THERMOECONOMICAL EVALUATION OF RETROFITTING STRATEGIES IN AIR CONDITIONING SYSTEMS

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Abstract. *In a building project, several subsystems are designed, among them the air conditioning system. Electrical energy consumption profiles show that this subsystem is responsible for 40 to 50% of total consumption in a commercial building. Besides the study of technical aspects that should be considered in order to assure the thermal comfort of the occupants as well the temperature and humidity conditions for an efficient equipment operation, an economical evaluation of this subsystem should be also made. In retrofit projects, the economical aspect is also critical for such projects in order to assure bigger efficiency in an economically attractive way. This paper analyses some strategies that might be adopted in retrofitting an air conditioning system installed in a commercial building with mixed occupation. By mixed we mean that some floors have a typical office occupation profile and other floors are mainly occupied by electronic equipment. This analysis includes both technical and economical evaluation. The proposed solutions performance are compared to the old system, which allows to verify the retrofitting impact in energy consumption reduction and its economical feasibility.*

Key words: *Air Conditioning, Refrigeration, Energy Analysis.*

1. INTRODUCTION

Electricity is considered a key factor in the economical growth of a country. Nowadays, it sums up approximately 40% of the Brazilian energetic matrix and its consumption increases 6,5% per year (DNPE, 1999). The electrical energy is provided mainly by hydraulic sources. However, there has been a lack of investments lately which implies in high deficit risk in the near future.

A competitive environment is characterized by productivity gains where the efficient use of energy and an environmental consciousness is very important. Among the several final uses of electricity there are commercial buildings and its sub-systems. In subsystems building design, one finds the air conditioning system. Electrical energy consumption profiles show that this subsystem is responsible for 40 to 50% of total consumption in a commercial building or shopping center.

During the design process, the study of technical aspects should be considered in order to assure the thermal comfort of the occupants as well the temperature and humidity conditions for an efficient equipment operation. Economical analysis of this subsystem, which evaluates the economical impact of different technical solutions, should be also made. The same analysis should also be applied to retrofit projects, where the economical aspect is more critical, once the system should not only be more efficient but also economically attractive.

Regarding to the retrofit problem, there is another aspect that interferes in the analysis. For an old system building all dimensions are already established, leaving little room for modifications. Several strategies should be analyzed in order to verify the ones more suitable for each situation.

This paper compares some strategies that might be adopted in retrofitting an air conditioning system installed in a commercial building with mixed occupation. By mixed we mean that some floors have a typical office occupation profile and other floors are mainly occupied by electronic equipment. This comparison includes both technical and economical evaluation. The proposed solutions performance are compared to the old system, which allows to verify the retrofitting impact in energy consumption reduction and its economical feasibility.

2. METHODOLOGY

Evaluation of the thermal performance of a building and its air conditioning system should not address only the air conditioning system and its components. An analysis of building structure, construction and occupation should be not left out due to their importance in the evaluation of the cooling load profile. Besides, the use of strategies that incorporates the thermal passive behavior can reduce cooling loads with a low investment (Givoni, 1994).

Therefore, the analysis of the building and its air conditioning system includes several aspects, such as:

1. Survey of the building characteristics and its occupation profile;
2. Inspection of the actual air conditioning systems conditions;
3. Establishment of a measurement strategy;
4. Evaluation of the cooling load profile;
5. Identification of the potential actions for electrical energy consumption reduction;
6. Technical and economical evaluation of the actions identified on item 5.

Each of these aspects will be explored for the building selected to be studied in the following items.

3. BUILDING CHARACTERISTICS AND OCCUPATION PROFILE

The building that is analyzed has eight floors with the following occupation profile:

Table 01. Profile occupation distribution.

Floor	Occupation profile	Indoor Dry Bulb Temperature/Relative Humidity	Schedule
1st, 2nd, 6th, 7th and 8th	office occupation	24 °C/ 50%	8:00 to 18:00
3rd, 4th, 5th	electronic equipment	22 °C/ 50%	0:00 to 24:00

The building walls are built with the following layers:

Table 02. Wall layer characteristics.

Layer	Thickness [m]	Thermal Conductivity [W/m.°C]	Density [kg/m3]	Specific Heat [kJ/kg.°C]
mortar	0,02	0,80	1790	0,78
brick	0,25	0,60	610	0,80
mortar	0,02	0,80	1790	0,78

Internal sources for each floor are shown in Tab. 03.

Table 03. Internal sources for each floor

Floor	People	Equipments [kW]	Lighting [kW]
1st	50	3,0	20,0
2nd	10	50,0	1,9
3rd	10	75,0	10,2
4th	10	160,0	3,8
5th	10	160,0	2,4
6th	10	160,0	2,6
7th	100	12,0	40,1
8th	100	12,0	40,1

The chilled water system is placed in the underground and there several fan coils located in each floor. The total capacity is 2380 kW (680 tons) divided into five equipments: three with 560 kW (160 tons) and two with 350 kW (100 tons). In the roof, there are three cooling towers for rejecting the heat with 880 kW (250 tons) each.

4. ACTUAL AIR CONDITIONING SYSTEMS CONDITIONS

The building is used by a telephone company in order to maintain part of its electronic equipment and administrative departments. Therefore, some floors have a typical office profile and others work in a 24 hours profile (see Tab. 01).

Regarding the air conditioning system, it is based in the vapor compression cycle concept. It is over 20 years old with several maintenance problems implying in a low COP. Based on measurements made, the system COP is 3,3, which is quite low comparing to values for new systems (4,5 to 5,0).

5. ESTABLISHMENT OF A MEASUREMENT STRATEGY

Based on steps presented earlier, a measurement strategy was established. Some of the measurements were made hourly and others were made in the peak condition to verify the performance of separated equipments, such as the fan coils. Therefore, the following parameters were evaluated:

- Fan-coil fan electrical energy consumption;
- Inlet and outlet chilled water temperatures;
- Chilled water pumps electrical energy consumption;
- Condensation water pumps electrical energy consumption;
- Fan coil inlet section dry bulb temperature and relative humidity;
- Conditioned room dry bulb temperature and relative humidity;
- Fan coil inlet section air velocity;
- Chillers electrical energy consumption;
- Condensation water inlet and outlet temperatures;
- Refrigeration system total electrical energy consumption.

6. EVALUATION OF THE COOLING LOAD PROFILE

The cooling load profile was evaluated with the software BLAST (Pedersen, 1993), developed by the University of Illinois, USA. This software is selected due to its reliability in evaluating the dynamic thermal behavior in buildings as well as its possibility of simulating different systems of central air conditioning. The model used in this software is based in the transfer method (ASHRAE, 1993).

The dry and wet bulb temperature, solar radiation, wind direction and velocity profiles used in this analysis are based in studies of São Paulo climate (Akutsu et al., 1987). The following peak values of those parameters are presented in order to roughly characterized the climatic conditions. It should be point out that these data were evaluated for a 10% occurrence frequency, as established by ASHRAE (ASHRAE, 1993) for summer conditions:

- Dry bulb temperature: 31,4 °C;
- Wet bulb temperature: 26,7 °C;
- Dry bulb temperature daily range: 11,2 °C;
- Main wind direction: NE;
- Average wind velocity: 2,8 m/s
- Peak solar radiation: 686 W/m^2.

Based on these conditions and the ones shown in Tabs. 01 to 03,one can see the total cooling load profile in Fig. 01.

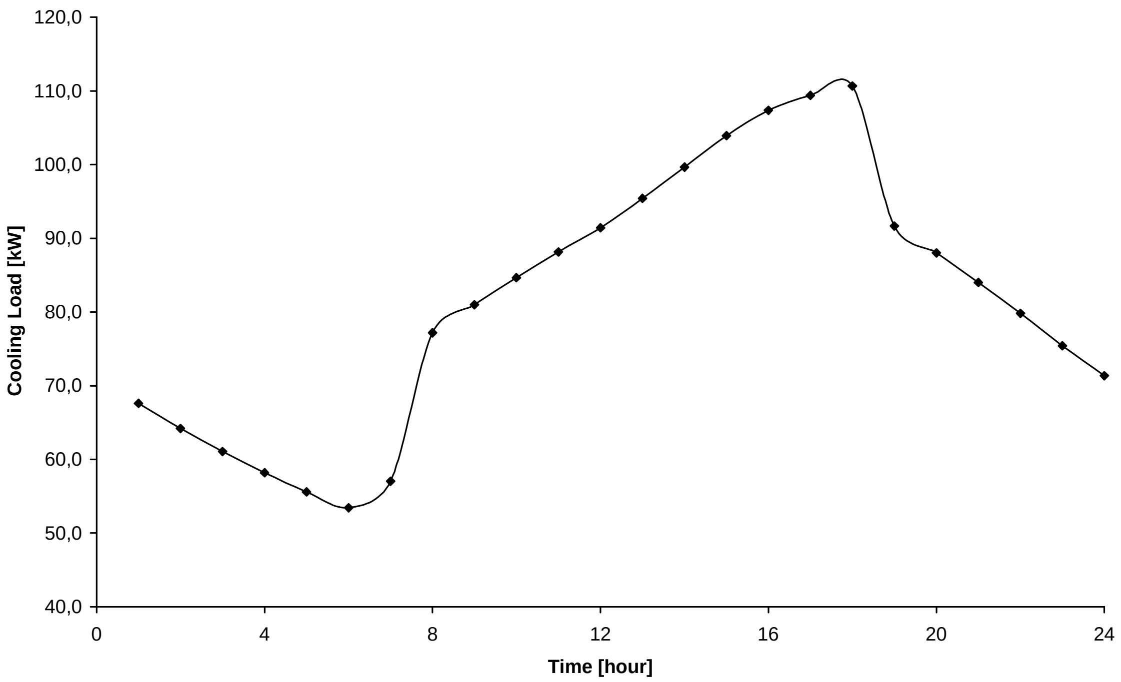

Figure 01 - Total cooling load profile.

7. POTENTIAL ACTIONS FOR REDUCING ENERGY CONSUMPTION

As mentioned before, the refrigeration system is working far from its optimum point. This is endorsed by measurements of fan-coils inlet water temperatures in a range of 9 to 11 °C, instead of 7° C, which is a nominal design value. Besides, several control valves of the fan-coils are out of order, implying in an increase of energy consumption. Several actions can be done to improve this situation, such as:

- Option A: complete replacement of the chilled water system and fan-coils;
- Option B: complete replacement of the chillers and retrofitting of the fan-coils, pumps and controls system;
- Option C: retrofit of the chilled water system and fan-coils;

8. TECHNICAL AND ECONOMICAL EVALUATION OF THE RETROFITTING ACTIONS.

As reference, it is used a 1144 kW (325 tons) cooling load demand supplied by a system with a COP of 3,3. This means that from the 2393,6 kW (680 tons) already installed, 1830,40 kW (520 tons) will be in a 24 hours operation and 563,20 (160 tons) will be used as stand-by. This is strategy is already used due to the need of a non-stop operation of the electronic equipments and, therefore, its air conditioning system. For option comparisons, a simple payback period calculation will be made.

As a first action, one can change the operation schedule of the chillers in order to distribute the cooling load demand during the day. Therefore the following schedule was proposed: from

0:00 to 8:00 and from 18:00 to 0:00 the system operates with 985,6 kW (280 tons) and with 1830,4 kW (520 tons) the rest of the day. This action already allows a reduction of 22,5 % in the energy consumption with a US$ 42.000,00 investment and a 1,5-year payback period.

For each option presented before, an economical and technical evaluation is made and results are shown in Tab. 04.

Table 04. Comparison of system retrofitting options.

Option	Capacity, [kW] (tons)			COP	Energy consumption [MWh]	Reduction [%]
	Operation	Stand-by	Total			
Reference	1830 (520)	563 (160)	2393 (680)	3,3	13,65	---
A	1267 (360)	422 (120)	1689 (480)	4,5	9,99	26,8
B	1478 (420)	563 (160)	2041 (580)	4,0	12,38	9,3
C	1689 (480)	704 (200)	2393 (680)	3,6	12,66	7,2

On Tab. 04, one can concluded that option A presents the highest energy reduction. This is expected because option A represents an overall change in the system, improving its total performance. This conclusion can be endorsed by Tab. 05, where the higher daily energy reduction is also for option A.

Nevertheless, by observing Tab. 06 it should be noted that option A implies in a larger investment and a bigger payback period. Option B provides a smaller energy reduction than option A with almost the same payback period. In the other hand, option C gives the smaller payback period with the lower energy reduction.

Table 05. Energy reduction of system retrofitting options with operation schedule profile change.

Option	Daily energy consumption [MWh]	Energy reduction [%]
Reference	17,61	---
A	9,99	43,3
B	12,38	29,7
C	12,66	28,1

Table 06. Economical evaluation of system retrofitting options with operation schedule profile change (*).

Option	Total cost [US$]	Energy cost [US$]	Cost reduction [US$/year]	Simple payback period [years]
Reference	---	152.538,00	---	---
A	412.222,00	80.358,00	72.181,00	5,7
B	262.500,00	99.534,00	50566,00	5,2
C	101.944,00	101.972,00	36338,00	1,9

(*) US$ 1,00 = R$ 1,80

The adoption of option A will imply in lower maintenance cost because it replaces the old system for a new one with a significant reduction in operation cost. Option B has no interest because the payback period is close to A, with almost the same investment, and with a energy reduction quite smaller than A. By choosing option C, it will increase the possibility of failures of the system, resulting in more maintenance costs. Also, this latter option will imply, in the future, in replacement of some equipment, falling in option A or B. Therefore, option C will only postponed the solution of the problem.

9. CONCLUSION

This paper present an actual case study of energetical analysis of air conditioning system in a commercial building with mixed occupation. Several alternatives of changes in the system are analyzed in its technical and economical aspects.

If one consider only the energy reduction aspect, option A should be chosen. But, option C can be an alternative if the building administration do not have the amount for the initial investment. It is also necessary to evaluate from where and how the investments will be taken, considering interest and other financial issues.

It should be point out that, in order to choose the best option, one should consider several aspects (technical, economical, operational, etc.). It should be pondered that the adoption of any of the solutions should account its reflections on the maintenance program of the system, which is usually neglected.

10. REFERENCES

Akutsu, M.; Sato, N. M. N., Pedroso, N. G., 1987, Desempenho térmico de edificações habitacionais e escolares – Manual de procedimento para avaliação (Publicação IPT 1732), São Paulo.

ASHRAE, 1993, Handbook of Fundamentals.

DNPE - Departamento Nacional de Política Energética, 1999, Balanço Energético Nacional.

Givoni, B., 1994, Passive and Low Energy Cooling of Buildings. Ed. Van Nostrand Reinhold,.

Pedersen, C. O. et al., 1993, BLAST - Building Load Analysis and System Thermodynamics, University of Illinois, Champaign - Urbana , EUA.