THE EFFECTS OF INDOOR CONDITIONS ON THE REDUCTION OF ENERGY CONSUMPTION IN COMMERCIAL BUILDINGS IN RIO DE JANEIRO

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ABSTRACT

Most of the Brazilian population is concentrated in the shore region in cities like Rio de Janeiro. In this town, there is a large number of mechanically conditioned buildings with no possibility of use of natural ventilation for passive air conditioning. Due to the diversified cooling load profile, the use of detailed software simulation is essential.

This paper presents the cooling load and energy consumption simulation results for a commercial building using the softwares BLAST and NBSLD. The indoor conditions are changed to analyze the thermal comfort impact and energy reduction. It is also presented considerations about the adequacy of the simulation models to the Brazilian conditions

INTRODUCTION

The use of detailed simulation software for cooling load and energy consumption calculations in buildings has been growing in Brazil (Neto, 1997). This follows a common trend in USA, which is also becoming more and more usual in Europe.

High temperature daily ranges, high relative humidities and intense solar radiation characterize most of Brazilian climate conditions. Besides, the occupancy schedule is quite variable, imposing different thermal indoor environmental dynamics. Therefore, a reliable energy consumption/cooling load evaluation becomes very difficult without using detailed simulation softwares. Over and above that, the use of more simple calculation methods do not take into account properly the transient conduction heat transfer in opaque materials and radiant heat transfer between internal surfaces.

In this paper the application of such softwares is shown in a case study for a building in the coastal region. Most of the Brazilian population is concentrated on this region in cities like Rio de Janeiro, which is among the 10 biggest cities in the planet.

This town has a large number of mechanically conditioned commercial buildings because of severe summer conditions (high temperature and humidity). Rio de Janeiro also has a big urban density that does not allow the use of sea winds and natural ventilation for passive thermal conditioning.

Such buildings are large energy consumers due to the fact that their air conditioning systems are designed for low indoor temperature and humidity, generating high gradients between the buildings interior and exterior.

In the years to come, Brazil will face a lack of electrical energy because of an exhaustion of the water resources with technical and economical potential. Studies (EPUSP, 1989, NUTAU'96, 1996) show that, if more effective actions will not be taken to decrease the energy demand, Brazil will have a severe crisis on the electrical sector.

This study presents how detailed simulation can be used to evaluate the potential reduction in energy consumption in air conditioning systems. This is achieved by simulating the thermal behavior of the conditioned building. The chosen air conditioning system is simple, without special sub-systems or devices. Changes are made in the indoor conditions along the year in order to get it as close as possible to the external conditions, but always in accordance of the requirements of ISO 7730 standard (ISO, 1994).

SOFTWARES DESCRIPTION

Two softwares were used in this paper: BLAST (Pedersen, 1993) and NBSLD (Kusuda, 1976). They were selected due to their reliability in evaluating the dynamic thermal behavior in buildings as well as their possibility of simulating different systems of central air conditioning.

The first one was developed by the U.S. Army Construction Engineering Research Laboratory (USACERL) under the sponsorship of the Department of the Air Force, Air Force Engineering and Services Center (AFESC) and the Department of the Army, Office of the Chief of Engineers (OCE). It is divided into three main parts: cooling/heating loads evaluation, fan systems/central plants simulation, which allow a complete air conditioning system design and analysis. This software is at moment under testing for Brazilian climate conditions and materials.

NBSLD was developed on the 70's and allows calculating the cooling loads in a conditioned space and the internal conditions of a non-conditioned room. It should be pointed out that most of the models used on NBSLD were used to develop BLAST routines. NBSLD was extensively tested for Brazilian climate conditions and materials with good results (Akutsu and Vittorino, 1996 and 1990).

Based on experimental measurements for many different buildings in Brazil, it can be concluded that the following routines/models are indispensable for a proper use of simulation software for Brazilian conditions:

a) Careful and complete analysis of transient heat conduction through walls and heat storage in zones. This can be done using, for example, response factors or finite differences methods for all zone surfaces.
b) The shaded and sunlit areas should be calculated hourly for all external surfaces.
c) Evaluation of the solar flux transmitted hourly through windows, with or without interior shading.
d) Determination of the view factors to calculate radiant heat transfer between zone surfaces as well as between external surfaces (walls, roofs, windows) and the earth/sky.
e) Evaluation of outside and inside convective heat transfer coefficients on walls/roofs.
f) Indoor air moisture and energy balance evaluation.
g) Use of specific strategies for daily, weekly or even seasonal room air temperature control.
h) Routines for simulation of fan systems and central plants based on cooling loads calculation for each thermal zone.

These features are present in both softwares except that showed in item "h", which is included only in BLAST. However, BLAST does not properly perform the moisture balance.

BUILDING DESCRIPTION

In order to analyze several aspects of energy conservation in conditioned rooms, a typical commercial building construction was chosen. Its dimensions (Fig. 1) and materials properties (Tab. 1) are shown below. It is established a 2,7 m room height and a 20-floor building.

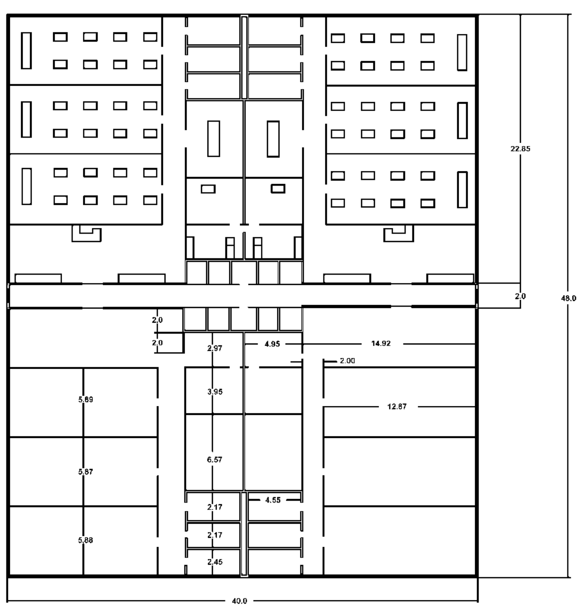

Figure 1. Main dimensions of a floor of a typical commercial building.

Table 1. Layer thickness and material properties.

Layer	Material	Thickness [mm]	Specific heat [J/(kg.°C)]	Thermal conductivity [W/(m^2.°C)]	Density [kg/m^3]
External walls					
1(external)	granite	10	740	3,5	2700
2	mortar	20	780	0,8	1790
3	concrete	140	750	1,5	2250
4(internal)	gypsum	10	1090	0,5	1300
Roof and floor					
1	concrete	140	750	1,5	2250
Fenestration					
1	blue glass	6	Shading coefficient=0,6		

SYSTEM DESCRIPTION

In order to focus on energy analysis, with indoor conditions changes, a simple air cooling system was chosen (Fig. 2).

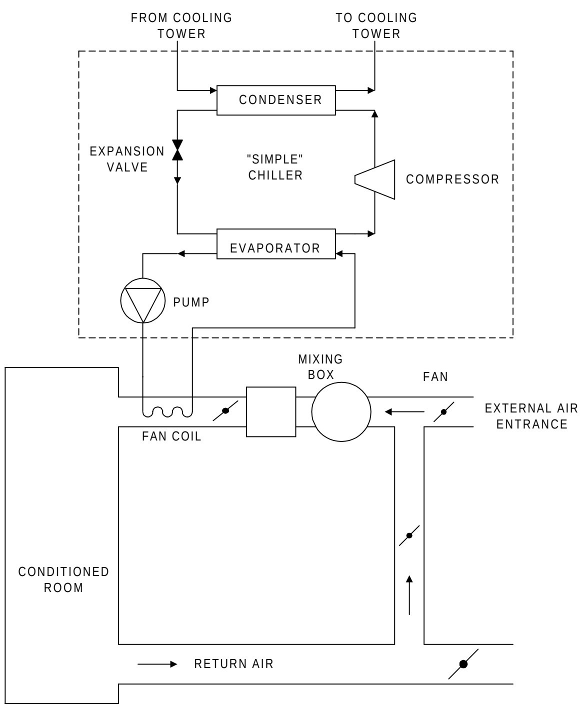

Figure 2. Cooling system diagram.

The following internal heat gains, per floor, were assumed with a fixed schedule (8:00 to 18:00):

- People: 100 persons (130 W per person).
- Equipment: 100 personal computers (100 W each).
- Lights: 20 W/m^2 .

The following sets of indoor conditions and mechanical ventilation were established:

- Indoor air temperatures: 22, 24, 26 and 28 °C.
- Relative humidity: 50 and 60 %.
- External air mass flow rate: 1 m^3/s.

The external air flow rate is determined based on ASHRAE 62-1989 standard (ASHRAE, 1989) and 1 m^3/s is the minimum value specified to assure health conditions in this office.

The indoor air temperature and relative humidity were selected based on analysis of the "predicted percentage of dissatisfied" (PPD), according to the method presented in the ISO 7730 standard for metabolic rates and typical clothing for offices (70 W/m^2, CLO=0,5, respectively) with maximum air velocity of 0,3 m/s. Fig. 3 presents a plot of PPD as function of dry bulb temperature and the relative humidity.

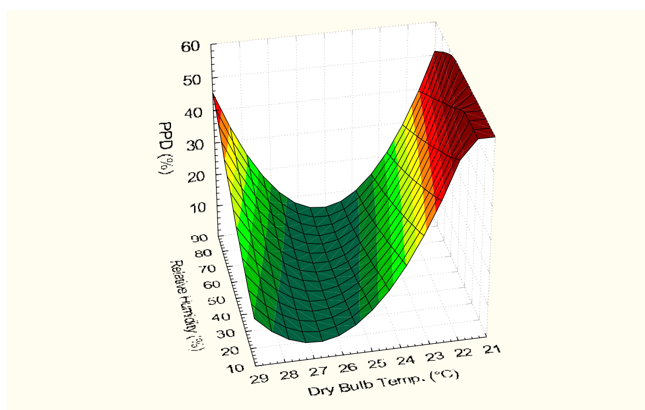

Figure 3. PPD as function of dry bulb temperature and relative humidity.

According to this, air temperatures equal to 22 and 28 °C are out of the thermal comfort zone for a minimum of 20 % PPD. Even though, for relative humidity less than 80%, the temperature of 28° C is still within the comfort zone.

For each indoor condition, a chiller/fan coil unit was simulated to provide the summer/winter peak cooling load using BLAST. Based on these simulations, energy consumption of the chiller unit and fan system was evaluated. A thermal comfort evaluation was also performed in order to analyze the effect of changes on indoor conditions in the occupants.

WEATHER DATA

The use of softwares that performs annual calculations such BLAST is still in the beginning in Brazil. The use of reliable annual weather files is important for more refined air conditioning systems energy consumption analysis. However, in Brazil, the climate files are sometimes neither available nor up-to-date. Therefore, in our studies, climate conditions for a typical summer and winter day were established and are shown in Tab. 2.

Table 2. Summer and winter weather data.

Parameter	Summer	Winter
Maximum air temperature [°C]	35,1	22,1
Minimum air temperature [°C]	29,7	15,8
Humidity ratio[kg/kg]	0,0168	0,0168
Total daily solar radiation in horizontal surface [Wh/m2]	5722	4030

RESULTS AND DISCUSSION

NBSLD was used to calculate the cooling load profile due to the fact that BLAST does not calculated dehumidification cooling load, which eliminates the latent cooling coil load profile in the simulation.

For the "simple" chiller simulation, the cooling coil demand and the energy consumption profiles were evaluated, for the summer and winter typical weather conditions, using BLAST.

The obtained internal and external temperature profiles for summer and winter conditions are shown in Fig. 4 and 5.

For the "simple" chiller, based on the product availability of this item in Brazil, its capacity was established as shown in the following table:

Table 3. Chiller capacity / number for the maximum cooling load.

Indoor dry bulb air temperature [°C]	Capacity [TR]	Number of chillers
22	180	5
24	200	4
26	180	4
28	200	3
	70	1

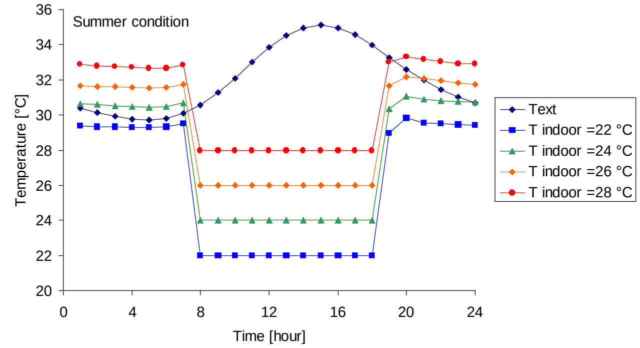

Figure 4. Internal and external temperature profiles (summer condition).

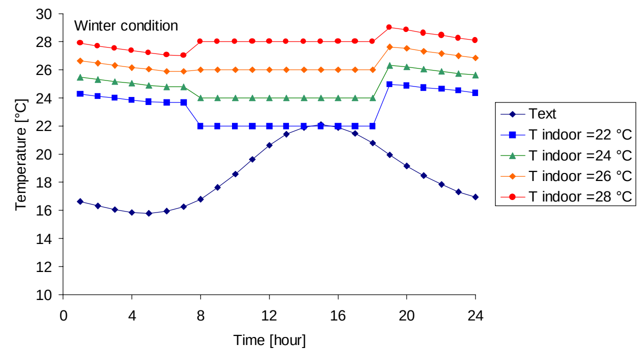

Figure 5. Internal and external temperature profiles (winter condition)

Using these data, the following equation was proposed to calculated the annual chiller/fan energy consumption:

$$AECC=(4.ECC_{winter} + 8.ECC_{summer}).21[day/month] \quad (1)$$

where:

AECC = annual energy chiller consumption, [MWh];

ECC = daily chiller energy consumption, [MWh]

A summary of the obtained results are shown in Tab. 4 and 5. In the Fig. 6 one can observes the relation between AECC and PPD as a function of indoor dry bulb air temperature.

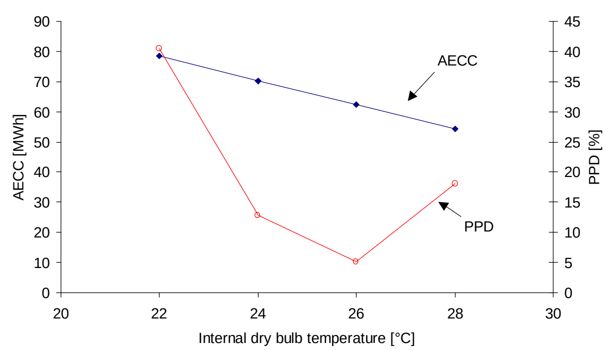

Figure 6. AECC and PPD profiles (ϕ = 60%)

Table 4. Overall energy parameters for 50% humidity ratio internal condition for each floor.

DBT [°C]	Season	w_{indoor} [kg/kg]	RCL [kWh]	CCL [kWh]	ECC [kWh]	COP [-]	AECC [MWh]
22	Summer	0,0082	1243	1705	373	4,6	78,5
	Winter		700	968	189	5,1	
24	Summer	0,0093	1168	1540	337	4,6	70,1
	Winter		617	810	162	5,1	
26	Summer	0,0105	1079	1386	303	4,6	62,4
	Winter		531	673	138	4,9	
28	Summer	0,0118	993	1221	265	4,6	54,2
	Winter		418	518	116	4,5	

Table 5. Overall energy parameters for 60% humidity ratio internal condition for each floor.

DBT [°C]	Season	w_{indoor} [kg/kg]	RCL [kWh]	CCL [kWh]	ECC [kWh]	COP [-]	AECC [MWh]
22	Summer	0,0099	1172	1639	355	4,6	74,8
	Winter		646	906	179	5,1	
24	Summer	0,0112	1084	1463	318	4,6	66,3
	Winter		556	755	153	4,9	
26	Summer	0,0126	989	1298	279	4,6	57,7
	Winter		464	594	128	4,7	
28	Summer	0,0143	898	1133	243	4,7	49,7
	Winter		375	426	106	4,0	

Table legend: RCL = seasonal room cooling load; CCL = seasonal cooling coil load; COP = coefficient of performance; DBT = indoor dry bulb air temperature; w_{indoor} = indoor humidity ratio

CONCLUSIONS

For Brazilian conditions, the need for using detailed simulation software is outlined in this paper. This is specially important due to the existence of diversified climate conditions profiles and the variety of air conditioning systems. For the latter, it is important to combine cooling and dehumidification processes keeping in mind, as a boundary condition, a low energy consumption requirement.

In such way, the simulation performed by NBSLD allows to evaluate the effect of changes on the indoor conditions in cooling load profiles. The confidence in these results come from an extensively validation process for Brazilian climate conditions and materials. BLAST also went through a similar process performed by previous researches in USA for both cooling load calculation and air conditioning systems simulation. This is a good indication that the results that comes from BLAST might be applicable to Brazilian conditions. One should bare in mind that the dehumidification process is not properly simulated and it has to be considered separately.

For the cooling system analysis, the use of detailed software such as BLAST allows to analyze the dynamic behavior of this system affected by different control strategies.

The results show that, even by not simulating sophisticated air conditioning systems, these softwares allow to evaluate in quick and reliable way energy consumption reductions in commercial buildings

Different indoor conditions analysis shows significant reduction in the energy consumption and also in the initial equipment cost.

If we consider a change of set point of the indoor air temperature from 22°C/50% (usual design indoor condition in Brazil) to 28°C/60%, it can be verified reductions of annual energy consumption of approximately 34%. Besides, for the same change, reductions of in the central plants are about 26%.

The value of 28 °C is a limit that might not be considered as a fully comfortable situation for most of the occupants. Therefore, based on Tab. 2, 3 and 4, a value of 26 °C for the air temperature is more widely acceptable for most of the occupants. Reduction on the energy consumption of 21% is achieved in respect of the 22 °C air temperature condition. It should also be pointed out that a reduction on the central plant of 25% for these same condition change.

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NOMENCLATURE

DBT	indoor dry bulb air temperature	[°C]
w_{indoor}	indoor humidity ratio	[kg/kg]
RCL	seasonal room cooling load	[kWh]
CCL	seasonal cooling coil load	[kWh]
ECC	seasonal chiller energy consumption	[kWh]
COP	coefficient of performance	[-]
AECC	annual chiller energy consumption	[MWh]