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ENERGY SAVINGS PROVIDED BY A FREE COOLING SYSTEM IN A DATA CENTER LOCATED IN SÃO PAULO

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Abstract. *Data processing is a fundamental operation for modern businesses, such as banks, reseller companies, technology companies, and factories, among others. However, computers dissipate heat and, as the operating temperature increases, these machines cannot operate properly. Therefore, air conditioning systems are essential to remove heat but they have their major drawback, increasing Data Centers electrical consumption. Considering this, the present work carried out an analysis of an indirect free cooling system. A decision algorithm was developed based on thermal parametric data and cooling demand. A case study is analyzed for a typical data center located in the city of São Paulo, Brazil. It has a demand of 0.5, 1.0, 2.0, 4.0, and 8.0 kW/m² of specific power installed at the half and a total load. Temperature and Humidity indexes are based on the data obtained from ASHRAE. The valid results show that, for a typical year, this system presents great opportunities for energy savings in all the cases, especially in the winter season. In conclusion, free cooling systems are a great alternative to reduce the energy consumption and operational cost of a Data Center.*

Keywords: *Free cooling, energy saving, Data Center, Air Conditioning*

1. INTRODUCTION

In recent years, the expansion of critical environments, especially data centers, has required the use of air conditioning systems. In a controlled environment, temperature and humidity must be set by several parameters for servers and mainframes operational safety. In commercial buildings, the air-conditioning system may account for up to 40% of the electrical bill (PAPADOPOULOS et al., 2003). In continuous operations, such as data centers, the electricity demand for cooling definitely rises. In a data center, it is possible to reach as much as 50 % of the final electrical bill (STRUTT et al., 2012). In some places in the world, electricity costs are higher at peak time (usually between 5 PM and 10 PM) due to public illumination and people arriving home (WORLD ENERGY COUNCIL, 2016). In addition, some offices and factories keep an evening work shift. Therefore, direct new investments are necessary to supply all the growing electrical demand (ANEEL, 2015). In this context, the use of alternative air conditioning systems is a technical and economic solution, such as free cooling economizer systems.

According to ASHRAE (ASHRAE, 2016b) computers should operate in the 5 - 40°C range and in the 20 - 90 % relative humidity range. At A1 condition, the temperature must be between 15°C and 35°C and the relative humidity between 10% and 90%.

The air-conditioning standard for Data Centers states that temperature and humidity must be controlled at the inlet of computer and servers, without any control in the discharge (ASHRAE, 2016b; STRUTT et al., 2012). This procedure reduces investments and operational costs, increases data processing efficiency, and reduces the maintenance stops (ASHRAE, 2016a). The recommended temperature can be reached with the inlet of ambient air entrance. Ambient air can also be cooled by water fan coils, in which the system is of the indirect expansion type. This type of free cooling is preferred because it is not needed a new class of air filter and more powerful ventilators.

This paper aims to evaluate the benefits of the indirect free cooling system and compare it with the conventional indirect expansion air conditioning system with heat dissipations of 0.5 kW/m², 1 kW/m², 2 kW/m², 4 kW/m² and 8 kW/m².

2. DATA CENTER COOLING

Servers and computers dissipate high thermal loads in the heat transfer form. In general cases, the dissipation of a Data Center ambient is around 2 kW/m², although it is variable, according to the application. In telecommunication applications, a Data Center can dissipate values around 0.5 kW/m². A Scientific application with Supercomputers could achieve 90.0 kW/m² (ASHRAE, 2018).

According to ASHRAE (ASHRAE, 2016b), the temperatures required for this application should be between 18 °C and 27 °C at the entrance of servers. The humidity should be between 10% and 60%. Fig. 1 presents this range.

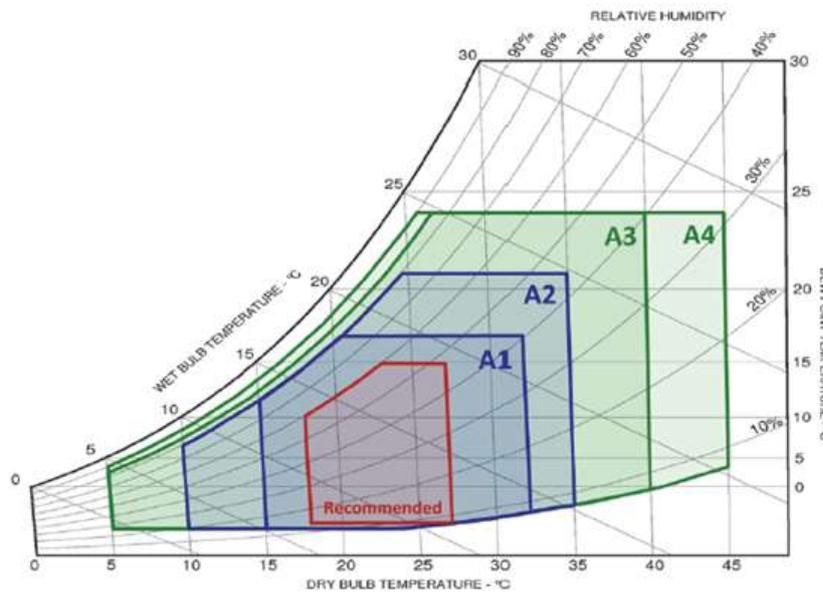


Figure 1 – Environmental conditions in entrance of serves (ASHRAE, 2016b),

2.1 Economizers for Free Cooling

In the past, economizers were used as additional devices in cooling at times in the year to improve the energy efficiency. In Data Centers, free cooling is considered the priority source, in cases of outdoor favorable conditions (DARAGHMEH e WANG, 2016; ORÓ et al., 2015; ZHANG et al., 2014). Free cooling can be conducted in 4 ways:

- **Direct Airside Free Cooling:** It occurs by direct entrance of ambient air and hot air exhaust to the environment.
- **Indirect Air Side Free Cooling:** It occurs by heat exchange between the return air and ambient air by means of enthalpy wheels.
- **Waterside Free Cooling:** It occurs by heat exchange between the return water provided by fan coils and the ambient air. Basically, it can be conducted in 3 ways: direct cold water source, direct free cooling system installed on the chiller, and cooling tower, which is presented in this manuscript.
- **Heat Pipe-System:** It is obtained by a thermosiphon passive system.

2.2 Waterside Free Cooling

Waterside Free Cooling can use a cold water source that carries out the heat exchange in the fan coil, differently from the traditional chiller. In this manuscript, the free cooling source is the cooling tower.

Fig. 2 shows the working of this technology, where the green line shows the condensed water, the cyan line presents the fan coil water and the dark blue line shows the circuit of heat exchangers for free cooling water. In hot days when the cooling tower water temperature T_{fETROC} (1) is higher than fan coil return water temperature T_{QSTROC} (3), the free cooling utilization is unavailable. The conventional process is realized for sequence 1–A–B–2–D–1 to chiller and 2–E–3–F–G–2 to fan coil. However, when the cooling tower reaches a temperature lower than fan coil return water, the free cooling can be realized. The condensed water runs out for the cooling tower (1) and flows to the heat exchanger (4), with temperature T_{fETROC} . In the opposite side, the system water runs out for the fan coil unit (3) in F and it is maneuvered to the heat exchanger (4) with temperature T_{QeTROC} . After heat exchange, the system water flow to G with temperature T_{QSTROC} . If the temperature is higher than work temperature, it is necessary to cool the water in chiller (2) to temperature T_{SUR} , in this case, the water in the condensed circuit flows from 4 to 2 and from 2 to 1. Meanwhile, if the temperature is lower or equals the working temperature, the water flows directly to point E and the chiller must be turned off. In this case, the chiller (2) is turned off, the water flows to point C, and goes directly to D and returns to the cooling tower with temperature T_{fETROC} (1) (BELIZÁRIO, 2018).

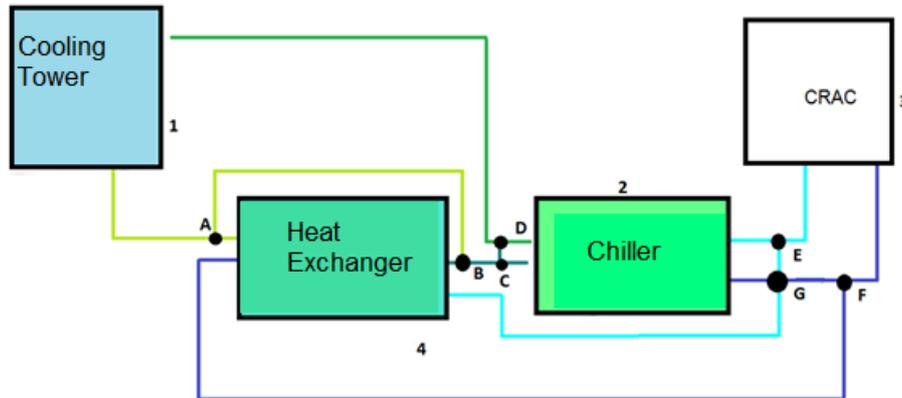


Figure 2 – Free Cooling Schematic

3. ENVIRONMENTAL CONDITIONS

For this work, we considered weather data for the city of São Paulo, Brazil, for a 24-hour period during 2016 (ASHRAE, 2017), namely: dry bulb temperature, wet bulb temperature, solar irradiation per square meter, and direct irradiation per square meter.

To carry out the analysis, a typical data center plant was adopted and the associated facilities, as schematically shown in Figure 3. For this building, the 625 m² data hall was the only conditioned area (blue square), out of the 2030 m² total building area. The solar collectors were installed on the rooftop of the total building area (2030 m²).

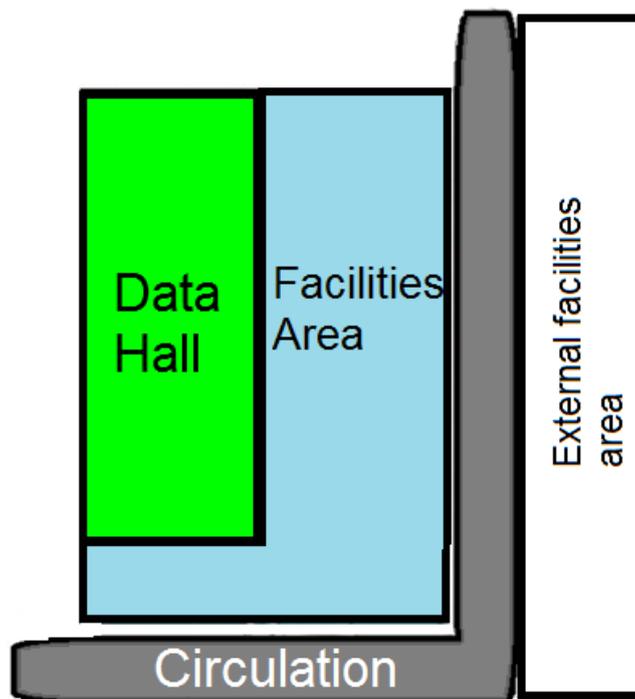


Figure 2 – Data Center plant analysed.

Computer racks dissipation densities were assumed to be 2 kW/m², computed from an average bank system (STRUTT et al., 2012), which resulted in a total dissipation of 1250 kW. Other facility areas (green square) are cold-water room (chillers room – 280 m²), fire facilities (80 m²), electrical infrastructure room (255 m²), technical aisles (fan coils room – 200 m²), circulation aisle (160 m²). These areas (except the data hall) must be air-conditioned according to human comfort rules and should not be included in the air conditioning system reported herein. Electrical generators area, cooling tower and primary cabinet of net energy are located outside the building. The computer room should follow the standard conditions for occupation and illumination (BELIZÁRIO, 2018).

To calculate the thermal load and to scale the chiller capacity, computer analysis was employed (CARRIER CORPORATION, 2016). In this simulation, the energy peak occurs in January, as the external temperature reaches 34°C and 40% relative humidity. The outdoor air flows into the technical aisle at this temperature and it is mixed with indoor return air at 34 °C, 22% relative humidity. Next, the mixed air circulates in the fan coils to be cooled at 22.3 °C, 45%

relative humidity. After that, the air is insufflated into a data hall to cool off the computers to exit at 34 °C, 22% relative humidity. Figure 5 shows the thermodynamic states and processes in the psychrometric chart.

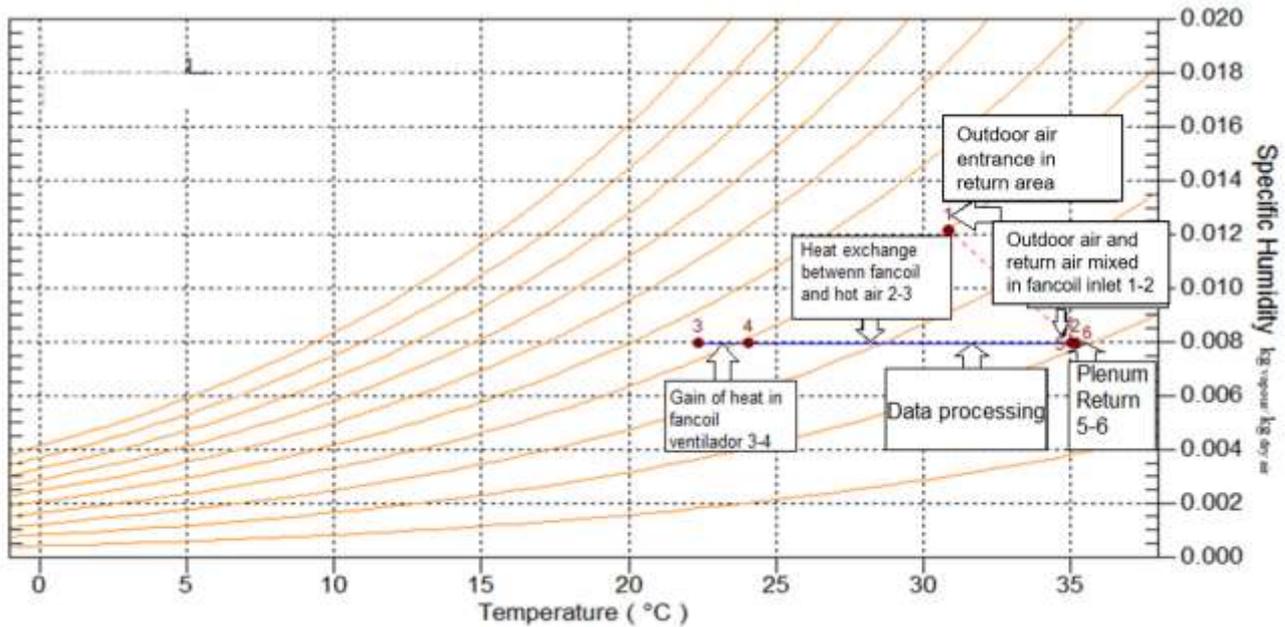


Figure 3 – Thermal load of a simulation system seen in a psychrometric chart(CARRIER CORPORATION, 2016).

For this case, the computers account for 86% of the thermal load (CARRIER CORPORATION, 2016). Conventional air conditioning systems use 24-hs non-stop electrical chillers. The power consumption by the chillers can be obtained from the manufacturer's data sheet and it can be calculated(BELIZÁRIO, 2018; TRANE, 2017) by Eq. (1) for the given thermal load to a chiller powered by a screw compressor. For other load densities, this equation would be corrected as suggested by (BELIZÁRIO, 2018; TRANE, 2017).

$$\dot{W}_C = -2 \cdot 10^{-7} \cdot \dot{C}_T^3 + 0,008 \cdot \dot{C}_T^2 - 0,7875 \cdot \dot{C}_T + 316,576 \quad \text{Eq. (1)}$$

Another important piece of information is the variation of the coefficient of chiller performance versus the required load of the equipment. Figure 6 shows the COP_E variation versus the percentage load equipment. In main situations, the chiller operates at partial load. This phenomenon is extended to combine the use of the solar thermal system and conventional electric chiller. Eq. 2 presents the third-degree polynomial interpolation, with R² = 0.9937.

$$\text{COP}_E = 14,507 \cdot \text{CH}^3 - 36,005 \cdot \text{CH}^2 + 27,321 \cdot \text{CH} - 0,6495 \quad \text{Eq. (2)}$$

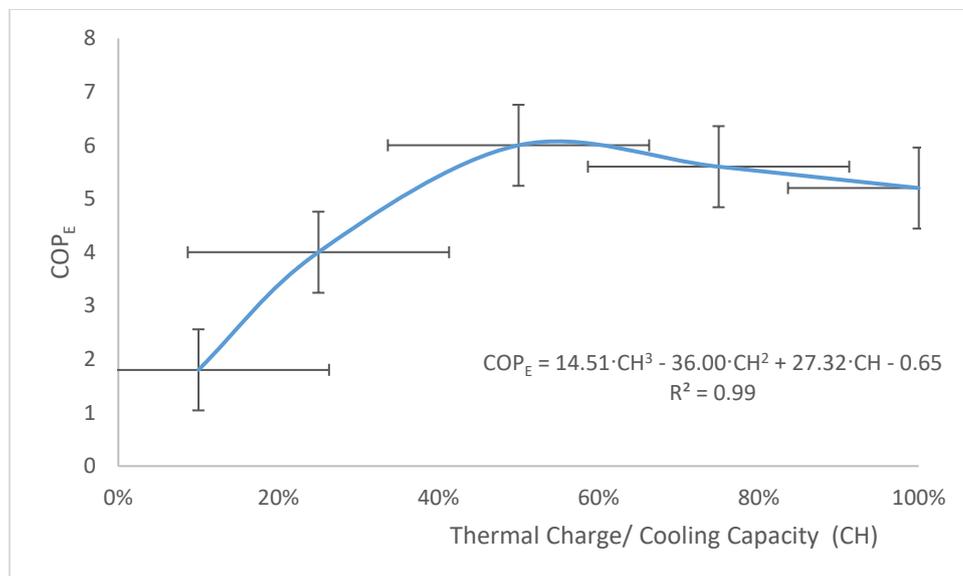


Figure 4 – Performance Curve of the complementary chiller(TRANE, 2017)

Figure 5 presents the chiller curve, showing the chiller has the maximum performance around 60% of charge; however, for lower thermal charges, above 50%, the COPs are smaller than the thermal charges over 50%.

4. PERFORMANCE ANALYSIS OF INDIRECT FREE COOLING

According to the state of São Paulo Database, the thermal load was calculated in 1-hour periods for the five selected computer dissipation densities. The thermal load accumulated (C_T) is provided by the E-20 program(CARRIER CORPORATION, 2016) and the results for different loads in a typical year are given in Table 2. The maximum hour thermal load is important because this value is the baseline to select the capacity of the chiller and our correlating curve. Another important value presented in Table 1 is the chiller annual electrical consumption. These values correspond to the sum of the 8.760 consumptions hour chiller. Local weather data are given by reference (ASHRAE, 2017).

Table 1 - Thermal load and electrical consumption by a conventional system.

Installation (kW/m ²)	Maximum hour thermal Load (TR)	Annual Consumption (GWh)
0.5	173.8	887.24
1.0	259.6	1703.24
2.0	440.3	2049.49
4.0	795.8	4877.46
8.0	1506.88	7544.06

Perhaps that part of the maximum thermal load and the annual consumption varies linearly with the computer dissipation densities and there is a minor part correlated with the external conditions (outdoor temperature, building properties). As the load increases, this share is less influential.

The next stage is the evaluation of the indirect free cooling alternative. Databases present the Wet Temperature in all hours in a demonstrate year. In the next stage is calculated the mass flux of water in chiller condenser (\dot{m}_t) and in chiller evaporator (\dot{m}_{UR}) by eqs. (3) and (4).

$$\dot{m}_t = \frac{C_T + W_{UR}}{[T_{fSTROC} - (T_{BU} + T_{app})] \cdot c_{H_2O}} \quad (3)$$

$$\dot{m}_{UR} = \frac{\dot{C}_T}{(T_{EUR} - T_{SUR}) \cdot c_{H_2O}} \quad (4)$$

Nevertheless, the values of temperatures are physically limited by heat exchange equation (5).

$$\dot{Q}_{troc} = U_{Troc} \cdot A_{troc} \frac{[(T_{QETROC} - T_{fSTROC}) - (T_{QSTROC} - T_{fETROC})]}{\ln \left[\frac{(T_{QETROC} - T_{fSTROC})}{(T_{QSTROC} - T_{fETROC})} \right]} \quad (5)$$

An interactive method is utilized to calculate this temperature and estimate the dissipation cooling flux, presented in figure 5. If the free cooling is enough to dissipate all computers heat load, the chillers is tuned off. If it is necessary a complementary cooling the chillers is turned on.

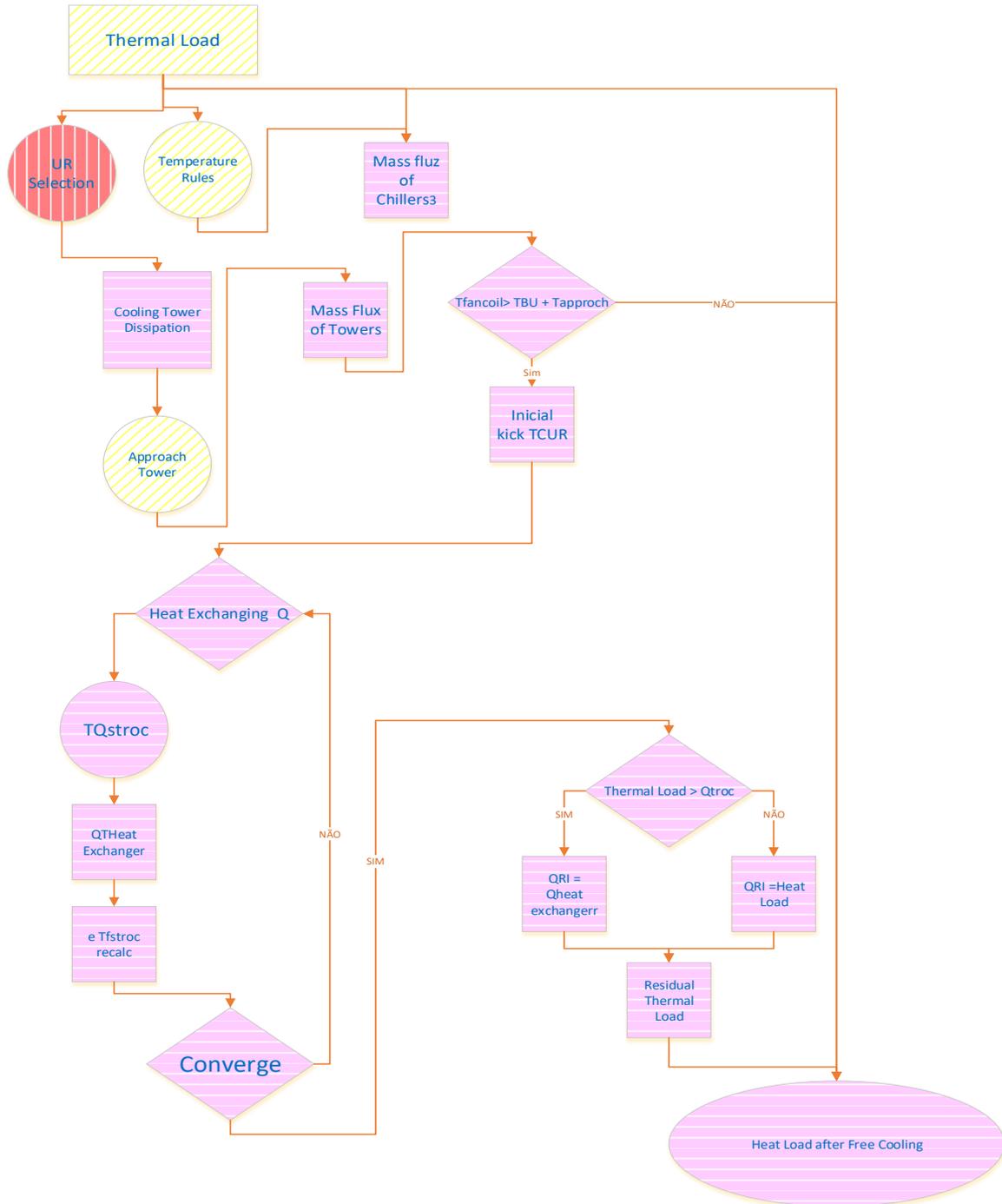


Figure 5 – Heat Exchanging calculation

5. RESULTS

An interactive method is utilized to calculate this temperature and estimate the dissipation cooling for a free cooling process. The achieved results are presented in Table 2.

Table 2 – Savings of Free Cooling System

	0.5 kW/m ²	1.0 kW/m ²	2.0 kW/m ²	4.0 kW/m ²	8.0 kW/m ²
Jan	59.17	98.25	115.22	290.61	474.46
Feb	54.50	90.45	105.87	267.97	435.66
Mar	53.86	88.49	106.01	248.05	419.34
Apr	45.00	80.09	89.51	202.90	354.00
May	34.91	69.79	71.39	138.08	266.39
Jun	30.81	68.01	62.65	124.98	244.69
Jul	31.85	69.75	64.98	124.50	246.68
Aug	29.99	70.33	59.62	125.07	245.35
Sep	32.42	68.89	65.70	131.07	253.97
Oct	45.01	79.33	90.12	195.40	346.21
Nov	45.02	76.09	89.94	191.14	339.45
Dec	54.96	92.60	107.80	257.46	430.45
Year	517.51	952.07	1028.82	2297.23	4056.65
Annual Savings	42%	54%	40%	53%	46%

The free cooling system reaches 48% of electrical consumption savings. For different load densities, there are little differences because of the different load of chillers for each one and the sizing of heat exchangers. For higher densities, It is required more water flow in condensation size and cooling size and bigger heat exchanger for free cooling.

Other important information was presented in Table 3. In the winter months, the electrical energy consumption in a system with free cooling is smaller than in summer months. It occurs because is supposed that the cooling towers provide water in the same temperature by the mission-critical chillers, in the winter. The wet-bulb temperature in São Paulo is lowest, characterized by the dry climate in this season.

6. CONCLUSION

Free cooling systems are presented for electrical energy saving and for reducing the grid electrical energy consumed in the air conditioning IT system.

In this study, the Data Center Thermal load and cooling needs were estimated for all IT densities. The savings were reached in 0.5 kW/m², by 42%; 1.0 kW/ m², by 54%; 2.0 kW/ m², by 40%; 4.0 kW/m², by 53%; and in 8.0 kW/m², by 46%.

In conclusion, for a new data center construction, the free cooling system to dissipate computer heating is fundamental and good practice to saving electrical energy and utilize the environmental conditions to improve the operation of a Data Center.

7. ACKNOWLEDGMENTS

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