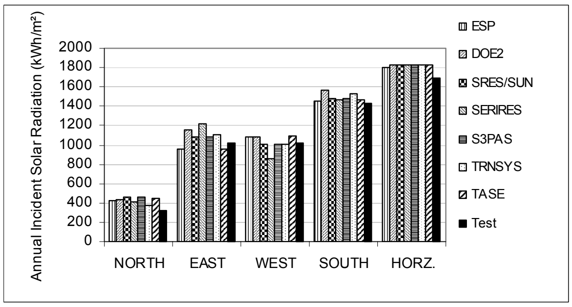

Figure 12. Annual incident solar radiation (kWh/m²)

The annual transmitted solar radiation predicted by the Test methodology is within the range of other software tested, as shown in Figure 13 for west-facing and south- facing windows.

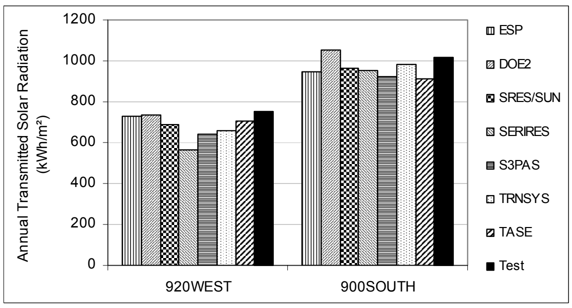

Figure 13. Annual transmitted solar radiation (kWh/m²)

CONCLUSIONS

The methodology presented in this paper was tested under ASHRAE Standard 140 and revealed good results for cases with low mass envelope.

Simulation of cases with high mass envelope showed weakness in the methodology to represent the influence of thermal inertia in the annual cooling and heating loads. However, high mass peak cooling and peak heating loads were well represented in the simplified tool.

This behaviour may be occurred by the utilization of only two typical days per month. It means that the iterations used to solve TFM calculations were run over the same daily pattern of temperature and solar radiation. Thus, the cooling load calculated in the hour 1 is affected by the cooling load of hour 24 of the same day and not by the day before, with different climatic variables. Such problem could be solved using more than two typical days per month.

Furthermore, the weather file used in BESTEST methodology represents a very severe climate, much different from most Brazilian climates, where the software will be applied. It is expected better results when running the cases with high mass envelope for some Brazilian climatic data.

This methodology could be used to analyse thermal loads and estimate annual energy consumption of non-residential buildings in 206 Brazilian locations, including 188 cities where hourly data are not available yet.

Future validation using HVAC BESTEST methodology should be carried out in order to test the air conditioner modelling. A comparison with a validated hourly simulation software, such as DOE-2.1E or EnergyPlus, could help in the analysis of the ability of the method presented here.

REFERENCES

Alvarez, S.; Velázquez, R.; Roldan, A. 1985. Determination of the long-term thermal performance of buildings by means of a “compressed” meteorological test year. In: Clima 2000. Vol. 2: Building Design and Performance. Proceedings. Copenhagen, 1985. p.283-287.

ASHRAE. 1997. ASHRAE Handbook - Fundamentals. American Society of Heating, Refrigeratin and Air-Conditioning Engineers, Inc. USA, Atlanta: 1997.

ASHRAE. 2001. ANSI/ASHRAE Standard 140-2001: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs. American Society of Heating, Refrigeratin and Air-Conditioning Engineers, Inc. USA, Atlanta: 2001.

Geller, H. S. 1992. O uso eficiente da eletricidade: uma estratégia de desenvolvimento para o Brasil. Rio de Janeiro: INEE – Instituto Nacional de Eficiência Energética. 223p. In portuguese.

Goulart, S. V. G., Lamberts, R e Firmino, S. 1998. Dados climáticos para projetos e avaliação energética de edificações para 14 cidades brasileiras. Eletrobrás, Procel, Núcleo de Pesquisa em Construção, Universidade Federal de Santa Catarina. 345 p. In portuguese.

Judkoff, R.; Neymark, J. 1998. The BESTEST Method for Evaluating and Diagnosing Building Energy Software. ACEEE Summer Study on Energy Efficiency in Buildings Proceedings 1998. Vol.5, p. 175-190.

INSTITUTO NACIONAL DE METEOROLOGIA – INMET. 1992. Normais Climatológicas (1961/1990). Governo Federal, Ministério da Agricultura, Pecuária e Abastecimento. 84p. In portuguese.

Jensen, S. O. 1995. Validation of building energy validation program: a methodology. Energy and Buildings, vol. 22, p 133-144.

Signor, R.; Westphal, F. S.; Lamberts, R. 2001. Regression analysis of electric energy consumption and architectural variables of conditioned commercial buildings in 14 Brazilian cities. In: Seventh International IBPSA Conference. Building Simulation 2001. Proceedings. Rio de Janeiro, august 13-15, 2001. p. 1373-1379.