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Evaluation of the Heat and Energy Performance of a Datacenter Using a New Efficiency Index: Energy Usage Effectiveness Design – EUED.

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HIGHLIGHTS

- New energy efficiency index in the design of a Datacenter - EUED.

Abstract: Data Centers are growing steadily worldwide, and they are expected to continue growing up to 53% in 2020. Energy efficiency, in high power consumption, is a key venue. There are methodologies to measure this efficiency, one example is using the PUE (Power Usage Effectiveness) index. In this paper is proposed a new index for measuring efficiency at the design stage, the EUED (Energy Usage Effectiveness Design). This index allows to evaluate systems using "free cooling" and adiabatic system. A comparison is performed considering the equipment in the worst situation. The thermodynamics parameter enthalpy is used to calculate the results. This new methodology allows to determine differences between the cities of São Paulo and Curitiba (1.21%) and between Rio de Janeiro and Curitiba (10.61%). The values for the EUED index were 1.245 kW/kW for Curitiba, 1.260 kW/kW for São Paulo and 1.377 kW/kW for Rio de Janeiro, respectively, reaching a difference of 16.86% for Curitiba, 16.19% for São Paulo and 10.31% for Rio de Janeiro in relation to PUE COA (Power Usage Effectiveness Constant Outdoor Air). The advantage of the EUED is that it works with the 8,760 hours in the design phase, using psychometric elements to determine when to use free cooling and evaporative system, and more importantly varying the COP according to environmental characteristics.

Keywords: Data Centers; PUE; EUED; Performance indexes; Data Center Cooling.

INTRODUCTION

Mobile traffic is expected to grow almost fourfold in less than a decade – from 3.9 ZB (Zettabytes) in 2015 to 14.1 ZB per year by 2020, according to Converge Comunicações, the main Brazilian communication group dedicated to the Information and Communication Technology (ICT) market(1). This expansion is attributed to the increasing migration of IT enterprise systems to the cloud. Cloud based systems have the ability to expand quickly and efficiently to support more workloads than fixed systems of traditional data centers (DCs). With higher DC virtualization rates, cloud operators will be able to offer a greater variety of services to businesses and consumers with optimized performance. According the analysis performed by Cisco, the cloud will dominate and exceed traditional DC growth by 2020 when 92% of the workload will be processed by cloud DC and 8% by traditional DCs [1].

Moreover by 2020, $298 million dollars or 68% of the cloud workload will be placed in public cloud data centers, compared to $66.3 million dollars or 49% recorded in 2015 – a 35% compound annual growth rate between 2015 and 2020. Resources like Internet of Things (IoT) and Big Data will boost the market. IoT will be a large data generator, reaching 600 ZB per year by 2020, which is 275 times greater than the projected traffic between DCs and devices/end users (2.2 ZB) – 39 times greater than the total traffic of DCs (15.3 ZB). Big Data is already driving the overall growth of storing data. Data stored in data centers will increase fivefold by 2020, reaching 915 Exabyte (EB) – an increase of 5.3 times (a compound annual growth rate of 40%) from the 171 level EB in 2015.

For the first time, Cisco also quantified and analyzed the impact of hyper scale DCs, which are expected to grow from 259 in 2015 to 485 by 2020 (1). DC hyper scale traffic is expected to increase fivefold over the next five years. These infrastructures will account for 47% of installed servers.

With the growth of DCs, one of the major challenges is to improve it the performance and efficiency, largely due to the heat dissipated by the servers, while the enormous number of equipment installed to increase the storage capacity also greatly increases the electrical power and consequently the heat dissipation. To improve heat dissipation, some DCs even moved to places where average air temperature is lower – places like the Arctic Circle or Sweden – to achieve better energy efficiency in the cooling process.

Efficiency metrics are defined and standardized to compare the efficiency of DC systems and their operating costs. A global consortium of IT equipment manufacturers, technology companies, government, education and R&D institutions, class associations and other sectors of society have also been set up to discuss, develop and recommend best practices for energy efficiency along with CO_2 em [2, 3] issions. One such metric is Power Usage Effectiveness (PUE) defined by The Green Grid, as an instrument to measure the energy efficiency of a DC. The parameter is the ratio of the total energy consumed by a DC and the power supplied to the IT equipment. The ideal PUE value would be 1.0. There are already reported cases of DCs with PUE = 1.02.

DCs are energy-intensive installations where a DC consumes around 25 to 50 times more than a normal office with the same area. The energy consumption for the DCs operation will increase 85% around Europe from 2007 to 2020. However, a recent study has shown that the rate of energy growth in DCs was not as high as expected due to virtualization and economic crisis in the US and Europe [4], and average power densities in datacenters are rapidly increasing and are expected to reach up to 3000 W/m^2 in the next 5 years [5].

Organizations such as the Green Grid, ASHRAE and the US Environmental Protection Agency have adopted the PUE metric to assess the energy efficiency of DC infrastructure. This metric is a relation between the total energy consumed by a DC and the fraction of energy consumed by the IT infrastructure. The result is always greater than or equal to one, where DC will be more efficient. Some organizations, for example, the European Commission use the inverse of the PUE, called DCiE (Data Center infrastructure Efficiency) metric. The overall energy use of a data center in relation to the energy use of IT equipment and infrastructure can also have positive effects on energy use. However, DCs need to be increasingly efficient and greener, which requires reducing the energy required to run IT infrastructures, ensuring system longevity and ensuring energy consumption from renewable sources in energy sources.

The Carbon Usage Effectiveness (CUE) [6] addresses the carbon dioxide (CO_2) emissions associated with the operations of a DC; Water Usage Effectiveness [7] addresses the use of water in DCs, including water used for humidification and water evaporated on site by energy produced or cooling from DC and its support systems. Green Grid also developed the Energy Reuse Effectiveness (ERE) metric to measure the benefit of reusing energy produced in DC in other external infrastructures. The Compute Power Efficiency metric seeks to quantify the total efficiency of a DC, taking into account the fact that not all the electrical energy delivered to the IT equipment is transformed by that equipment into a useful work product [8].

Providing free cooling in a typical DC power supply is primarily designed for an IT infrastructure and a cooling system, prepared to remove the heat generated in IT equipment. This power supply varies according to the specification of the DC and the installed cooling system. The consumption of the cooling system can be reduced using the space available via air or water economizers. Depending on the configuration of the economizers and local climatic conditions, the energy use of the cooling system varies [9]. An economizer can be constructed in a simple manner as a set of dampers, which allows the mixing of external (renewal) air with recirculating air when this air has thermodynamic characteristics favorable to its use as discharge air. Outer air in favorable conditions of temperature and humidity (low temperature and humidity values) can reduce the thermal load on the cooling system when compared to the recirculated air. This air may be in conditions that require larger work by the system to suit the thermodynamic characteristics of the air in the air-conditioned environment [10]. Khalaj et al. compared worldwide the energy use of various air economizers with a conventional cooling system to find the most efficient air economizer in each location and the best location with minimal cooling energy use [10].

The DCs have air economizers to directly distribute the ambient air after adjusting its humidity and pollutant levels according to the ASHRAE standard [11]. However, indirect air economizers use cold ambient air to cool the DC return air and redistribute it in DC. In this process, humidifier, dehumidifier, filters, heat wheels, heat pipes, direct and indirect evaporative coolers depending on the type of economizers can be used. As energy consumption, thermal performance, and final cooling cost are highly dependent on local climatic conditions, the above mentioned economizers were simulated with both air-cooled and water-cooled coolers. A renewable energy system typically converts wind energy, sunlight, sea waves, water fall, biomass and geothermal heat, into usable electricity or thermal energy. Most of these sources can be extracted directly or indirectly, they are renewable energies. Due to the growing demand for cheap and clean energy sources, it had sufficient technical and economic strength in various regions. However, the integration and large-scale deployment of these resources in the grid can have substantial technical, economic, environmental and social impacts.

Energy and economic impacts of wind and solar energy as promising renewable sources of energy considered in DCs have been evaluated to develop a sustainable energy system [10]. Batteries are also an efficient mean of storing the surplus energy supplied by photovoltaic modules and wind turbines. This surplus energy can be stored in battery banks and extracted from them when the total energy generated by renewable energy sources is insufficient.

The ideal location for a sustainable data center, after selecting the optimum air economizer for each location and with a solar generator and battery, is given by the most independent location of the power grid for its construction. This condition is achieved by calculating the total installed grid power by the DC at each location.

The growth of DC facilities is resulting in a significant increase in electrical consumption in IT and cooling systems. This high energy consumption is a major concern in design and operation. Khalaj et al. propose the integration of an economizer based refrigeration system with a hybrid system in the place of generation of energy and a system of storage in batteries, thus being more sustainable and less energy use of the electric network [11].

According to Lajevardi et al, DCs have substantially increased energy consumption with the growth of the IT industry. Various annual metrics have been suggested to overcome the challenges of energy efficiency and thermal management. The performance of datacenters in thermal management was monitored for 6 weeks [12]. The results are analyzed, current energy efficiency and thermal management issues are discussed in relation to the relative effectiveness of the various metrics, as shown in Table 1.

Despite the development of several metrics to assess DC efficiency, no metrics were proposed to simultaneously assess the impact of the central level and rack level (i.e., infrastructure and IT equipment) changes in energy efficiency.

The most usual metric (PUE) is limited due to the infrastructure and IT loads that appear in the denominator of the expression. Thus, if improvements are made in the energy use of IT equipment without simultaneous changes in the energy use of the infrastructure, the metric value of the PUE will actually increase. Due to the challenges and limitations of existing metrics, future work to be developed should focus on developing a metric to more efficiently evaluate energy efficiency and the impact of data center changes. This would allow higher-level decision makers to evaluate results based on a single metric rather than requiring the measurement, analysis, and evaluation of a set of metrics. Such an approach would be more direct and time-effective and would potentially reduce the effect of evaluating competing metric results. These data centers therefore represent a significant energy load, which, in turn, must be managed through new technologies and control strategies [13].

Beitelmal documented the effectiveness of a data center. The Power Use Efficiency (PUE) metric is a reference tool used to analyze the infrastructure of a datacenter in relation to the existing IT load. A PUE ratio of 2.0 indicates that the IT equipment uses about 50% of the measured building energy and the remainder is used for cooling and other support resources. Other metrics were proposed for rack-level performance assessments; for example, “Supply Heat Index (SHI)”, is a metric that has been introduced as a dimensionless parameter that helps quantify the amount of heat infiltrated in the cooled air supplied to a rack" [14]. This metric is the relationship between the enthalpy increase due to heat infiltration at the rack entrance and enthalpy rise at the rack outlet, with a detailed analysis to develop the composite relationship between the geometry parameters and the feed load. A correlation between the SHI metric and the overall energy efficiency of the datacenter has not yet been documented. Research work becomes necessary to take this and other metrics used for data center energy analysis. For example, the variables used to calculate the PUE metric can be difficult to measure if the DC is in a mixed-use building. In addition, the metric is simple and does not provide the technical background needed for proper engineering analysis. For example, if all the servers in a data center are inactive and do not produce any work, while being the cooling resources well provisioned, the energy consumed by cooling and other support resources will be only 20% of IT energy, perfect 1.2. In this example, the PUE metric gives the indication that the DC is very well optimized, however, the datacenter is wasting energy, since no work is being done [14].

A public memorandum has been created that addresses the agreement reached by the Global Metrics Harmonization Task Force on standard approaches and reporting conventions for Data Center energy Productivity (DCeP). DC owners and operators evaluate and improve the performance of their equipment with energy efficiency metrics. This agreement recommends quantifying useful work.

Beitelmal defines a thermodynamic system as a server on the local scale and as a data center on the global scale. The energy efficiency metrics cover the relationship between the dynamic power (the power proportional to the use of the system) and the total energy consumed by the system. The sample for a single server and for a datacenter were presented to determine the energy efficiency metric for each case. The results of this analysis show that the efficiency increases with increasing CPU utilization and it is higher for a multi-processor server than for a single processor server. This condition occurs due to idle power tends to reduce the overall server efficiency, so consolidating processors on the same server platform would minimize this effect. The DC case study is conducted into a hypothetical datacenter scenario where the estimated energy of the cooling resources is calculated using the chiller system. Work on these energy performance metrics is necessary to develop standardized methods for evaluating and classifying heterogeneous dataservers and datacenters based on their actual utilization and consumption [14].

With growing business, a Portuguese telecommunications operator considered the construction of a new DC in Portugal with 12.000 m² of white space and 40 MW of electricity. The installation in terms of energy efficiency means that the DC must have a PUE equal to or less than 1.25. This will be the largest DC built in Portugal and its project should be used as a reference not only in terms of energy efficiency but also sustainability. Finding the most satisfactory place to achieve the economic, environmental and risk objectives [4].

According to Covas et al., the complexities of DCs in technical and organizational infrastructure that guarantee the best performance and highest reliability in modern information and communications systems. A multicriteria decision analysis approach (MCDA) was proposed, identifying the most sustainable locations for DC facilities, taking into consideration technical, social, economic, environmental and environmental aspects. Evaluations of DCs in Portugal were carried out based on written research and interviews, to estimate the potential loss of opportunity in terms of energy savings due to their location. Evaluating the environmental performance of DCs, leading to a literature review to compile the metrics used. These metrics are presented in Table 2 [15].

The PUE was adopted as a metric guide to evaluate the efficiency of DCs. However, the use of the PUE metric showed some concerns among analysts and expert designers of a DC since they concluded that it did not promote energy efficiency practices. Criterion.

Considered two DCs in two different locations with the same systems (IT, power distribution, generators, UPS, etc.), but with different cooling systems. Being one of the DCs is in warmer weather but they have the same PUE. This means that their refrigeration infrastructures (all others being equal) are using the same amounts of energy, which means that under the PUE metric, they can be considered equally efficient. However, a DC located in a very cold climate, as in the Arctic, taking advantage of free external cooling, rather than to a DC located in a warmer climate, such as Portugal. With this lower temperature, it would be more efficient in DC power consumption located in the hot region. Because the owner companies never considered building a DC in the Arctic, where they did not imagine their employees living near DC, and that other employees, including DC customers, could easily visit DC for maintenance or other operations. Seeing the public image of the company, not building its ventures in other countries [15].

ASHRAE reference bibliography discusses that the free cooling has connection with the reduction of PUE, also demonstrated a mean reduction of 2.0 of PUE to up to 1.5 using free cooling. PUE can be computed using either energy (kilowatt-hour) or power (kilowatt) measurements. Energy measurements are more accurate because power measurements only sample the energy flow at the exact time of measurement, while energy measurements accumulate power flow over time. First-time PUE estimates often use power-based sampling more accurately reflects long-term energy use and is now preferred by the industry. Most monitoring systems can be configured to report energy [16].

Table 1 - Metrics for Datacenters [15].

Metrics	Initials	Definition
Power Usage Effectiveness	PUE	$\frac{Power\ total\ instillation}{IT\ Power\ to\ equipment}$
Datacenter Infrastructure efficiency	DCiE	$\frac{1}{PUE} \cdot 100$
Carbon Usage Effectiveness	CUE	$\frac{CO_2\ issued\ (kgCO_2eq)}{Power\ unit\ (kWh)} \cdot PUE$
Water Usage Effectiveness	WUE	$\frac{Annual\ on\ site\ water\ use}{IT\ Power\ equipment}$
Energy Reuse Effectiveness	ERE	$(1 - \frac{Reuse\ energy}{Energy\ total}) \cdot PUE$
Compute Power Efficiency	CPE	$\frac{IT\ Use\ of\ equipment}{PUE}$
Power Overhead Multiplier	SI-POM	$\frac{DC\ Power\ Consumption\ on\ Utility\ Meter}{Total\ hardware\ consumption\ linked\ IT}$
Hardware Power Overhead Multiplier	H-POM	$\frac{Load\ of\ machines\ connected\ in\ AC}{Loading\ computers}$
Deployed Hardware Utilization Ratio	DH-UR	$\frac{Nº\ Servers\ Running\ Applications}{Total\ servers\ actually\ deployed}$
Corporate Average Datacenter Efficiency	CADE	Efficient installation · IT Efficiency of assets
Temperature of the region usage effectiveness	TRUE	$\frac{IT\ eq.\ power + Lighting\ power + others}{IT\ Power\ Equipments} + Cf \cdot \frac{cooling\ sistem\ power}{IT\ Equipment\ Power}$

There are other factors that are not included in this research work, such as: energy availability, and seismic risk, focusing exclusively on areas of greater impact beyond the IT equipment itself such as thermal areas. A typical DC (with PUE = 2.1) has the distribution of the electricity consumption shown in Figure 1[15].

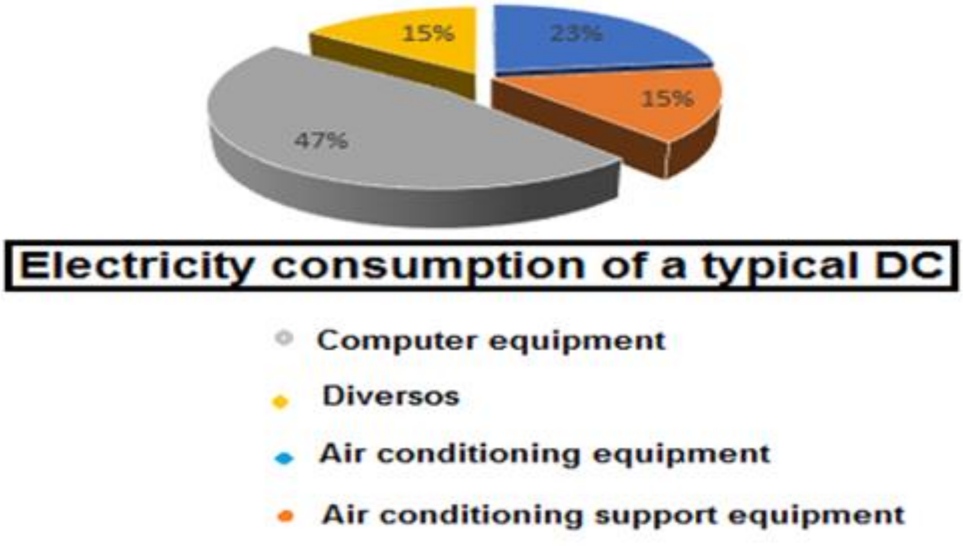


Figure 1 - Distribution of the electricity consumption in a typical DC [17].

Thus, in a typical DC, except for the 47% out of the remaining 53% of electrical consumption used in the IT equipment, the air conditioning system is responsible for 38% of total electricity consumption. IT and air conditioning correspond to about 72% of all electrical consumption in the infrastructure, Figure 1. Since the emphasis of this work is not directed at the efficiency of computer equipment, the idea is to use a performance index that can help investors to have the needed support when deciding the most suitable location for the installation of a DC, using an abacus with simple and basic elements. According to Ernts &Young, executives need to "Increase the speed of decision making and the efficiency of project execution to take advantage of windows of opportunity" [9]. One such metric is Power Usage Effectiveness (PUE), defined by The Green Grid as an instrument to measure the energy efficiency of a DC. This parameter is the ratio of the total power consumed by a DC and the power supplied to the IT equipment. The ideal PUE value would be 1.0. There are already reported cases of DC with PUE = 1.02 [19].

In this work, a new and truly accurate metric proposed: Energy Usage Effectiveness Design (EUED). This metric will emphasize the outside environmental characteristics of the DC, studying the weather and geothermal characteristics. Thus, a pre-project study using natural indexes can accelerate decision making considering the most appropriate location for a thermal DC, i.e., making use of an index involving four elements. In the correlation, the proposed index for decision making uses the following parameters:

- Dry bulb air temperature;
- Wet bulb air temperature;
- Soil temperature (geothermal);
- Dew point air temperature.

The EUED emphasizes on energy rather than power as the PUE does.

In addition to the PUE, the Thermal Guidelines for Data Processing Environments already have some simulations for the use of "Free cooling" for some cities of the United States of America, like Chicago. However, in this work the evaporative and geothermal adiabatic systems are included in the simulations to the new index EUED to evaluate DCs performance [18].

This work starts with the analysis of ASHRAE Thermal Guidelines for Processing for 3 target cities [19], intended for the calculation of the EUED and subsequent comparison with the PUE values. The analysis and discussion of results, provide a higher level of information to be used in the decision making of the suitable location to install a DC.

SELECTED CITIES AND THEIR CHARACTERISTICS

This research work is based on a high-density Data Center. The chosen cities to analyze the influence of the location of the DC installation on the energy consumption:

- Curitiba (CTBA), Paraná, Brazil;
- São Paulo (SP), São Paulo, Brazil;
- Rio de Janeiro (RJ), Rio de Janeiro, Brazil.

Table 2 includes the altitude (H), dry bulb (TDB) and wet bulb (TWB) air temperatures of cities of Curitiba, São Paulo, and Rio de Janeiro.

Table 2 - Data from the cities of Curitiba, São Paulo, and Rio de Janeiro [12].

City	Year frequency	T_{DB} [°C]	T_{WB} [°C]	H [m]
Curitiba	0.4%	30.9	23.2	908
	1%	29.8	22.6	
	2%	28.7	22	
São Paulo	0.4 %	32.0	23.2	803
	1%	31.0	22.6	
	2%	30,0	22.1	
Rio Janeiro	0.4%	34.0	26.6	3
	1%	32.7	26.2	
	2%	31.8	25.8	

Note: percentage of the total hours of the year in which the indicated design temperatures could be exceeded [17].

The difference between the dry bulb temperatures of cities Curitiba and São Paulo is 3.56% and between Curitiba and Rio de Janeiro is 10.03%.

For comparison purposes, a high density DC of 414 m² is used, measuring 28.8x14.4 m, and with a heat dissipation of equipment (347.3 kW of sensible heat, that is 0.84 kW/m²), and an internal thermal load of 48 kW (conduction, lighting = 8 kW in total), people and others (40 kW of losses in Nobreak and others). 8 equipment were selected (4 active equipment and 4 reserved) of 30 Tons of refrigeration (TR) "dual Fluid", with 85% Sensitive Heat Factor, as shown Table 3. It is considered 1 Refrigeration Ton = 3516.853 W [16].

The dual fluid equipment has the technical specifications described in Table 3.

Table 3 - Standard Features of the Dual fluid air conditioning equipment used in DCs.

Model L99	Unit	Value
Total cooling capacity	kW	194.6
Sensible cooling capacity	kW	89.3
Sensible Heat Ratio (SHR)		0.85
Energy Efficiency Rate (EER)		3.40
Number of compressors	N	2
Air flow	m³/h	21100
Max. External Static Pressure (ESP)	Pa	90
Sound pressure level	dB(A)	66.9
Width	mm	2550
Depth	mm	890

The approximate power of 30 Refrigeration ton (104.6 kW, for each of the eight equipment, being 1 active and another reserved) has an Energy Efficiency Rate (EER) of 3.4 kW/kW (in the condition of direct expansion), i.e. the power feeding point of the air conditioning to meet the thermal load will be 123.5 kW, therefore, the index Power Usage Effectiveness Constant Outdoor Air (PUE COA) is the fraction of the total energy (data equipment + air conditioning + lighting + losses of nobreak and inverters, and others) to the data equipment energy.

$$PUE\ COA = \frac{Total\ energy}{Data\ equipment\ energy} = \frac{347.30+123.05+8.00+40.00}{347.3} = 1.50\ \mathrm{kW/kW} \qquad (1)$$

A PUE COA = 1.50 kW/kW is an excellent value since a typical DC already quoted above has a value PUE COA = 2.1 kW/kW. These yields of air conditioning equipment were based on an air inlet temperature in the condenser from 33ºC to 35°C. These temperature values are close to the values found in two cities already mentioned, i.e. the PUE of the two cities would be the same.

COMPARISON OF PUE COA AND EUED

The PUE COA index is similar to the PUE index, but with an emphasis on the external temperature at the average value of 0.4% of the current higher temperatures of ASHRAE WEATHER DATA VIEWER that is the same than NBR 16401 (HVAC Design Brazilian Standard) [20].

Unlike the PUE that is related only with power indexes, the EUED index is related with the 8760 hours (the metrics uses energy instead of power, which is already a suggestion of ISO 50006 for commercial buildings, the metric with units of specific energy, kWh/m²).

Using the annual dry bulb temperature index associated with the coincident dew point temperature (data from the ASHRAE Weather Data Viewer), the EUED index is classified as [20]:

- Free Cooling - System that allows the use of the enthalpic characteristics of the external air to acclimatize an enclosure;
- Evaporative - Adiabatic cooling, which consists of cooling the environment using the wet bulb temperature;
- COP – Coefficient of Performance, which is used to evaluate the relationship between the refrigeration capacity and the work spent.

Based on an average discharge temperature of 20°C, the calculation following the EUED methodology considered the following factors:

- When the temperature is below 20°C, and the enthalpy is below 18.4 BTU/lb, only Free Cooling will be used;
- When the temperature is between 15ºC to 24°C, and the enthalpy is between 18.4 and 24 BTU/lb, the Evaporative system will be used;
- When the temperature is above 20°C, and enthalpy is above 24 BTUlb, the normal system will be used under the following conditions:

o Air inlet temperature between 24ºC and 27°C: COP1;
o Air inlet temperature between 27ºC and 30°C: COP2;
o Air inlet temperature between 30ºC and 33°C: COP3;
o Air inlet temperature above 33°C: COP4.

In order to simulate the conditions of COP1, COP2, COP3, and COP4, the Cool pack software was used to simulate a standard isentropic coefficient in order to identify the COP with the variation in the condensation temperatures. The temperature effect of condensation is based in the average air intake temperature for each situation added to 11°C., with the following conditions, Table 4:

Table 4 - Distribution of electricity consumption in a typical DC.

Cases	Power of base equipment [kW]	Condensing Temperature [ºC]	Evaporation temperature [ºC]	Cooling Fluid	COP [kW/kW]
COP1	104.5	36.5	5.0	R410A	4.381
COP2	104.5	39.0	5.0	R410A	4.101
COP3	104.5	42.5	5.0	R410	3.745
COP4	104.5	44.0	5.0	R410A	3.633

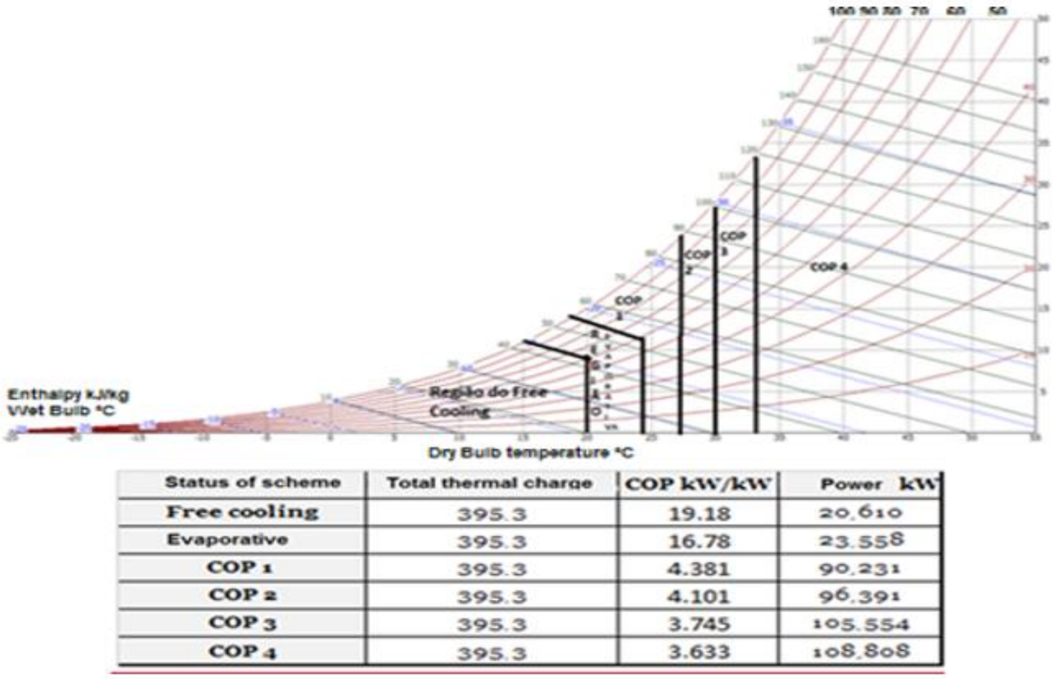
In all studies for this case, the calculation for COP4 considers fans powered at 7.36 kW. In the case of study COP4, the value of the COP without the fans reaches 4.829. To achieve the COP with the fans, the following equation will be used: (104.5 / 21.64 kW from compressors + 7.36 kW from fans) = 3.633 kW/kW.

COP3 considered fans powered at 7.36 kW, that is: a COP of 5.087, with the fans, the COP value is (104.5 / (20.54 kW from compressors + 7.36 from fans) = 3.745 kW/kW.

COP2 have fans powered at 7.36kW. The COP will be (104.5 kW / (18.12 from compressors + 7.36 from fans) = 4.101 kW/kW; and without fans it will go up to 5.768 kW/kW.

COP1 considers fans powered at 7.36 kW. The COP will be (104.5 kW / (16.49 + 7.36) = 4.381 kW/kW; while the COP without fans will go to 6.338 kW/kW.

From the COP values a system of wide psychrometric coverage was elaborated for all possible external temperature points, either for "Free Cooling", "Evaporative Cooling" or just "Cooling". Using ASHRAE (2013), the association of the dry-bulb temperature frequencies with the coincident dew point temperatures was defined as method; and at each point, the enthalpy associated with this relation was found in the following cumulative frequencies for each system and city (Table 5) (Figure 1):



Status of scheme	Total thermal charge	COP kW/kW	Power kW
Free cooling	395.3	19.18	20.610
Evaporative	395.3	16.78	23.558
COP 1	395.3	4.381	90.231
COP 2	395.3	4.101	96.391
COP 3	395.3	3.745	105.554
COP 4	395.3	3.633	108.808

Figure 2 – Psychrometric chart [18].

The EUED index classifies the frequencies in working hours for the three cities. It is noteworthy that between cities there are differences. In Curitiba, the evaporative system has the highest frequency (3453.887 hours) when the temperature is between 15ºC to 24°C and the enthalpy is between 18.4 to 24 BTU/lb. In São Paulo, the frequency is 4713.20 hours and in Rio de Janeiro, the frequency is 2131.860 hours.

The Free Cooling system, with a temperature below 20°C and an enthalpy lower than 18.4 BTU/lb, Curitiba has 4410 hours of frequency, São Paulo has 2574.191 hours, and Rio de Janeiro has 159.515 hours [16].

According to Table 5, it is verified that with the rules proposed in the EUED, six levels were classified: Free Cooling; Evaporative; COP1; COP2; COP3; COP4. The cities of Curitiba, São Paulo and Rio de Janeiro, have different consumption energy according to their temperature and enthalpy. In a period of 8760 hours, São Paulo used 18.06% more energy than Curitiba, and Rio de Janeiro used 57.35% more energy than Curitiba. Table t also shows the relation between COP and energy. The higher the COP the lower is the energy consumption. In Tables 6 and 7, calculations using index EUED rules and results in the calculations using the EUED index rules.

Table 5 - Frequency in hours of usage.

System status	t_{CTBA} **[h]**	t_{SP} **[h]**	t_{RJ} **[h]**
Free Cooling	4410.000	2574.191	159.515
Evaporative Cooling	3453.887	4713.820	2131.860
COP1	579.743	906.945	4536.432
COP2	269.874	434.482	1108.059
COP3	45.987	122.639	554.971
COP4	0.509	7.922	269.163

Table 6 - Calculations using index EUED rules.

Operating System	**Total Thermal Load [kW]**	**COP [kW/kW]**	**Power [kW]**	t_{CTBA} **[h]**	t_{SP} **[h]**	t_{RJ} **[h]**
Free Cooling	395.3	19.18	20.610	4410.000	2574.191	159.515
Evaporative	395.3	16.78	23.558	3453.887	4713.820	2131.860
COP1	395.3	4.381	90,231	579,743	906.945	4536432
COP2	395.3	4.101	96.391	269.874	434.482	1108.059
COP3	395.3	3.745	105.554	45.987	122.639	554.971
COP4	395.3	3.633	108.808	0.509	7.922	269.163
Operating System	E_{SP} [kWh/yr]	E_{CTBA} [kWh/yr]	E_{RJ} [kWh/yr]	$E_{Equip.}$ [kWh/yr]	$E_{Lighting}$ [kWh/yr]	E_{Others} [kWh/yr]
Free Cooling	53054.104	90890.143	3287.599	3042348	70080	420480
Evaporative	111047.266	81366.013	50221.945			
COP1	81834.164,	52310.503	409324.685			
COP2	41880.210	26013.493	106807.078			
COP3	12945.054	4854.091	58579.443			
COP4	862,021	55.362	29287.177			
Total air spending	301622.819	255489.606	657507.928			

Table 7 - Results in the calculations using the EUED index rules.

Parameter	Value
E_{CTBA} [kWh year]	3788397.606
E_{SP} [kWh year]	3834530.819
E_{RJ} [kWh year]	4190415.928
$EUED_{CTBA}$	1.245
$EUED_{SP}$	1.260
$EUED_{RJ}$	1.377
$(EUED/PUE\ COA)_{CTBA}$ year	16.86%
$(EUED/PUE\ COA)_{SP}$ year	16.19%
$(EUED/PUE\ COA)_{RJ}$ year	10.31%

Energy consumption with infrastructure, which is the sum of the energy consumption plus air conditioning, equipment, lighting and other equipment, between cities show a difference larger than 1.21% for São Paulo in relation to Curitiba; and 10.61% for Rio de Janeiro in relation to Curitiba. The indexes obtained with application of the EUED index were, respectively, 1.245 kW/kW for Curitiba, 1.260 kW/kW for São Paulo, and 1.377 kW/kW for Rio de Janeiro, showing a difference of 16.86% for Curitiba, 16.19% São Paulo, and 10.31% for Rio de Janeiro in relation to the PUE, as shown in Table 8.

In Figure 3 and Table 8, the comparative information of the COP PUE COA and COP EUED shows that the COP EUED is much larger than the other indexes, so this is the best way to map the possibilities in the project design phase and to have satisfactory results in the installations of new DCs.

Table 8 - Comparison of PUE COA, EUED, COP PUE COA and COP EUED.

CITIES	PUE COA	EUED	COP PUE COA	COP EUED
Curitiba	1.455	1.245	3.745	13.553
São Paulo	1.467	1.260	3.642	11.481
Rio de Janeiro	1.481	1.377	3.463	5.629

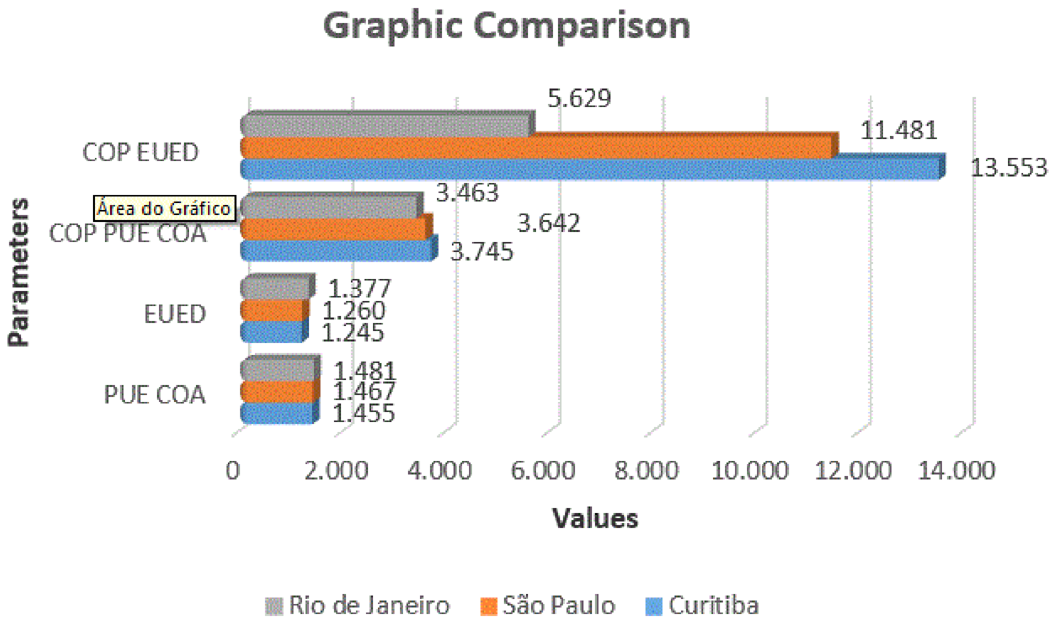


Figure 3 – Comparison of COP PUE COA and COP EUED.

TEWI is a metric of the global warming impact of equipment based on total greenhouse gas emissions during the operation of the equipment and the disposal of end-of-life operational fluids. TEWI considers both the direct stealth emissions, indirect emissions produced through the energy consumed in the equipment operations. TEWI is measured in units of mass in kg of carbon dioxide equivalent (CO_2) [18]. This methodology was applied in the development of the DC's project, determining a COP PUE COA to make the comparative of efficiency with the EUED in the three calculated localities, Curitiba, Rio de Janeiro and São Paulo. The data was selected in ABNT NBR 16401-01-2008. In this step, the city of Chicago (USA) was added. The comparison of the data of Dry Bulb and Wet Bulb temperatures is shown in Table 9 [20].

Table 9 – Comparison of TEWI values.

CITIES	EUED	COP PUE COA/VENTILATOR	Consumed Energy	TEWI
Curitiba	1.277	3.745	255489.60	667042.128
São Paulo	1.163	3.642	301622.819	709946.022
Rio de Janeiro	1.389	3.122	657507.928	1040919.173
Chicago	1.246	3.477	258533.316	1781566.043

According to Table 9, it was found that although Curitiba and Chicago have similar HVAC annual energy consumption , the TEWI of the cities is completely different: The TEWI of Chicago (USA) is 1781566.043 CO_2 kW/10 years and Curitiba (Brazil) is of 667042.128 CO_2 kW/10 years. Thus, Chicago has an annual expense 267.08% larger than Curitiba, as shown in Figure 4.

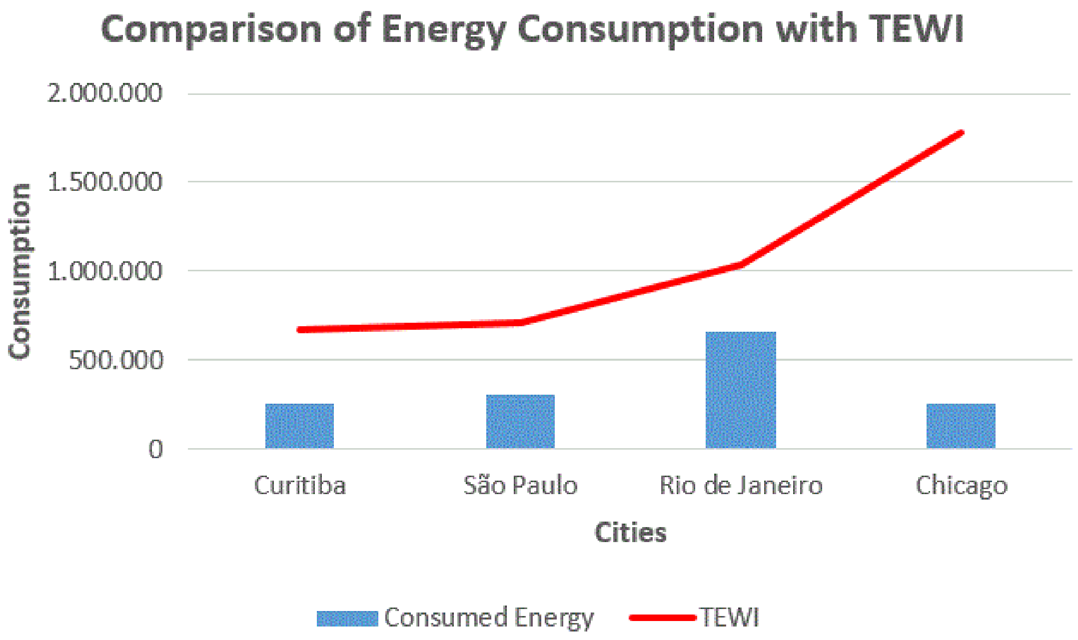


Figure 4 – Comparison of energy consumption with TEWI.

CONCLUSIONS

The proposed EUED index is a more reliable index than the PUE index to analyze the energy efficiency in new DCs by the fact that it uses energy rather than power for comparison between systems as a metric.

Enthalpy is an essential tool for choosing the best place to install a DC.

Energy consumption with infrastructure, which is the sum of energy consumption with air conditioning, equipment, lighting and other equipment. Between the chosen cities, Curitiba, São Paulo and Rio de Janeiro, the energy consumption difference is more than 1.21% of São Paulo in relation to Curitiba and 10.61% of Rio de Janeiro in relation to Curitiba. The EUED values are, respectively, 1.245 kW/kW for Curitiba, 1.260 kW/kW for São Paulo and 1.377 kW/kW for Rio de Janeiro, giving a difference of 16.86% for Curitiba, 16.19% for São Paulo and 10.31% for Rio de Janeiro in relation to the PUE COA. Using TEWI as metric, for a similar annual HVAV energy consumption between Curitiba and Chicago, the TEWI values determined are extremely different, where TEWI of Chicago (USA) is 1781566.043 CO_2 kW/10 years and Curitiba (Brazil) is 667042.128 CO_2 kW/10 years. The USA city value corresponds to an annual expense 267% greater than in Curitiba. The advantage of the EUED is that it works with the 8,760 hours in the design phase, using psychometric elements to determine when to use free cooling and evaporative system and more importantly varying the COP according to environmental characteristics.

NOMENCLATURE

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers	**UPS**	Uninterruptible Power Source
USA	United States of America	**CTBA**	Curitiba
DC	Data Center	**SP**	São Paulo
PUE	Power Usage Effectiveness	**RJ**	Rio de Janeiro
EUED	Energy Usage Effectiveness Design	T_{DB}	Dry bulb temperature [ªC)
PUE COA	Power Usage Effectiveness Constant Outdoor Air [kW/kW]	T_{WB}	Wet bulb temperature [ªC)
ICT	Information and Communication Technology	***NBR***	Brazilian standards
H	Altitude [m]	**ISO**	International Organization for Standardization
T	Temperature [ºC]	**TEWI**	Total Equivalent Warming Impact
SHR	Sensible Heat Ratio	**MCDA**	Multicriteria Decision Analysis Approach
EER	Energy Efficiency Rate [kW/kW]	**SHI**	Supply Heat Index
ESP	External Static Pressure [Pa]		
COP	Coefficient of Performance [kW/kW]		
T	Time [h]		
E	Energy [kWh/yerar]		
ERE	Energy Reuse Effectiveness		

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