COOL STORAGE STRATEGY SELECTION APPLIED TO AN AIRPORT TERMINAL

Robson Fernandes Dombrosky, robdombrosky@yahoo.com.br
Universidade do Vale do Rio dos Sinos, Av.Unisinos 950, São Leopoldo/RS, Brazil

Abstract. *The use of cool storage systems have a key role on large size air conditioning energy savings. However, to fully meet this purpose, not only the system should have been properly designed, but it also needs to be properly operated. The appropriate operating strategy selection for a thermal storage system is therefore an important step to achieve the expected energy savings. Planning to turn that selection into a simpler and straightforward process, this paper proposes a tool that graphically presents the analysis and decision making involved in this operating strategy selection, taking as example a large Brazilian airport. Finally, to validate the presented tool, a hypothetic airport energy bill is simulated, where it is found that the graphical tool actually guided the selection towards the strategy which results in the lowest energy bill*

Keywords*: cool storage, operating strategy, energy bill.*

1. INTRODUCTION

The main purpose of a thermal storage system in an air-conditioning plant is the possibility to make the "consumption of cold" totally independent from its "production". This separation allows the full functioning of the chiller during periods when conditions are most suitable, since normally these periods do not coincide with times of increased demand for cooling. An air conditioning system equipped with thermal storage facility is also able to meet higher thermal loads, as compared to same size systems without the use of thermal storage.

Moreover, the differential energy rates practiced in Brazil when the consumption is directed to off-peak hours, also create an interesting scenario for the use of thermal storage. In that way, a significant reduction in the energy bill can be obtained, since the storage provides a potential energy consumption reduction within the so-called on-peak time (ANEEL 2005).

During the summer, on a large airport, the thermal load profile is characterized by the need of continuous chillers operation, seven days a week. Throughout the night, despite the clear reduction of thermal load, there is still plenty of demand for cooling. With that in mind, it becomes clear that a very significant portion of the energy bill in a large airport is due to its air conditioning system. Then, it also becomes clear how important is thermal storage role to a large airport cooling system, even becoming mandatory when it is intended to make a rational energy use on a large building like the one considered in this study.

However, to fully meet the advantages of thermal storage, it is necessary that the system, besides being properly designed and installed, should also be properly operated. Not only are different systems configurations adapted to different situations, but also there are different ways to operate the same system, each of them suiting better to a specific scenario. The descriptions of thermal storage managements, in search for its efficient operation in known as "operating strategy" (ASHRAE 2008). Its determination must necessarily involve careful analysis, not only at the characteristics of the equipment itself, but also at the whole scenario in which the system is embedded.

Aiming to develop that analysis in a more clear and direct form, this paper works the steps required to the selection of the best operating strategy for a chilled water thermal storage system, taking as example a large Brazilian airport terminal. The study seeks the development of a graphical presentation of the steps that normally guide the decision-making related to the strategy selection. Having these steps structured and outlined, then the method presented is applied at the scenario presented. An energy bill spreadsheet simulates the effect of using different strategies for an existing thermal storage structure. Through these simulations, it is confirmed the method accuracy, as the answer eventually converges to the strategy that results in the lower energy bill.

2. OPERATING MODES

The concepts of operating strategy and operating mode are closely linked. The determination of an operating strategy is based on the performance of different storage operating modes. An operating mode describes which task, among several possible, the system is running at a given time (ASHRAE 2008). Roughly, the airport thermal storage system is able to work within five different operating modes, described below.

a) Chillers Charging Storage

In this operating mode, the chillers work only to remove heat from the thermal storage tank. Typically, the chiller operates at constant set point to provide chilled water to the tank at an also constant flow. The loading starts at a predetermined time, and continues until the storage is fully completed, or until the available time for recharge is finished.

b) Chillers Meeting the Load

The terminal cooling demand is attended only by the chillers. In this situation there is no water flow in or out of the storage tank.

c) Chillers Charging Storage While Meeting the Load

Besides removing heat from the storage tank, the chillers work simultaneously meeting the terminal thermal load. This operation is fairly more complex than the previous one, but becomes necessary in situations where the conditioned environment requires continuous cooling. On the other hand, in times of reduced demand for air conditioning, chillers can simultaneously meet the required load while storing the exceeding energy.

d) Storage Meeting the Load

In this situation the tank in discharged, the chillers are not operated and the terminal is cooled only with the energy previously stored in the tank, so that it begins to receive heat from the terminal.

e) Storage and Chillers Meeting the Load

The terminal cooling demand is met by both chiller and storage tank. There should be an automated control system capable of continuously dosing which portion of the load is met by the tank and by the chiller. This control is usually complex due to the large number of variables to select from, determining which equipment must operate and in what capacity.

3. OPERATING STRATEGIES

An operating strategy refers to the way the system works considering the operating modes and set-points available, so that the purpose for which it was designed can be fully achieved. Through the operating strategy, all the storage logic control is set.

According to Dorgan (1993), the operating strategies are divided into two main groups: **full storage** and **partial storage**. These terms refer to the amount of cooling load that is shifted to off-peak hours. The full storage strategy shifts the entire thermal load generated by the chiller from on-peak to off-peak periods. This strategy is shown in Fig. 1, where the letters inside the hatched areas correspond to the operation modes as described in the previous section. A system designed to use this strategy usually have the chillers working at full load during the off-peak period of a given cycle. As a result, the system will these chillers will be able to remain turned off during all the on-peak period, which is considered, in this study, from 6 p.m. to 9 p.m. The total cooling demand of this period will then be met from the stored energy.

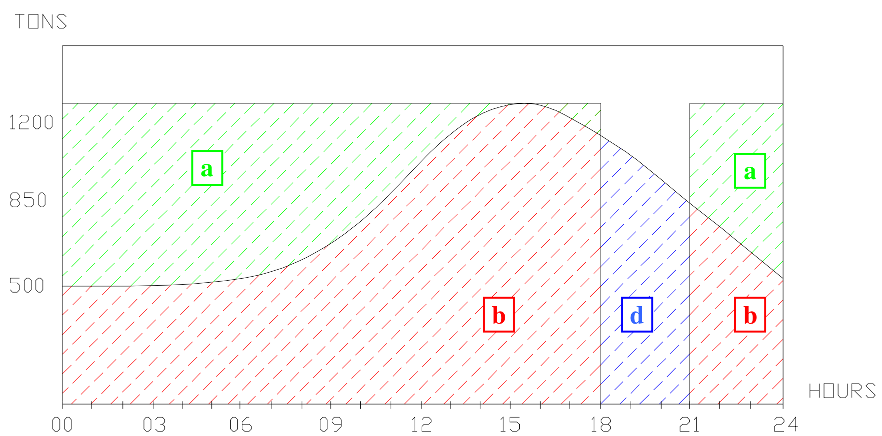

Figure 1. Full storage

Within the context of full storage, there is another strategy variation, which allows more flexibility in the matter of tank sizing. This variation is still full storage, but with a partial leveling on load demand. In this strategy, illustrated in Fig. 2, the tank starts meeting the load not only during the on-peak period, but it starts discharging a few hours before, with the purpose of complementing the chiller capacity during the time of the day with the highest cooling demand.

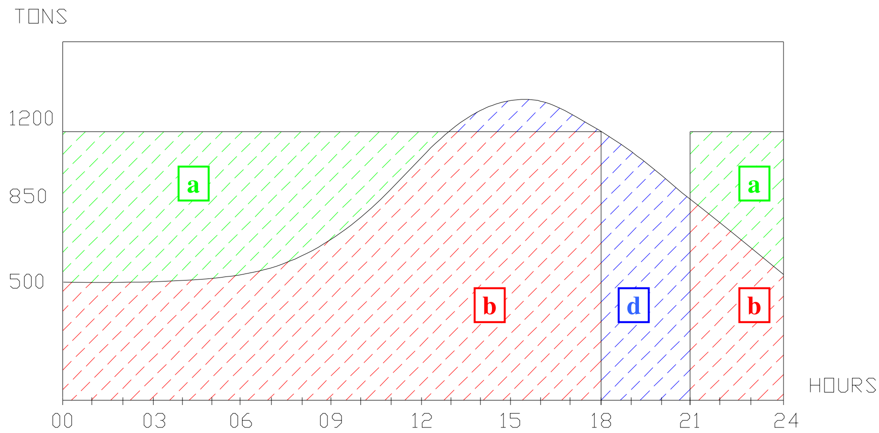

Figure 2. Full storage with partial load leveling

In **partial storage** strategy, however, the thermal storage system meets only a portion of the peak time load, and the remainder is met by the chillers, which remains in operation. Systems that make use of partial storage strategies can be further subdivided according to the operating approach, which may work as a **load-leveling** or **demand-limiting** system (Dorgan, 1993).

Acting as a **load-leveling**, the thermal storage system usually keeps the chiller running at full capacity throughout the cycle. Thus, there are two situations that might occur during its operation: when the load is lower than the power delivered by the chiller, the excess is stored and when the load exceeds the chiller capacity, the energy stored is then applied to supplement the demand load.

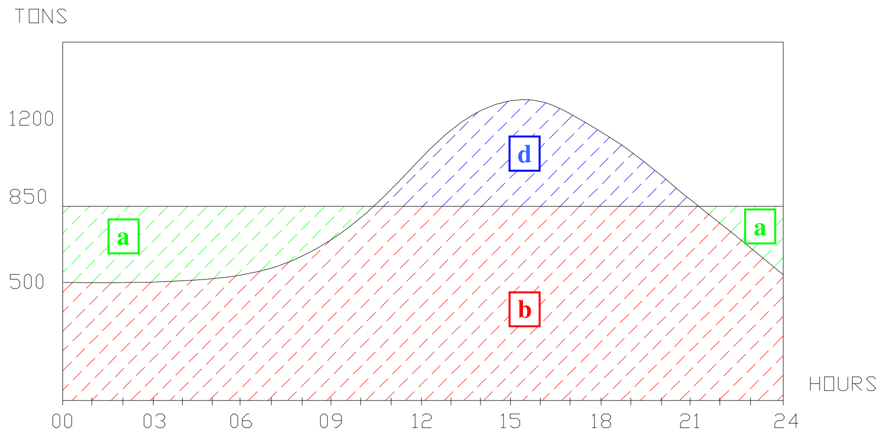

Figure 3. Load-leveling partial storage

On the other hand, when a storage system works as a **demand-limiting**, the chiller operates at reduced capacity (limited demand) during on-peak hours. This limitation comes into play so the chillers can operate without exceeding the contracted electric power demand, otherwise it would highly increase the price paid to the energy utility.

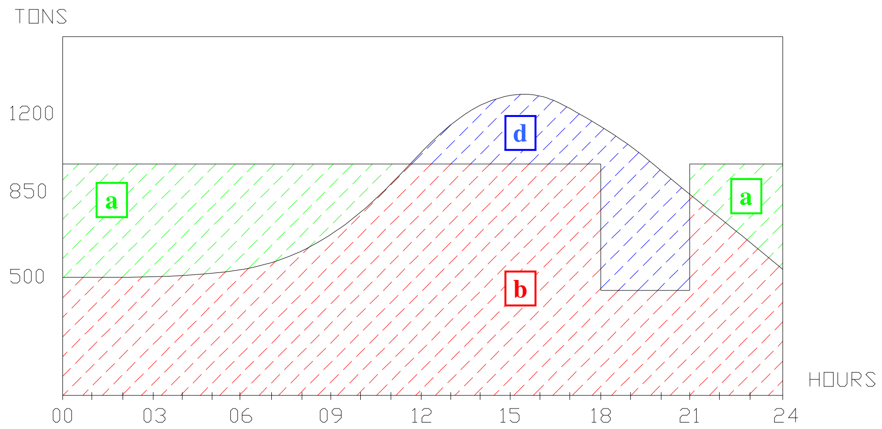

Figure 4. Demand-limiting partial storage

4. METHODOLOGY FOR STRATEGIES SELECTION

Determining a thermal storage operating strategy requires a clear and objective definition of what are the benefits pursuits, and what means should be explored to achieve this benefits. With the information that describes the assumptions for each approach, this paper proposal is to present on a graphical form the decisions normally involved in the operating strategy selection, making them more transparent and thus enabling a quick understanding of all the concepts involved.

All the analysis that lead to a model that can later be used as a guide to operating strategies selection are shown below, step by step. From there, it is organized into a flowchart form that subsequently serves as a tool for selecting the most appropriate thermal storage operation strategy to a specific scenario. Once developed, this tool is applied to the strategy selection for the storage system used as example in this paper. This is done by entering the characteristics of the scenario into the analysis tool previously structured.

4.1. Choosing between full storage and partial storage

For the feasibility of a full storage strategy, the initial investment in equipment is higher, but in a medium and long term they end up becoming profitable, due to higher potential energy savings in this type of installation. Sebzali and Rubini (2007), comment and quantify this potential difference within storage strategies applied in Kuwait.

To be operated under the full storage strategy, however, the installation must meet some prerequisites, outlined in Fig. 5. One of them is the existence of large production and storage cooling capacities, otherwise a partial storage strategy would be the one to be chosen. For large storage capacity, it means the tank is capable of meeting alone the totality of the load during on-peak hours.

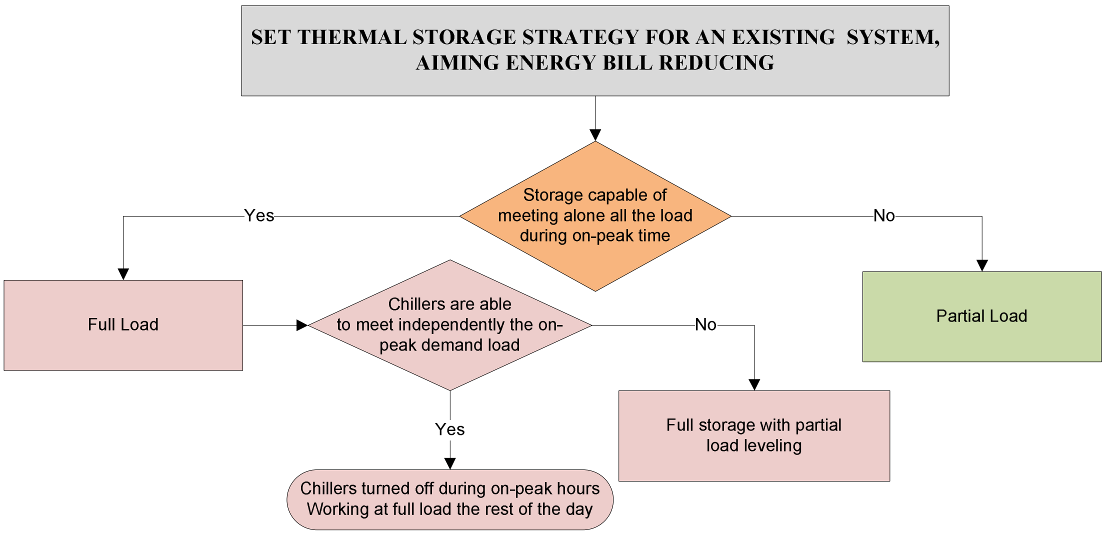

Figure 5. Step for the choice between total and partial storage

4.2. Choosing between chiller priority and storage priority

Figuring as a middle range between total and partial storage, takes place the total storage with partial load leveling strategy, as described and sketched in Fig. 4. Within this context, there may be two operation modes, shown in Fig. 6. The definition between one or another might be ruled by the time of the day, during which different energy tariffs are applied.

In the **chiller priority** strategy, the aim is to use the chiller to meet as much of the load as possible and the energy stored in the tank is used only to supplement what exceeds the chiller capacity. This operation is normally used during off-peak hours, when the electric power demanded for the chillers operation has less impact.

Compared to the chiller priority, the **storage priority** works on the other way round, witch is, to use the chiller only when the load exceeds the storage capacity, while the tank meets the majority (and typically the totality) of the load. Following the same reasoning as above, this strategy is used during on-peak hours, where due to its higher pricing, the stored energy cost becomes lower than that from direct chiller cooling (Dorgan, 1993).

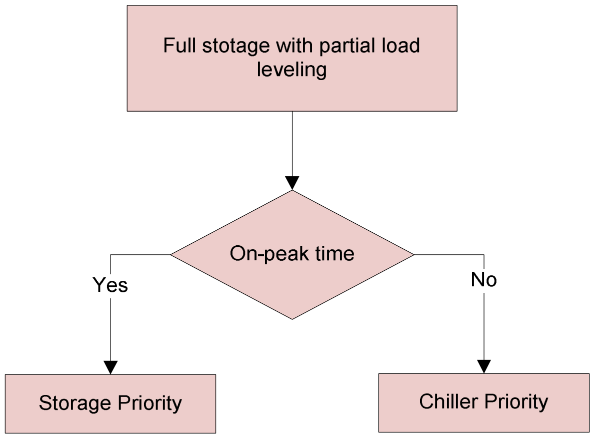

Figure 6. Step for the choice between storage priority and chiller priority

4.3. Choosing between load leveling and demand limiting

Turning into the partial storage strategy, there are two subdivisions that must be selected according to the system operating focus. These are the load leveling and demand limiting strategies, as illustrated in Fig. 7. Both of them allow the design and use of smaller chillers and storage than those required for full storage strategy.

In **load leveling** strategy, the chillers are sized to meet the average period's load, normally a value taken from the design day. Thus, the chillers are designed for continuous operation, so when cool generation exceeds consumption, the storage is loaded. On the other hand, during times of higher cooling demand, it is the tank that complements the portion of energy that the chiller can not supply.

A partial storage system with **demand limiting** is considered a middle range between the full storage and partial storage load leveling strategies. It becomes useful when the rated capacity of the chiller exceeds the daily global average load, but at the same time it is not enough to make possible turning the chillers off during on-peak hours.

To make use of the demand limiting strategy, it is mandatory the existence of an electric demand monitoring system. Thus, according to Braun (2007), it is ensured that total on-peak energy demand is kept below a predetermined value. Consequently, the air conditioning system can work without the risk of a demand excess and the financial losses it could cause.

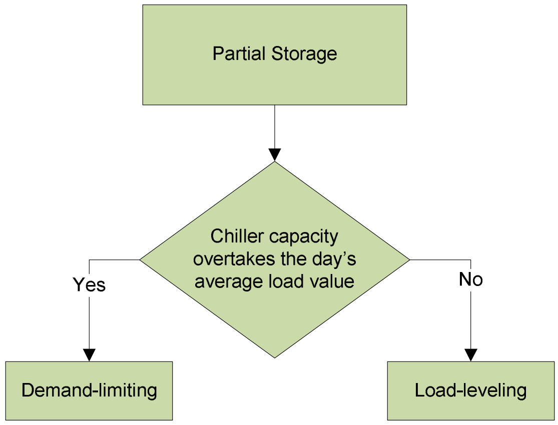

Figure 7. Step for the choice between demand limiting and load leveling

5. AIRPORT´S MOST SUITABLE STRATEGY SELECTION

For exemplification purposes, the information presented in this study is based on an airport terminal equipped with indirect expansion type cooling system, with installed cooling capacity of 1125 tons, and a 2200 m^3 chilled water storage tank. The thermal storage capacity is 7440 tons.h, with a 1550 tons peak discharge. The terminal´s load was set as 1250 tons.

The analysis starts with the infrastructure verification, according to the criteria discussed previously, but now based on the flowchart shown in Fig. 8, which was structured from the decision-making processes, concerning the characteristics and prerequisites for each strategy. The steps that constituted the assembly of this tool, as well as the presentation of the decisions involved in the process are described below.

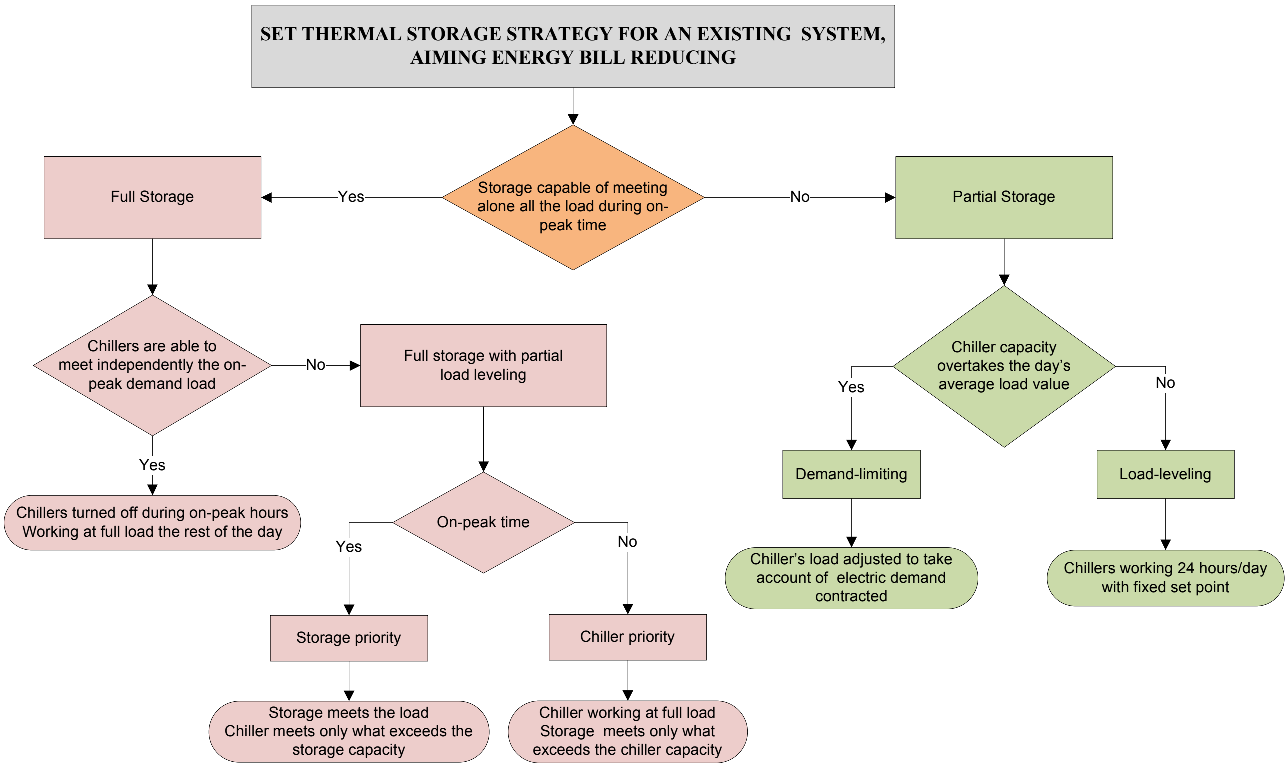

Figure 8. Flowchart final structure

Having the thermal storage operation strategy aimed to reducing energy costs, the first analysis to be performed within the existing scenario is related to the cool storage capacity. Considering an airport thermal load of 1250 tons, it results in 3750 tons.h of energy consumption during the three hour daily on-peak time. Since the tank thermal storage capacity was defined as 7440 tons.h, the statement **"storage capable of meeting alone all the load during on-peak time"** is confirmed true and the strategy to be used is full storage.

After the primary strategy has been set, it follows yet another check, based now on the statement "**chillers are able to meet independently the on-peak demand load"**. This also proves to be true, since the storage providing 1550 tons of peak discharge capacity, makes it enough to cover the terminal peak load, stipulated as 1250 tons.

From this point, and considering the scenario presented, the flowchart points how the airport thermal storage system discussed in this study should be operated. This is defined by keeping the chillers full operation during off-peak period, allowing them to be turned off during on-peak hours, since along this period, the load will be fully met by the energy stored in the tank. Analyzing the same situation from a different perspective, if by chance the terminal load would exceed the rated chillers capacity, according to the flowchart, the strategy to be used would be then, full storage with partial load leveling.

For validation purposes of the flowchart created, energy bills simulations for the airport considered were produced, according to the hourly-varying electric rates presented in Tab. 1. In a study seeking to improve the performance of ice storage systems, Henze *et al* (2003) noticed that the reduction of operating costs can vary considerably depending on the tariff structure adopted. It showed that the use of different pricing rules can strongly influence the potential savings on a particular operating strategy.

For the simulation performed in this study, it aims to confront the several strategy possibilities with the values obtained for an electric bill generated by using the flowchart pointed strategy. The result expected is that the strategy achieved using the flowchart is actually the one that provides the lowest energy bills.

Table 1. Electric rates charged by a Brazilian utility

Rate title	Off-peak consumption	On-peak consumption	Off-peak demand	On-peak demand
Hourly-varying "blue" rate	127,8 R$/MWh	196,11 R$/MWh	8,42 R$/kW	36,14 R$/kW
Hourly-varying "green" rate	127,8 R$/MWh	1.035,40 R$/MWh	8,42 R$/kW	-

The simulation results for comparison between non storage, full storage and partial storage are represented by Tabs. 3, 4 and 5, which were taken from a simulation spreadsheet to the airport energy bills on summer. Comparative tables were then assembled, aiming to highlight the possible demand and consumption reductions from the moment that the refrigeration equipments are turned off. And this includes not only the chillers, but also some cooling towers engines and condensation pumps. Consequently, through simulations, the reductions in demand and energy consumption in each thermal storage strategy can be determined.

To make those identifications, the chillers demanded power was read hourly along a typical summer day. These values are variable because the cooling delivered by the chillers is automatically modulated according to the terminal cooling demand. Based on the rated chillers electric power (Carrier 2000) and making the correlation between load percentage and electric powers, it becomes possible to define how much from the total electric demand and load is the air conditioning system consumption. These data were consolidated in Tab. 2, in which all simulations were based.

Table 2. Electric power values considered for energy bill simulations

Chillers - average off-peak power	498 kW
Chillers - average on-peak power	573 kW
Chillers - one-day global average power	508 kW
Chillers - rated power	819 kW
Pumps and auxiliary engines	205 kW

First of all, an overview without any storage strategy is presented by Tab. 3, where it is shown that around 50% of the airport electric consumption and demand is taken by air conditioning, making it clear that this is a situation where cool storage can play an important role, offering good possibilities for energy bill reductions. To measure the cooling equipments participation in the total electrical demand, it was considered the rated power of the chillers in full operation, together with the auxiliary engines power, as shown in Tab. 2.

Table 3. Fares comparison: no thermal storage situation

	Chiller's only	Total	Hourly-varying "green" rate	Hourly-varying "blue" rate
Off-peak consumption	443.032 kWh	1.118.363 kWh	R$ 142.926	R$ 142.926
On-peak consumption	70.047 kWh	120.789 kWh	R$ 125.064	R$ 23.687
Off-peak demand	1.024 kW	2.324 kW	R$ 19.568	R$ 19.568
On-peak demand	1.024 kW	2.324 kW	-	R$ 83.989
Bill Total			**R$ 287.558**	**R$ 270.170**

In the tariffs simulation considering a partial storage strategy, as seen in Tab. 4, the electrical demand has been reduced due to plain operation of the chillers, set for the day´s global average cooling demand instead of the rated power of the equipments.

Table 4. Fares comparison: partial load situation

	Chiller's only	Total	Hourly-varying "green" rate	Hourly-varying "blue" rate
Off-peak consumption	448.944 kWh	1.124.275 kWh	R$ 143.682	R$ 143.682
On-peak consumption	64.135 kWh	114.877 kWh	R$ 118.943	R$ 22.528
Off-peak demand	697 kW	1.997 kW	R$ 16.816	R$ 16.816
On-peak demand	697 kW	1.997 kW	-	R$ 72.181
Bill Total			**R$ 279.441**	**R$ 255.207**

Finally, when simulating a full storage strategy, as shown in Tab. 5, the electrical demand for cooling equipments follows the same tendency presented to the non-storage situation.

Table 5. Fares comparison: full load situation

	Chiller's only	Total	Hourly-varying "green" rate	Hourly-varying "blue" rate
Off-peak consumption	513.079 kWh	1.188.410 kWh	R$ 151.878	R$ 151.878
On-peak consumption	0	50.742 kWh	R$ 52.538	R$ 9.951
Off-peak demand	1.024 kW	2.324 kW	R$ 19.568	R$ 19.568
On-peak demand	0	1.300 kW	-	R$ 46.982
Bill Total			**R$ 223.984**	**R$ 228.379**

6. CONCLUSION

The criteria analysis for a thermal storage operation system is not a high complexity process, provided that certain limiting restrictions for the use of each operating strategy are met. To that purpose, besides all the theoretical knowledge of operating conditions, it is necessary to correctly manager the scenario features where the equipments are installed, so that it becomes feasible to set an effective strategy.

Focusing on this combination of theory and scenario evaluation, this paper proposed a tool that aims to turn the section of an appropriate thermal storage strategy into a simpler and more direct task. In addition to proposing and developing this tool, some energy bills simulations were carried out, taking as example a Brazilian airport terminal, where the applicability of the proposed tool could be demonstrated. In fact, it eventually guided the selection of an operating strategy to one that would actually generate the least amount of energy bill for the building.

The energy bills simulation as well as the spreadsheets data presentation allowed an easy understanding of the tariffs differences that a large scale consumer is subject to, according to the utility contract structure. It is also well known how a large size air conditioning system depends on the correct use of a thermal storage facility, whenever there is a concern about energy rational use.

The flowchart developed could present the cool storage strategy selection process in a simple and straightforward format. Moreover, it was shown that the full storage strategy, identified as the most advantageous by the flowchart, has really proved capable of generating the lowest energy bill in both hourly-seasonal energy fare classes, considering the characteristics extracted from the airport terminal, used as an example in this study.

7. REFERENCES

ANEEL - Brazilian Nacional Agency of Electrical Energy. **Rates for Electricity Supply,** 2005.

ASHRAE. **HVAC Applications Handbook,** 2008.

Braun, J. E., **A Near-Optimal Control Strategy for Cool Storage Systems with Dynamic Electric Rates,** HVAC&R Research, Vol. 13, No. 4, July 2007.

Carrier Company, **Installation, operation and maintenance,** 30 HXC/GX Chillers manual, 2000.

Dorgan, C.E., Elleson, J.S., **Design guide for cool thermal storage**. ASHRAE, 1993.

Henze, G. P., Krarti, M., Brandemuehl, M. J. **Guidelines for improved performance of ice storage systems**. Energy and Buildings 35 (2003) 111–127.

Sebzali M.J., Rubini P.A., **The impact of using chilled water storage systems on the performance of air cooled chillers in Kuwait.** Energy and Buildings 39 (2007) 975–984.

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