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Evaluation of the Thermal Performance and Energy Efficiency of CRAC Equipment through Mathematical Modeling Using a New Index COP WEUED

Alexandre F. Santos [1,2], Pedro D. Gaspar [1,3] and Heraldo J. L. de Souza [2,*]

1 Department of Electromechanical Engineering, University of Beira Interior, 6201-001 Covilhã, Portugal; d1682@ubi.pt (A.F.S.); dinis@ubi.pt (P.D.G.)
2 FAPRO—Professional College, Curitiba 80230-040, Brazil
3 C-MAST—Centre for Mechanical and Aerospace Science and Technologies, 6201-001 Covilhã, Portugal
* Correspondence: heraldo@escolaprofissional.com.br; Tel.: +55-41-999748928

Abstract: As the world data traffic increasingly grows, the need for computer room air conditioning (CRAC)-type equipment grows proportionally. The air conditioning equipment is responsible for approximately 38% of the energy consumption of data centers. The energy efficiency of these pieces of equipment is compared according to the Energy Standard ASHRAE 90.1-2019, using the index Net Sensible Coefficient Of Performance (NetSCOP). This method benefits fixed-speed compressor equipment with a constant inlet temperature air-cooled condenser (35 °C). A new method, COP WEUED (COP–world energy usage effectiveness design), is proposed based on the IPLV (integrated part load value) methodology. The IPLV is an index focused on partial thermal loads and outdoor temperature data variation for air intake in the condenser. It is based on the average temperatures of the USA's 29 major cities. The new method is based on the 29 largest cities worldwide and with data-center-specific indoor temperature conditions. For the same inverter compressor, efficiencies of 4.03 and 4.92 kW/kW were obtained, using ASHRAE 90.1-2019 and the proposed method, respectively. This difference of almost 20% between methods is justified because, during less than 5% of the annual hours, the inlet air temperature in the condenser is close to the NetSCOP indication.

Keywords: ASHRAE 90.1; data center; IPLV; Net Sensible COP; AHRI 1361

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1. Introduction

The Cisco Annual Internet Report forecasts the global adoption of the Internet. The proliferation of devices/connections and network performance, by the year 2023, will be [1]:

- 5.3 billion internet users (66% of the estimated population in 2023).
- 3.6 global devices and connections per capita.
- Average global speed of fixed broadband of 110 Mbps.
- In North America, 92% of the population will use the Internet.

In addition to the increasing number of users, there have been systems improvements, such as lower response time to search information, lower downtime (online for longer, without problems at critical moments), upgrade without interruption (in one click, management of active and unlimited resources), resilience and self-repair (makes the data pulverized automatically, and its update process is much simpler and optimized).

To sustain this growth in the global database and in user demand, the number of data centers and their energy consumption have been increasing. In 2018, it was estimated that data centers consumed 1% of all the global electricity generated. From 2010 to 2018, the number of computers skyrocketed (Figure 1) [2].

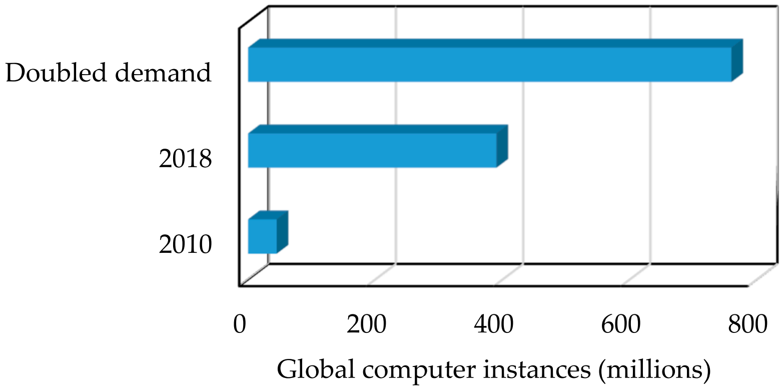

Figure 1. Growth of global data center instances [2].

Despite this growth, it is estimated that due to the increase in efficiency from 2010 to 2018, the total energy to serve the data centers grew by only 6%, and this is directly explained by the better efficiency of the data center equipment. The energy consumption of a data center is 10 to 100 times greater than that of a standard commercial building of the same dimensions. In Leadership in Energy and Environmental Design (LEED) buildings, the average energy consumption with an electrical load of 68% of the buildings was 10.8 W/m^2 [3]. According to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), data centers are installations with an enormous demand for energy, highlighting the relevance of the theme. High-density data centers can reach 10,764 W/m^2, although on average, their consumption ranges from 430 to 861 W/m^2 [4]. Even though specific information technology (IT) equipment has evolved, within the data center, air conditioning systems are one of the main sinks of energy consumption. If energy consumption in data centers is considered of high relevance, the air conditioning topic becomes an indispensable item of discussion. On average, air conditioning systems are responsible for 38% of the energy consumption of data centers [5]. According to Santos et al. [6], the load distribution of a data center is distributed as shown in Figure 2.

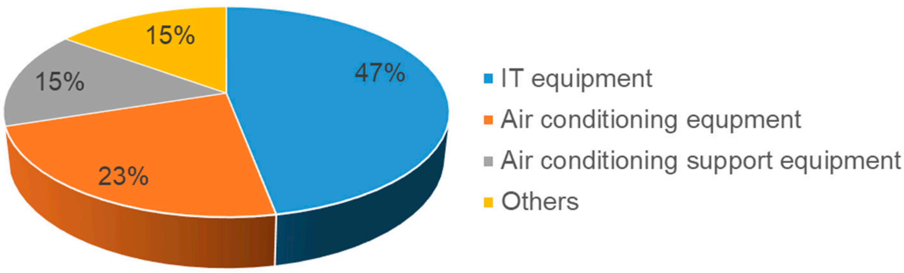

Figure 2. Distribution of electricity consumption in a typical DC with power usage effectiveness (PUE) = 2.1 [6].

Analyzing the current methodologies to measure the energy efficiency of computer room air conditioning (CRAC) equipment in data centers is an important action since it is the largest load apart from the IT equipment itself. Thus, suggesting a new methodology to measure the thermal performance and energy efficiency that considers the characteristics of the data center location is relevant in terms of sustainability.

2. Current Methodology (ASHRAE 90.1-2019 Standard)

A data center is different from ordinary commercial facilities, as it has a high sensible heat rate. Rack coolers are better if designed only for a sensible rate (without wet coils), and the coils can even be above the dew temperature [7].

Based on this high sensible heat rate, wisely, the ASHRAE 90.1-2019 Standard uses the Net Sensible Coefficient Of Performance (NetSCOP) index as a basis for the user to compare the efficiency of the air conditioning machine with a minimum of efficiency specified in the standard. This condition is important because, in some medium data centers, standard equipment (self-contained air conditioning) can be used, and split-type air conditioning system may be used in some smaller data centers [8]. Different from common equipment, the CRAC is designed specifically for data centers. The project type of downflow air supply is used often, and CRAC has the appearance of a closet, designed for a high sensible heat rate, providing more reliability. Figure 3 shows a sectional view of CRAC equipment installed in a data center, and Figure 4 shows a plan view of CRAC installation within a downflow safe room.

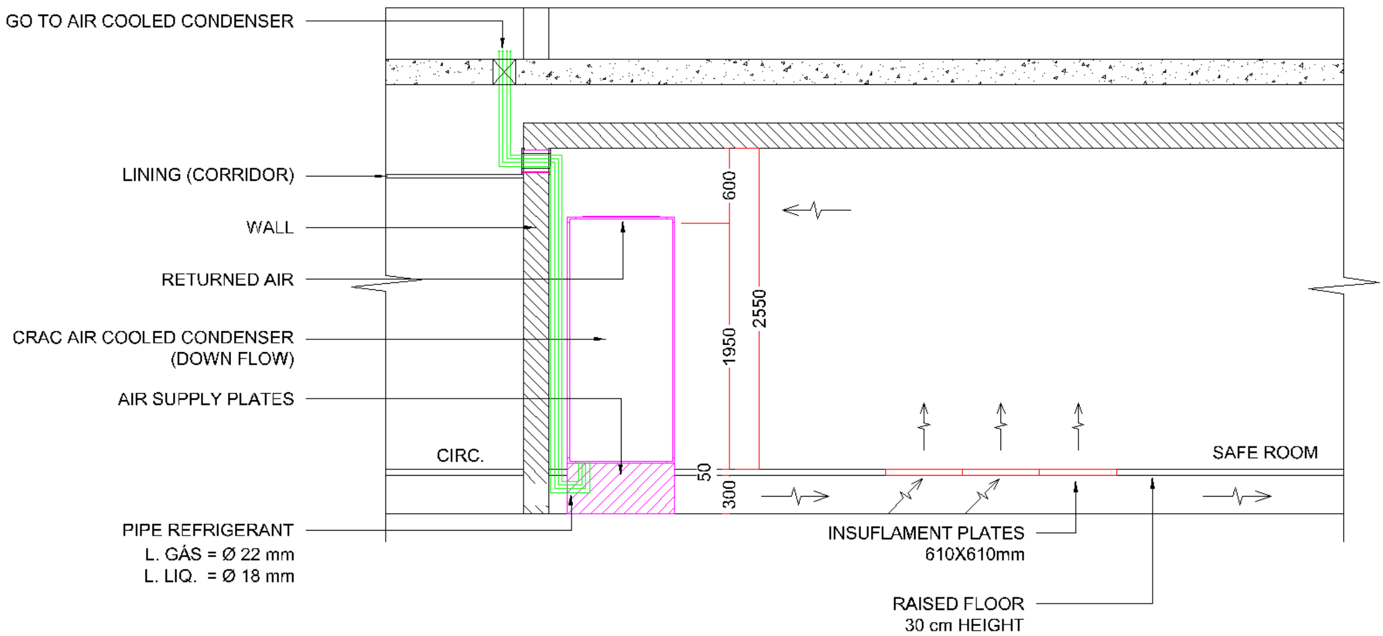

Figure 3. Sectional view of CRAC equipment installed in a data center.

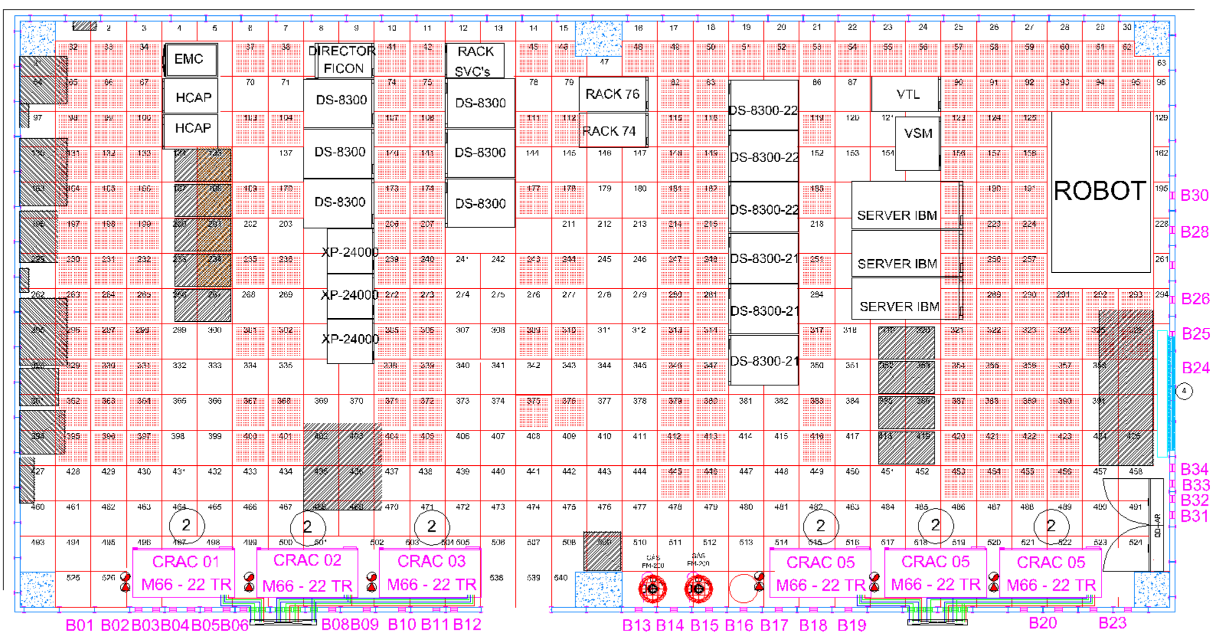

Figure 4. Plan view of CRAC installation within a downflow safe room.

Table 1 shows the minimum efficiency requirements and the Net Sensible COP in ASHRAE 90.1-2019 Standard indicated for floor-mounted air conditioners and condensing units serving computer rooms [8] considering the rating conditions for dry-bulb (DBT) and dew-point (DPT) temperatures.

Table 1. Minimum efficiency requirements and the Net Sensible COP in ASHRAE 90.1-2019 Standard indicated for floor-mounted air conditioners and condensing units serving computer rooms [8].

Equipment Type	Standard Model	Net Sensible Cooling Capacity COP	Minimum Net Sensible COP (kW/kW)	Rating Conditions Return Air (DBT/DPT)	Test Procedure
Air-cooled	Downflow	<23 kW	2.70	29 °C/11 °C (Class 2)	AHRI 1361
		≥23 and <86 kW	2.58		
		≥86 kW	2.36		
	Upflow-duct	<23 kW	2.67		
		≥23 and <86 kW	2.55		
		≥86 kW	2.33		
	Upflow-nonduct	<19 kW	2.16	24 °C/11 °C (Class 1)	
		≥19 and <70 kW	2.04		
		70 kW	1.89		
	Horizontal	<19 kW	2.65	35 °C/11 °C (Class 3)	
		≥19 and <70 kW	2.55		
		70 kW	2.47		

The values for the most used equipment, which is the downflow, are based on a fixed characteristic of return temperature and dew point based on Class 2. According to TC 9.9, classes are divided according to the types of equipment/needs of a data center, as shown in Table 2 [9].

Table 2. Classes for certain characteristics of data center enclosures [9].

2008 Classes	2011 Classes	Applications	Information Technology Equipment	Environmental Control
1	**A1**	Data center	Enterprise servers, storage products	Tightly controlled
2	**A2**		Volume servers, storage products, personal computers, workstations, laptop, printers	Some control
	A3			Some control, use of free cooling techniques when allowable
	A4			Some control, near full-time usage of free cooling techniques
3	B	Office, home, transportable environment, etc.	Personal computers, workstations, laptops, printers	Minimal control
4	C	Point of sale, industrial, factory, etc.	Point of sale equipment, ruggedized controllers or computers, PDAs	No control

A1—A data center environment with strict control of the psychrometric parameters: dry-bulb temperature (DBT), dew-point temperature (DPT), relative humidity (RH), and in a mission-critical operation. Generally developed for large companies with a large number of racks.

A2—Generally a technological production environment or an office or a laboratory with some control over environmental parameters. They are locations that shelter small racks; they can be personal servers or workstations.

The values of return dry-bulb temperature (DBT) and dew-point temperature (DPT) of 29 and 11 °C, respectively (see Table 3), are recommended for Class 2. These values are not recommended for Class 1, but they could be allowable.

It is also important to note that a return temperature does not mean the intake of air in the rack, which will certainly be at a lower temperature.

Table 3. ASHRAE 2015 Thermal Guidelines classes [10].

Equipment Environmental Specifications for Air Cooling							
Product Operations						**Product Power Off**	
Class	**DBT (°C)**	**Humidity Range**	**MDP (°C)**	**Max. Elevation(m)**	**Max. ΔT/hour (°C/h)**	**DBT (°C)**	**RH (%)**
Recommend (suitable for all four classes)							
A1–A4	18 to 27	−9 °C (DPT) to 15 °C (DPT) and 60% RH					
Allowable							
A1	15 to 32	−12 °C (DPT) and 8% RH to 17 °C (DPT) and 80% RH	17	3050	5/20	5 to 45	8 to 80
A2	10 to 35	−12 °C (DPT) and 8% RH to 21 °C(DPT) and 80% RH	21	3050	5/20	5 to 45	8 to 80
A3	5 to 40	−12 °C (DPT) and 8% RH to 24 °C (DPT) and 85% RH	24	3050	5/20	5 to 45	8 to 80
A4	5 to 45	−12 °C (DPT) 8% RH to 24 °C (DPT) and 90% RH	24	3050	5/20	5 to 45	8 to 80
B	5 to 35	8% RH to 28 °C(DPT) and 80% RH	28	3050	N.A.	5 to 45	8 to 80
C	5 to 40	8% RH to 28 °C(DPT) and 80% RH	28	3050	N.A.	5 to 45	8 to 80

The parameters and methodologies to arrive at the values of ASHRAE 90.1-2019 are specified in AHRI 1361-2017. The air supply parameters of Table 4 of the standard of the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) corroborate with ASHRAE 90.1-2019.

Table 4. Indoor return air temperature standard rating conditions [11].

Mounting Locations	**Standard Model**	**Cooling (Return Air DBT/DPT) (°C)**	**Humidification (Return Air DBT/DPT) (°C)**
Ceiling mounted unit	Ceiling mounted unit ducted	24.0/11.0	24.0/5.6
	Ceiling mounted unit nonducted		
Floor mounted unit	Upflow unit nonducted	24.0/11.0	
	Upflow unit ducted	29.5/11.0	
	Downflow unit	29.5/11.0	
	Horizontal flow unit	35.0/11.0	

In contrast, AHRI 1361-2017 also offers the air intake temperatures in the condenser, as shown in Table 5. It must be noted that:

1. All ratings are at standard atmospheric pressure.
2. For the NetSCOP calculation, add allowance for cooling tower fan(s) and heat rejection loop, water pump power input in kW to the unit total input in kW = 5% of the unit net sensible capacity.
3. For the NetSCOP calculation, add allowance for dry cooler fan(s) and heat rejection loop glycol pump power input in kW to the unit total input in kW = 7.5% of the unit net sensible capacity.
4. For the NetSCOP calculation, add allowance for chilled water pump power input in kW to unit total input in kW (See Equation (1)).

Table 5. Heat rejection/cooling fluid standard rating conditions [11].

System Type	Fluid Condition	Test Condition
Air-cooled units	Entering outdoor ambient DBT (°C)	35.0
Water-cooled units (typically connected to a common glycol loop)	Entering water temperature (EWT) (°C)	28.5
	Leaving water temperature (LWT) (°C)	35.0
	Water Flow rate (L/s)	N/A
Glycol-cooled units (typically connected to a common glycol loop)	Entering glycol temperature (°C)	40.0
	Leaving glycol temperature (°C)	46.0
	Glycol Flow rate (L/s)	N/A
	Glycol solutions concentration	40% Propylene glycol by volume
Chiller-water units (typically connected to a common chilled water loop)	Entering water temperature (EWT) (°C)	10.0
	Leaving water temperature (LWT) (°C)	16.5

It is appropriate that in a place of thermal load and air supply conditions constant at 8760 h, the priority is the efficiency in Net Sensible COP. However, although there is no variation internally, there is an external factor in the equipment: the temperature of the air inlet in the condenser constantly changes, implying a positive or negative change in the performance of the air conditioning equipment. This temperature variation has a relevant impact on the performance of the inverter or digital compressor equipment type.

The integrated part load value (IPLV) is a performance characteristic developed and used in AHRI's methodology. This methodology considers variable air intake temperature in the condenser and variable thermal load based on the average temperature of the 29 major cities in the United States of America (U.S.A.).

IPLV is a methodology in which COP is measured in partial loads. IPLV is a parameter to consider even in chillers for data centers. Its parameters are described in AHRI 550/590-2015 [12]. These parameters are in accordance with Equation (1) and described in Table 6.

$$\text{IPLV (or NPLV)} = 0.01 \cdot \text{A} + 0.42 \cdot \text{B} + 0.45 \cdot \text{C} + 0.12 \cdot \text{D} \quad (1)$$

where,

A: COP at 100% capacity, (kW/kW).
B: COP at 75% capacity, (kW/kW).
C: COP at 50% capacity, (kW/kW).
D: COP at 25% capacity, (kW/kW).

Table 6. Partial load conditions for calculating IPLV/NPLV.

Evaporator (all types)	Unit	Values
100% capacity leaving water temperature (LWT)	(°C)	6.7
Volumetric flow	(m^3/h·ton)	5.45
Fouling Factor	(m^2·°C/W)	0.000018
Water condenser		
100% capacity entering water temperature (EWT)	(°C)	29.4
75% capacity EWT	(°C)	23.9
50% capacity EWT	(°C)	18.3
25% capacity EWT	(°C)	18.3
0% capacity EWT	(°C)	18.3
Volumetric flow	(m^3/h·ton)	6.81
Fouling Factor	(m^2·°C/W)	0.000044
Air condenser		
100% capacity entering water temperature (EWT)	(°C)	35.0
75% capacity EWT	(°C)	26.7
50% capacity EWT	(°C)	18.3
25% capacity EWT	(°C)	12.8

From a macro point of view, there is an index that analyzes the conditions of free cooling, evaporative system, and variable COP in data centers: the Energy Usage Effectiveness Design (EUED), with the following characteristics (see Figure 5) [13]:

- When the outside air temperature is below 20 °C and the enthalpy is below 42.7979 kJ/kg, only free cooling will be used.
- When the temperature is between 15 and 24 °C and the enthalpy is from 42.7979 to 55.8233 kJ/kg, the evaporative system will be used.
- When the temperature is above 20 °C and the enthalpy is over 55.8233 kJ/kg, the normal system will be used under the following conditions:
    1. Air intake temperature between 24.1 and 27 °C, called COP1.
    2. Air intake temperature between 27.1 and 30 °C, called COP2.
    3. Air intake temperature between 30.1 and 33 °C, called COP3.
    4. Air intake temperature above 33.1 °C in any condition, called COP4.
    5. If a geothermal temperature is available, it will be used to determine the COP, with a differential of 4 °C of the geothermal temperature.

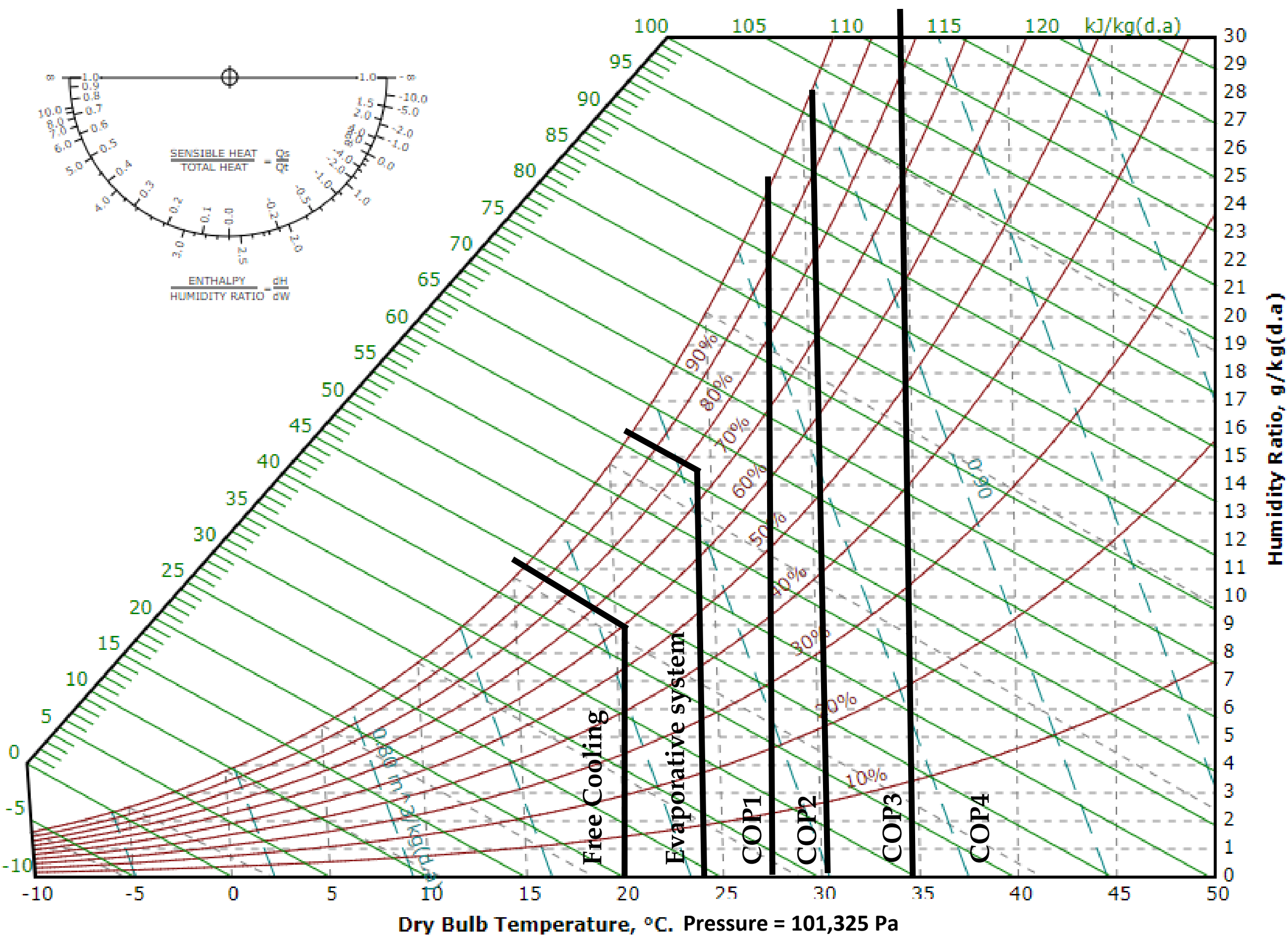

Figure 5. Psychrometric chart with variation of case studies.

3. New Methodology

The new methodology proposed in this paper considers the superposition of the three methodologies: Net Sensible COP, IPLV, and EUED, to create a specific index for CRAC equipment with an air-cooled condenser with downflow air supply named COP WEUED (COP World Energy Usage Effectiveness Design). This index emphasizes the CRAC equipment with the compressor on (i.e., active refrigeration cycle), knowing that indexes such as EUED or statistical analysis for predicting location-specific data center PUE and its improvement potential, already use free cooling and evaporative cooling for their methodologies. The air intake characteristics in the condenser must consider the use of the refrigeration cycle in the data center air conditioning system. Among the characteristics of the new index are [3,13]:

(1) Fixed air return temperature conditions equivalent to ASHRAE 90.1-2019, that is, 29 °C with a dew point temperature of 11 °C, thus considering a standard evaporation temperature of 12 °C.

(2) Air intake temperatures in the condenser calculated for four values (levels) shown in Table 7. Each of the values of COP1, COP2, and COP3 are the average values of the EUED methodology, whereas COP4 is the value used by AHRI 1361 for air intake in the condenser.

(3) Considering the principle in the IPLV that is based on the 29 largest cities in the U.S.A., in this case, the 29 largest cities in the world are used. Table 8 lists the 29 most populous cities according to the 2018 United Nations report [14].

Table 7. Air inlet temperatures in the condenser.

Level	Calculation Temperature (°C)
COP1	25.5 (COP1 average from 24.1 to 27 °C)
COP2	28.5 (COP2 average from 27.1 to 30 °C)
COP3	31.5 (COP3 average from 30.1 to 33 °C)
COP4	35 (All temperatures above 33.1 °C)

Table 8. World cities and their populations [14].

No.	City	Country	Population [×1000]
1	Tokyo	Japan	37,468
2	Delhi	India	28,514
3	Shanghai	China	25,582
4	São Paulo	Brazil	21,650
5	Mexico City	Mexico	21,581
6	Al-Qahirah-Cairo	Egypt	20,076
7	Mumbai	India	19,980
8	Beijing	China	19,618
9	Dhaka	Bangladesh	19,578
10	Osaka	Japan	19,281
11	New York	USA	18,810
12	Karachi	Pakistan	15,400
13	Buenos Aires	Argentina	14,967
14	Chongqing	China	14,838
15	Istambul	Turkey	14,751
16	Calcutta	India	14,681
17	Manila	Philippines	13,482
18	Lagos	Nigeria	13,462
19	Rio de Janeiro	Brazil	13,293
20	Tianjin	China	13,215
21	Kinshasa	Democratic Republic Congo	13,171
22	Guangzhou	China	12,638
23	Los Angeles	USA	12,458
24	Moscow	Russia	12,410
25	Shenzhen	China	11,908
26	Lahore	Pakistan	11,738
27	Bangalore	India	11,440
28	Paris	France	10,901
29	Bogota	Colombia	10,574

The ASHRAE Weather Data Viewer [15] was used to determine the average temperature condition of each of the 29 largest cities in the world. Table 9 shows how many hours in each of these cities in the world are for COP1, COP2, COP3, and COP4. It is important to remember that the hours of free cooling and evaporative cooling will not be part of the refrigeration equipment index with the compression cycle.

Table 9. COPs of cities worldwide [15].

City	Country	Annual Hours COP1 (24 to 26.9 °C)	Annual Hours COP2 (27 to 29.9 °C)	Annual Hours COP3 (30 to 32.9 °C)	Annual Hours COP4 (≥33 °C)
Tokyo	Japan	910	674	284	57
Delhi	India	879	1481	1323	1873
Shanghai	China	1190	817	340	125
São Paulo	Brazil	1.215	454	147	13
Mexico City	Mexico	2.610	1669	1168	1020
Al-Qahirah-Cairo	Egypt	1345	947	785	660
Mumbai	India	1915	3412	1844	468
Beijing	China	1051	526	262	86
* Dhaka	Bangladesh	1561	2.685	1.487	794
Osaka	Japan	959	849	416	130
New York	USA	545	260	95	18
Karachi	Pakistan	1201	2476	1848	1053
Buenos Aires	Argentina	1083	389	85	9
Chongqing	China	743	743	437	309
Istambul	Turkey	830	443	126	15
Kolkata (Calcutta)	India	1561	2685	1487	794
Manila	Philippines	1959	4436	2024	262
* Lagos	Nigeria	1345	1762	1708	2686
Rio de Janeiro	Brazil	2807	1533	494	91
Tianjin	China	955	668	321	94
* Kinshasa	Dem. Rep. Congo	2966	1746	997	216
Guangzhou	China	1737	1685	822	341
Los Angeles	USA	198	63	18	4
Moscow	Russia	205	85	23	6
Shenzhen	China	1708	2049	911	138
Lahore	Pakistan	985	1320	1103	1525
Bangalore	India	2164	1156	520	156
Paris	France	257	113	42	12
Bogota	Colombia	2	0.2	0.04	0
TOTAL		36,886	37,126	21,117	12,955
Average		1271.92	1280.20	728.17	446.72
Total Hours		3727.02			

Note: * Specifically, the ASHRAE Weather Data Viewer [15] has temperatures in 26 of the 29 cities. For the cities of Dhaka, Lagos, and Kinshasa values from nearby cities, Calcutta, Niamey, Brazzaville, respectively, were used.

As shown in Table 9, using the weighted average of the 29 largest cities in the world, the use of compression refrigeration in data centers is essential in 3727.2 h per year of the 8760 h available. That is, it is feasible to use free cooling and evaporative cooling for the other 5032.8 h per year, as shown in Figure 6.

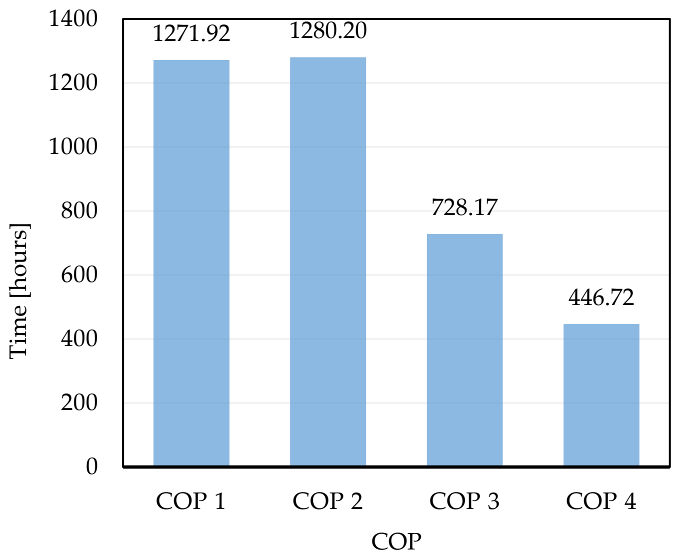

Figure 6. COPs vs. annual hours of refrigeration system usage.

Using part of the IPLV formula, EUED, and AHRI 13621 concepts, Equation (2) was determined using percentages of COPs shown in Figure 7 [16].

$$COP\ WEUED = ((0.34 \cdot COP1) + (0.34 \cdot COP2) + (0.20 \cdot COP3) + (0.12 \cdot COP4)) \cdot SLR \quad (2)$$

where SLR is the sensible heat rate.

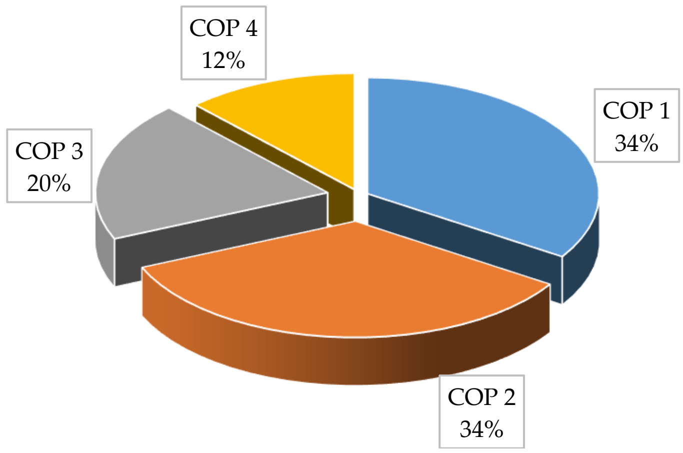

Figure 7. COPs percentages.

4. Analysis and Discussion

To demonstrate experimentally the difference between a system with both conditions, a calculation using the Bitzer Inverter Scroll compressor software is firstly developed for the AHRI 1361 condition and then with the COP WEUED condition. The considerations exposed in Table 10 were used.

AHRI conditions and thermal load:

- Sensible cooling capacity = 50 kW;
- Total cooling capacity = 55 kW;
- Inlet air condenser temperature = 35 °C (AHRI 1361 conditions) [16];
- Approach between bubble temperature and condenser air inlet = 10 °C;
- Condensing temperature = 45 °C;
- Evaporating temperature = 10 °C;
- Suction gas superheat = 10 °C (EN 12900-2013 conditions);
- Liquid subcooling (in condenser) = 0 °C (EN 12900-2013 conditions) [17].

COP Sensible WEUED conditions:

The conditions are the same as the AHRI conditions except for the air inlet temperature in the condenser. The comparison of results is shown in Table 10 for the compressor Bitzer GSD60137VA4.

Table 10. AHRI vs. COP WEUED result comparison.

	AHRI	**COP1**	**COP2**	**COP3**	**COP4**
Compressor freq. (Hz)	73	64	67	69	73
Cooling capacity (kW)	55	55	55	55	55
Evaporator capacity (kW)	55	55	55	55	55
Condenser capacity (kW)	67.5	64.1	65.6	66	67.5
COP/EER (kW/kW)	4.43	5.98	5.46	4.97	4.43
Min. cooling capacity (kW)	26.4 (35 Hz)	329.6 (35 Hz)	28.6 (35 Hz)	27.7 (35 Hz)	26.4 (35 Hz)
Max. cooling capacity (kW)	56.4 (75 Hz)	63.5 (75 Hz)	61.3 (75 Hz)	59 (75 Hz)	56.4 (75 Hz)
Mass flow (kg/h)	1240	1115	1159	1186	1240
Discharge gas temp. w/o cooling (°C)	76.7	64.2	68	71.9	76.7
Result COP (kW/kW)	4.03	4.92			

The COP WEUED is determined using Equation (2):

$$\text{COP WEUED} = ((0.34 \times 5.98) + (0.34 \times 5.46) + (0.2 \times 4.97) + (0.12 \times 4.43)) \times 0.91 = 4.92\ \text{kW/kW}$$

As can be analyzed from results, while the Net Sensible COP with AHRI 1361 conditions is 4.43 kW/kW (but with sensible heat equal to 4.03 kW/kW), the proposed COP WEUED index value is 5.41 kW/kW (but with sensible heat equal to 4.92 kW/kW). A considerable difference of 19% is determined, due to:

(a) With the AHRI 1361 method for CRAC equipment, it is impossible to show the difference between fixed compressors and inverter for data centers in COP evaluations.
(b) It has been proven that even at fixed thermal loads, there is an advantage of an air conditioning system with a variable flow of refrigerant fluid (inverter system).
(c) Just as in AHRI, there are the IPLV and NPLV that use the same formula. The main difference between them is that IPLV is based on AHRI characteristics and NPLV is based on local characteristics. COP WEUED can also be used based on local characteristics. For example, using the same methodology for the city of São Paulo, Equation (2) provides:

$$\text{COP NEUED} = ((0.66 \times 5.98) + (0.25 \times 5.46) + (0.08 \times 4.97) + (0.01 \times 4.43)) \times 0.91 = 5.23\ \text{kW/kW}$$

That is, in the case of São Paulo, the difference would be 23% to COP NEUED vs. COP WEUED. While the current NetSCOP method value was 4.03 kW/kW, COP WEUED was 4.92 kW/kW, and with specific data from the city of São Paulo, COP NEUED was 5.23 kW/kW, all simulated with the same inverter compressor.

5. Conclusions

Despite the evolution of data centers in reducing energy consumption, the index used to measure and compare energy efficiency between CRAC equipment does not yet use inverter technology resources (variable refrigerant flow) in its methodology. The IPLV for equipment already was developed for comfort air conditioning, but the Net Sensible COP methodology favors fixed-capacity equipment. The energy efficiency index needs to keep up with new technologies; according to Wen et al. [18], the compressor frequency variation is one of the greatest technologies for reducing energy consumption in CRAC equipment. Both data center equipment and air conditioning systems are evolving. Another technology is microchannels coils with microfluids that can reduce heat dissipation from IT equipment with both air and water cooling [19]. However, microchannel coils can also be used in air conditioning equipment and improve energy savings [20]. The COP WEUED index measures more accurately the benefits of these new technologies.

Just as the IPLV is an important milestone for air conditioning equipment, a COP WEUED index was created based on the 29 major cities in the world, which could be an important tool to compare CRAC equipment, gathering the best of the AHRI 1361, which prioritizes sensible heat, with the calculation of the EUED method and also with the IPLV formula.

This methodology can be useful for further studies, as it can serve as a basis for manufacturing CRAC equipment with more connection to the real temperatures of the outside air, even recalculating the condenser fans, since the specific mass of the air is also related to temperatures.

In addition to these advantages, the proposed method favors high-performance air conditioning equipment in the range in which they will be truly used, since technologies such as free cooling and evaporative cooling are already realities in data centers.

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Abbreviations

CRAC	Computer room air conditioner.
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers.
COP	Coefficient of performance.
SLR	Sensible heat rate.
EUED	Energy Usage Effectiveness Design.
WEUEDN	World Energy Usage Effectiveness Design Nonstandard.
IPLV	Integrated part load value.
LEED	Leadership in Energy and Environmental Design.
IT	Information technologies.
TC	Technical committee.
AHRI	Air-conditioning, Heating, and Refrigeration Institute.
NPLV	Non-standard part load value.
PUE	Power usage effectiveness

References

1. CISCO. By The Numbers. Projecting the Future of Digital. 2020. Available online: https://www.cisco.com/c/en/us/solutions/executive-perspectives/annual-internet-report/infographic-c82-741491.html (accessed on 12 October 2020).
2. Masanet, E.; Shehabi, A.; Lei, N.; Smith, S.; Kooney, J. Recalibrating global data center energy-use estimates. *Science* **2020**, *367*, 984–986. [CrossRef] [PubMed]
3. Lei, N.; Masanet, E. Statistical analysis for predicting location-specific data center PUE and its improvement potential. *Energy* **2020**, *201*, 117556. [CrossRef]
4. Amiri, A.; Ottelin, J.; Sorvari, J. Are LEED-Certified Buildings Energy-Efficient. *Sustainability* **2019**, *11*, 1672. [CrossRef]

5. Ni, J.; Bai, X. A review of air conditioning energy performance in data centers. *Renew. Sustain. Energy Rev.* **2017**, *67*, 625–640. [CrossRef]
6. Santos, A.F.; Gaspar, P.D.; Souza, H.J.L.d. New Data Center Performance Index: Perfect Design Data Center—PDD. *Climate* **2020**, *8*, 110. [CrossRef]
7. NREL. *High-Performance Computing Data Center*; National Renewable Energy Laboratory (NREL), U.S. Department of Energy: Denver, CO, USA, 2014.
8. ASHRAE. *Standard 90.1-2019 (SI Edition)—Energy Standard for Buildings Except Low-Rise Residential Buildings (ANSI Approved; IES Co-sponsored)*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2019.
9. ASHRAE. *ASHRAE TC 9.9—Data Center Networking Equipment—Issues and Best Practices*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2016.
10. ASHRAE. *ASHRAE—Thermal Guidelines Classes*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2015.
11. AHRI. *AHRI 1360. Performance Rating of Computer and Data Processing Room Air Conditioners*; Air-Conditioning, Heating, and Refrigeration Institute (AHRI): Arlington, VA, USA, 2017.
12. AHRI. *AHRI Standard 550/590 (I-P). Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*; Air-Conditioning, Heating, and Refrigeration Institute (AHRI): Arlington, VA, USA, 2015.
13. Santos, A.F.; Gaspar, P.D.; Souza, H.J.L. Evaluation of the Heat and Energy Performance of a Datacenter Using a New Efficiency Index: Energy Usage Effectiveness Design—EUED. *Braz. Arch. Biol. Technol.* **2019**, *62*, e19190021. [CrossRef]
14. United Nations Department of Economic and Social Affairs, Population Division. *The World's Cities in 2018*; ST/ESA/SER.A/417 Data Booklet; UN: New York, NY, USA, 2018.
15. ASHRAE. *ASHRAE Weather Data Viewer, Version 5.0*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2016.
16. AHRI. *AHRI Standard 1361. Standard for Performance Rating of Computer and Data Processing Room Air Conditioners*; Air-Conditioning, Heating, and Refrigeration Institute (AHRI): Arlington, VA, USA, 2017.
17. ES. *DIN EN 12900—Refrigerant Compressors—Rating Conditions, Tolerances and Presentation of Manufacturer's Performance Data*; European Standard (ES), Deutsches Institut fur Normung E.V. (DIN): Berlin, Germany, 2013.
18. Wen, J.; Wenlun, C.; Bei, C.; Yuyao, H. An inverter testing system for CRAC. In Proceedings of the 2014 International Conference on Intelligent Green Building and Smart Grid (IGBSG), Taipei, Taiwan, 23–25 April 2014; pp. 1–5. [CrossRef]
19. Cairone, F.; Gagliano, S.; Bucolo, M. Experimental study on the slug flow in a serpentine microchannel. *Exp. Therm. Fluid Sci.* **2016**, *76*, 34–44. [CrossRef]
20. Park, C.Y.; Hrnjak, P. Experimental and numerical study on microchannel and round-tube condensers in a R410A residential air-conditioning system. *Int. J. Refrig.* **2008**, *31*, 822–831. [CrossRef]