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High Performance Data Centers and Energy Efficiency Potential in Greece

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Abstract

Data centers are amongst the most complex and energy demanding building environments. The trends of increasing data center capacity and power use by information technology equipment, re-emphasize the need to reduce cooling loads, first cost for HVAC equipment, and finally related energy and operational costs. The first part of the paper presents an overview of relevant information and available resources for the efficient design and operation of these critical environments. The second part considers two large data centers located in Athens that serve two major Hellenic banks as case studies in order to investigate and quantify the potential measures for improving their energy performance. The two facilities were audited and actual energy consumption were used for an energy assessment. According to simulation results of various efficiency measures, the Power Usage Effectiveness may be improved from 2.49 to 2.11 for the first case study and from 1.89 to 1.66 for the second one.

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Keywords: data centers; high performance; ASHRAE datacom series; energy audit; power usage effectiveness; PUE

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1. Introduction

Data centers (DCs) are amongst the most complex and energy demanding building indoor environments, as a result of high internal loads, low indoor temperature and humidity settings, and continuous (uninterrupted) operation. The facilities are characterized by very high concentration of information technology (IT) equipment, peripherals (e.g. servers, computers, data storage media, network devices, electronic accessories) and facility equipment, for

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example, power distribution equipment, standby generators, uninterruptible power supplies (UPS), cooling systems (chillers, fans, pumps etc.), computer room air conditioner (CRAC) units (air-handling units tailored for DCs that are situated on the DC floor), cooling towers, artificial lighting and ancillary services.

IT and HVAC equipment are the two major energy end-users. IT equipment consumes electrical energy but also generate very high internal heat loads. The HVAC systems in return consume more energy to remove the heat and maintain the proper indoor operating conditions. As a result, DCs consume up to 100 to 200 times as much electricity as standard office spaces[1]. Power demand can range significantly as a result of available space, type and arrangements of IT equipment. Values range from 54 W/m^2 as high as 2600 W/m^2 (including infrastructure draw) and frequently well over 1000 W/m^2 are reported[2]. Typical heat loads per product footprint depend on the equipment category, rack dimensions and occupancy, e.g. 16 kW/m^2 for storage servers, 40 kW/m^2 for high density, up to 96 kW/m^2 for extreme density communication equipment[3].

A typical breakdown from measured data in data centers[4] is illustrated in Fig. 1., although large variations can be observed in different facilities given the evolution of equipment efficiencies or depending on the type of cooling and air-handling system. A typical power installation process starts with the utility (or standby generator) electricity that is fed to UPS systems, which provide both power conditioning (typically supplied via a distribution transformer, switchgear and suitable bus bar and cabling systems) that are handled by power distribution units that then supply the rack distribution units and finally the IT equipment. There are some losses that occur in this sequence, but these are usually minor compared to the energy consumption of other facilities equipment.

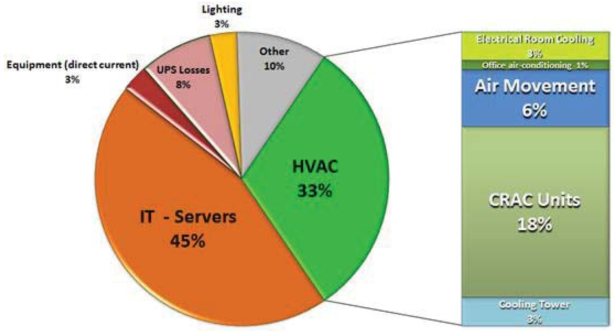


Fig. 1. Typical breakdown of data center energy use.

Energy demand of DCs is estimated at about 1.3% of global electricity consumption[5]. In the United States, DCs consume over 100 TWh of energy per year that is more than 2% of overall electricity use[6]. In Europe, DCs used ~78 TWh in 2015[7] from ~56 TWh in 2007 and is projected to reach 104 TWh in 2020[8]. An annual growth up to 15% is anticipated since technology developments that improve the efficiency and energy use of IT units are outbalanced by the increase of the absolute numbers of DCs to satisfy the quench for more computing power.

Given the trends of increasing DC capacity and power use by IT equipment re-emphasize the need to reduce cooling loads, first cost for HVAC equipment, and finally related energy and operational cost in these critical environments. There are several metrics and assessment methods that can be used to monitor and benchmark DC performance, depending on the available data and the stakeholder or business objectives[2]. The most commonly used benchmark is the Power Usage Effectiveness (PUE), which was introduced by the Green Grid to represent the amount of energy consumption (or peak electric power demand) for the entire facility (including IT equipment and supporting infrastructure) per unit delivered to the IT equipment. A typical PUE ranges about 2.0, which means that for every kWh that is delivered to IT equipment, an additional kWh is required for cooling and infrastructure. Improved operations could result to a PUE of 1.7, best practice installations average 1.3, while state-of-the-art facilities reach 1.06 or better[9]. The reciprocal of PUE is defined as the Data Centre infrastructure Efficiency (DCiE), i.e. the IT equipment power divided by the total facility power.

The first part of the paper presents an overview of available resources like the ASHRAE Datacom Series and from on-going European efforts and work in the frame of related projects, complemented by an overview of popular energy efficiency measures. The second part of the paper considers two large data centers in Athens, Greece that were audited to collect operational data and use simulations to investigate and quantify the effectiveness of potential measures for improving their energy performance.

2. Data Center Guidance

The large energy consumption and booming number of DCs have attracted a lot of attention and have also triggered the development of numerous guidelines to support stakeholders on how to save money and reduce electricity use. Collaborative efforts are advancing this sector to new performance standards, exploiting viable solutions to design new and retrofit existing facilities.

2.1. ASHRAE Datacom Series

Over the years, ASHRAE has developed a 13 volume Datacom Series[10] that provide a comprehensive treatment of data center cooling and relevant topics. They address various topics and provide guidance on baselines, trends, best practices, special cases and metrics. The series are recognized worldwide as authoritative resources for high performance data centers. Table 1 summarizes the available resources in chronological order of their original publication, along with a brief overview of their contents. The publications are prepared by a technical committee (ASHRAE TC 9.9 Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment). It is recognized as a leader in driving the data center environmental knowledge and best practices in the industry. Complementary information is also available in the ASHRAE Handbook[11] that is regularly updated to reflect the current best practices as in the ASHRAE Datacom Series.

Table 1. ASHRAE Datacom Series[10]

Title (Latest edition)	Short description
Thermal Guidelines for Data Processing Environments (2015)	Provides equipment manufacturers and facility operations staff with a common set of guidelines for the design and construction of their respective equipment or facility, for maximizing the performance and health of the facility.
Datacom Equipment Power Trends and Cooling Applications (2012)	Provides new and expanded equipment power trend charts through 2020 to allow facility designers to more accurately predict equipment loads and supplies ways of applying the trend information to facility designs today.
Design Considerations for Datacom Equipment Centers (2009)	Provides basic design information (e.g. design criteria, HVAC loads, cooling systems overview, air distribution) and covers additional topics (e.g. ancillary spaces, contamination, acoustics, seismic design, fire suppression, commissioning).
Liquid Cooling Guidelines for Datacom Equipment Centers (2013)	Provides guidance for liquid cooling including aspects such as transferring waste heat to the facility liquid cooling loop, reducing the airflow volume needed by the racks, and reducing processor temperatures to increase compute performance.
Structural & Vibration Guidelines for Datacom Equipment Centers (2009)	Provides best design practices, recommendations for new and renovated building structures, infrastructure (e.g. raised-access floor systems, vibration sources and control), and equipment (e.g. shock and vibration testing, seismic anchorage).
Best Practices for Datacom Facility Energy Efficiency (2009)	Provides design information to minimize life-cycle cost and to maximize energy efficiency. Covers environmental criteria, mechanical & electrical systems, economizers, airflow distribution, controls, commissioning, O&M.
High Density Data Centers - Case Studies and Best Practices (2008)	Provides case studies of high density data centers and a range of ventilation schemes that demonstrate how loads can be cooled using a number of different approaches.
Particulate and Gaseous Contamination in Datacom Environments (2013)	Provides insight on how to control particle contamination resulting from dust and dirt that can lead to unexpected shutdowns of critical IT equipment. Identifies equipment susceptibility and operational impact, strategies for prevention, control, contamination testing, and analysis.
Real-Time Energy Consumption Measurements (2010)	Provides examples of how to use energy consumption data in calculating power usage effectiveness (PUE) and for a data center housed in a mixed-use facility. Identifies all equipment must be monitored and controlled, standardize reporting etc.
Green Tips for Data Centers (2010)	Provides owners and operators a clear understanding of energy-saving opportunities. Covers the mechanical and electrical systems, and the most promising technologies. Guidance is provided for conducting a preliminary energy assessment.
PUE™: A Comprehensive Examination of the Metric (2013)	Provides a high level of understanding of the Power Usage Effectiveness, the industry-preferred metric for measuring infrastructure energy efficiency, along with actionable information useful for all stakeholders.
Server Efficiency - Metrics for Computer Servers and Storage (2015)	Provides information on current server and storage subsystem energy benchmarks, and information needed to select the best measure of performance and power. Presents various metrics and examples of data generation and interpretation.
IT Equipment Design Impact on Data Center Solutions (2016)	Provides guidance for stakeholders and equips facility planners, operators, IT equipment manufacturers, HVAC&R manufacturers and end users to select the equipment and design best suited to modern and evolving facilities.

ASHRAE is also developing a standard to establish the minimum energy efficiency requirements of DCs for the design, construction, and plan for operation and maintenance (O&M), and utilization of on-site, or off-site renewable energy resources. This proposed standard is intended to work in concert with the flagship ASHRAE

Standard 90.1 that provides the minimum requirements for energy-efficient design of most buildings (except low-rise residential buildings) and complement it by proposing criteria to support the specialized nature of large data centers.

To properly cool IT equipment, the cooling system must deliver air and/or coolant (typically facility water) that meet recommended and allowable equipment environment specifications (Table 2). Based on recent ASHRAE research, the ranges of specific conditions have been expanded to include lower humidity levels[12], expanding ASHRAE classes to chillerless facilities and providing for free cooling, if weather conditions allow it[13]. Data center operators can choose an appropriate class to operate in the most energy efficient mode and still achieve the desired reliability.

Table 2a. Equipment environment specifications for air-cooled applications[12]

Class*	Dry-bulb (°C)	Humidity range (noncondensing)	Max dew-point (°C)	Max rate of change (°C/h)**	Dry-bulb (°C)	Relative (rh) humidity (%)	Max dew-point (°C)
Product operation					Product power off		
Recommended (suitable for all four classes)							
A1 to A4	18-27	5.5°C DP to 60% rh & 15°C DP					
Allowable							
A1	15-32	20%-80%	17	5/20	5-45	8-80	27
A2	10-35	20%-80%	21	5/20	5-45	8-80	27
A3	5-40	-12°C DP & 8% rh to 85%rh	24	5/20	5-45	8-80	27
A4	5-45	-12°C DP & 8% rh to 90% rh	24	5/20	5-45	8-80	27

* *A1: tight environmental control (e.g. enterprise servers, storage products); A2/A3/A4: some environmental control (e.g. volume servers, storage products, PCs, workstations); A2 has narrowest temperature and moisture requirements; A4 has the widest environmental requirements. ** 5°C/h for data centers employing tape drives and 20°C/h for data centers employing disk drives. Max elevation (3050 m) in all classes. Additional notes for this table can be found in ASHRAE Thermal Guidelines for Data Processing Environments*

Table 2b. Equipment environment specifications for liquid-cooled applications[12]

Class*	Main cooling equipment	Supplemental cooling equipment	Facility supply water temperature (°C)
W1	Chiller / Cooling Tower	Water side economizer	2-17
W2			2-27
W3	Cooling tower	Chiller	2-32
W4	Water side economizer	N/A	2-45
W5	Building heating system	Cooling tower	>45

* *W1&W2: typically cooled using chillers and cooling tower, with optional water-side economizer; W3: without chiller, for most locations; W4: operated without chillers; W5: water temperature exiting IT equipment is high enough to heat local buildings. Note that there is limited IT equipment available for classes W3-W5.*

2.2. Other resources

A notable publication by CIBSE[14] provides guidance to the significant issues of DCs that might be considered. Topics address owners, designers, constructors, operators and all those who have an interest in DC design, operation and space planning. The guidance covers site selection and building criteria, planning, site and space, energy and sustainability, engineering systems design, air management, fire safety, security and building construction.

Several EU research projects also elaborate new metrics for evaluating DC flexibility as well as of the effects of DC optimization to their general operational efficiency[15]. The projects (e.g. www.geyser-project.eu) pave the way beyond self-sustainable DCs to the role of energy prosumers that can trade off energy demand and supply within a smart city, while ensuring energy efficiency at facility level and maintaining the quality of service, with lower operational costs and carbon footprint.

Since 2008, the European Commission through the Joint Research Centre (JRC) initiated a European Code of Conduct for data centers, as a voluntary initiative[16]. The program was created in response to increasing energy consumption in DCs and the need to reduce the related environmental, economic and energy supply impacts. The Code addresses primarily DC owners and operators, and secondly the supply chain and service providers. Parties signing up are expected to follow the intent of the initiative and abide by a set of agreed commitments (e.g. energy measurement and energy audit to identify major energy saving opportunities, set-up and implement an action plan, while regularly monitoring energy use to document progress). To date, the participants are about 115 DCs, along with 234 program endorsers. The metrics suggested for the EU Data Centre Code of Conduct targeting mechanical and electrical infrastructure (i.e. not reflecting the efficiency with which IT services, the end product, are delivered to users). The proposed analysis metrics for operators support detailed analysis and prediction of the impacts of changes, based on breakdown analysis of DCiE as a facility fixed overhead multiplier (i.e. describe the utility electrical load that is present irrespective of IT equipment electrical load) and facility proportional overhead multiplier (i.e. describe the additional utility electrical load of the data center above the fixed overhead that is proportional to the IT electrical load). An overview comparison of PUE & DCiE, the fixed & proportional metrics and full simulation modelling under common use cases documents that a combination of metrics and methods is required to effectively support operators and improve the efficiency with which IT services are delivered[17].

EU Regulation 617/2013 on Ecodesign requirements for computers and computer servers establishes relevant requirements as they also relate to DCs. Findings of the preparatory study, evolution of relevant policies and other resources are available at www.ecodesign-servers.eu.

2.3. Energy efficiency measures

There are several energy efficiency measures (EEM) to help improve the energy and operational performance of DCs[13,18-19] including measures for the:

- entire facility (e.g. audit facilities, ensure effective regular maintenance, install blanking plates where there is no equipment to reduce hot air re-circulating through gaps in the rack, turn off lights),
- software or IT equipment (e.g. contained hot or cold aisles, use of energy star compliant hardware),
- electromechanical (E/M) equipment (e.g. airflow management and design, installation of draught excluders or cover plates to eliminate air leakage in racks, equipment segregation, separate environmental zones according to equipment operating conditions, variable speed fans, low energy lighting, temperature and energy monitoring)
- optional practices (e.g. select and deploy equipment at actual power density to avoid running the cooling system outside design conditions, consider free cooling, sequencing CRAC units, power factor correction).

Upgrading the DC cooling facilities is a continuous process in order to keep up with higher equipment reliability, greater energy efficiency incorporating Energy Star certified products, additional capacity and meeting green building certification system program requirements (e.g. LEED). According to a recent survey in the United States and Canada[20], about 40% of DC cooling systems have been upgraded in the past five years, nearly 20% are in process and about 31% will be upgraded before the end of 2016. Additional resources and ways to save energy in DCs and server rooms are also available from Energy Star (www.energystar.gov). Furthermore, heat rejected by the datacenter could be considered as a heat source distributed to users located in the neighboring vicinity[5].

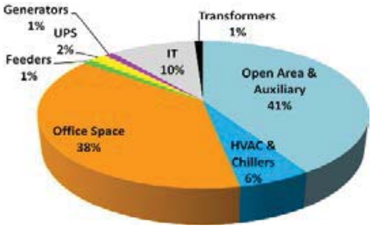
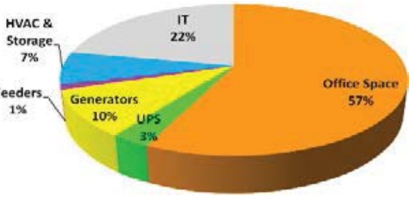
Energy savings can be in the order of 20-60% and sometimes more[21]. Large DC users like internet-related service companies are focusing on reducing energy use while serving the explosive growth of the internet. For example, Google has been monitoring its entire fleet of DCs around the world, reporting a comprehensive trailing twelve-month PUE of 1.12 in 2015 from 1.23 in 2008[22], redesigning their facility fundamental cooling technologies on average every 12 to 18 months, while Facebook reports a PUE of 1.07[23].

3. Case Studies – Two Hellenic Data Centers

Two of the largest data centers located in Athens, Greece that serve two major Hellenic banks were used as case studies in order to investigate and quantify savings resulting from potential EEMs. The facilities are mixed-used data centers (i.e. a DC located in a single floor within a larger office building) in two nearby locations and operate continuously (24h/7 days a week). Their basic infrastructure, system and environment characteristics are summarized in Table 3. The two data centers were audited to collect relevant data and simulations were performed using the 6SigmaRoom CFD software to assess different scenarios to reduce cooling loads and energy demand.

Table 3. Infrastructure, system and environment characteristics for the two data centers.

Parameter	DC-1 (since 2008)	DC-2 (since 1996)
Gross building area (m^2)	12,250 (4 floors, ground, basement)	11,000 (4 floors, ground, basement)

Data center & IT areas (m^2)	870 & 450 (5 computer rooms) 	1,046 & 690 (2 computer rooms) 
UPS & Standby systems	2 strings X 3 UPS 120 kVA (for critical equipment); 320 batteries (81 Ah each); 1 UPS 200 kVA (for less critical equipment-building); 3 diesel generators (2X 630 kVA for IT, 800 kVA for building)	2 strings X 3 UPS 330 kVA (for the whole building); 3 diesel generators 1500 kVA each
HVAC	14 CRAC units, with total active ~373 kW; [two active in each large room] and 1 in small room; one backup in each room: [2(3X53.4 kW); 3X45.1 kW; 3X28.5 kW]; 2X11.8 kW. Raised-floor plenum Chillers: 2 X 430 kW (on the roof) with free cooling exchangers of water/glycol mixture, and one backup	10 CRAC units installed at 41 kW each, with total active ~164 kW; two active in each room, all others as backup, auxiliary for future expansions. Raised-floor plenum Chillers: 2 X 450 kW (in the basement) old units with R-22, and one backup. Heat exchangers in each chiller are used to heat water supplied to the building
Total annual energy use intensity-EUI (kWh/m^2)	2489 (56% HVAC; 36% IT; 5% UPS losses; 3% lighting)	2089 (33% HVAC; 52% IT; 11% UPS losses; 4% lighting)
PUE & DCiE	2.53 & 40%	1.87 & 53%

In DC-1, the IT equipment occupies 10% of the floor area (in anticipation of future expansion), but there is no flexibility to control the operation and conditioning of the unoccupied areas. This resulted to significant equipment oversizing, e.g. the server room has an IT load of 430 W/m^2 served by CRACs with a cooling capacity of 2174 W/m^2 and the expansion room with 288 W/m^2 IT load that us served by 1770 W/m^2. Most CRACs are used 15-30% of their nominal power throughout the year. The set-points were 22^{o}C / 45% rh in DC-1 and 22^{o}C / 50% rh in DC-2. The use of multiple UPS that were lightly loaded (45% each for DC-2 and 25% for DC-1) and the old UPS technology for DC-2, were the key reasons for the low efficiency of UPS. In both DCs, lighting is always on (24/7) for security reasons, with 8 W/m^2 in DC-1 and 10 W/m^2 in DC-2. The facilities are equipped with building energy management systems (BEMS); DC-1 since its design and as of 2008 in DC-2.

Energy bills over a two-year period were collected and analysed. Accordingly, the average annual total electricity use per unit floor area of the entire building (offices & DCs) was 297.6 kWh/m^2 for the first and 420.7 kWh/m^2 for the second building, averaging 2,489 kWh/m^2 of DC-1 and 2,089 kWh/m^2 of DC-2. This indicates a 16% lower consumption in DC-2 compared to the oversized DC-1 facility. The loads in both DCs remain nearly constant throughout the day and have small seasonal variations (i.e. higher energy use in summer by ~10 kWh/m^2).

3.2. Operational issues, EEMs and savings

The annual energy consumption for lighting that operates 24/7 throughout the facilities is 50,467 kWh/year for the DC-1 and 60,549 kWh/year for DC-2. Since continuous lighting is desired for security reasons, scarce lighting can be provided at all hours, with additional lighting for occupied periods. BEMS can automatically turn off lights during weekends or reduce operating power by 50%, to save up to 60% of energy consumption. Increasing UPS efficiency in DC-2 to about 94% (using similar technology to that of DC-1) can save about 17 kW or 151 MWh/year, which translates to annual savings of 18,230 €.

Air-recirculation is the most common problem that occurs with the cooling path (i.e. air movement from the CRACs to the IT equipment and back), which can cause overheating and efficiency problems, bypasses, and vortices. Recirculation occurs when the exhaust air from the IT equipment finds its way back into the cabinet to the inlets of the IT equipment. This can result to higher equipment inlet temperatures and the need to over cool the supply air. Blanking plates can prevent the air flow from the hot (exhaust) side of the cabinet to the cool (inlet) side.

The CFD simulations of the existing facilities are illustrated in Fig. 2. Predicted indoor conditions compared very well with measured values. For DC-1, only 20% of the air from the CRAC units is successfully delivered to the equipment and only the 19% of the heated air from the equipment was returned to the CRACs. The CRAC cooling in use was calculated at 142 kW, which is only a third of the actual nominal cooling capacity of 373 kW (Table 3). The DCiE was estimated at 40.2% and the PUE at 2.49. For DC-2, almost all IT equipment were at a temperature above the recommended levels. The supply and return CRAC effectiveness was higher at 74%, with a mean cabinet air recirculation at 20%. The total cooling capacity was calculated at 145 kW, close to the actual nominal cooling capacity of 164 kW. The DCiE was estimated at 52.7% and the PUE at 1.89.

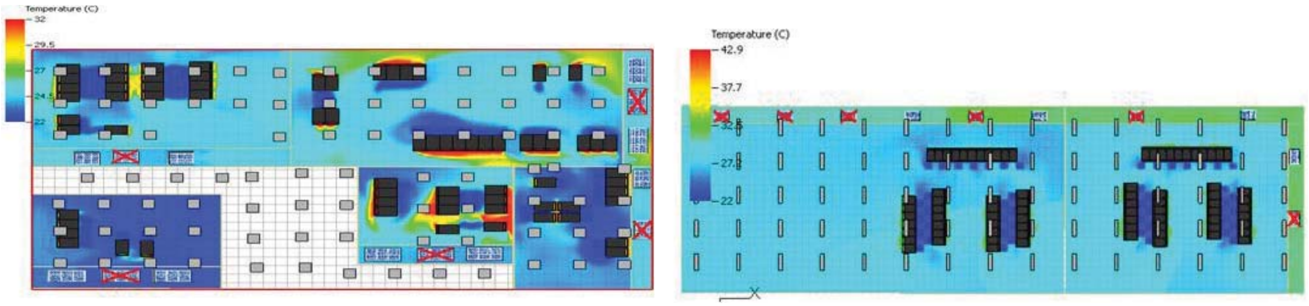


Fig. 2. Simulation results of DC-1 (left) and DC-2 (right) indoor conditions. The backup CRAC units are identified with an "X" symbol.

For DC-1, three scenarios were investigated. First, using one CRAC in each room coupled with the necessary chillers, which are sufficient to cover the current IT loads, resulted to a decrease of the total power use from 244.4 kW to 220.4 kW or 210,240 kWh energy savings per year, reducing the PUE to 2.24. The second scenario also considered the installation of blanking plates and enclosures to prevent air-flow from the hot to the cool side of the cabinets. Enclosures can concentrate and distribute the cold air from the grilles to the cabinets without spreading the air within the room. Installation of the enclosures significantly reduced the maximum inlet temperature of the IT equipment to around 28°C which is important for the safety margin of the equipment and allows an increase of the room temperature without adverse effects on IT equipment operation. The supply effectiveness increased by 58%, the CRAC return by 54% and the equipment supply and return temperature by 15%. Finally, increasing the room temperature from 22°C to 27°C along with the blanking plates, improved DCiE from 45.0% to 46.6% and the PUE from 2.24 to 2.11, respectively. While still within acceptable IT operating temperature limits, the power reduction of 2.4 kW provides up to 21,024 kWh annual energy savings. With an estimated cost of ~12 € per 1U (gap) blanking plate, the estimated total cost for the 25 servers is 11,500 €, which results to a payback period of 9 years. Considering the total savings from all three scenarios and reduced lighting, this drops down to about 1 year.

For DC-2, the first scenario included the installation of blanking plates and enclosures that improved the supply effectiveness by 2%, the equipment supply and return temperature by ~29%, practically eliminating air recirculation (0.07%) and decreasing the annual power demand by 1.8 kW or 15,768 kWh. The second scenario also increased the room temperature from 22°C to 27°C, which improved DCiE from 53.0% to 54.7% and the PUE from 1.87 to 1.81, respectively, achieving an additional power reduction of 6 kW or 52,260 kWh annual energy savings. The third scenario considered replacing the obsolete CRAC (i.e. equipped that had traditional centrifugal fans that operate through a belt-and-pulley system, resulting to high energy losses) and chillers (i.e. had no free cooling and still using phased-out R-22). A new chiller with free cooling was considered that can save up to 105,275 kWh per year, or ~10% of the total annual energy use. The proposed new CRACs use electronically commutated fans that minimize the operating costs due to the higher motor efficiencies and integrated electronic controls, ensuring that the motors always run at their optimal load (e.g. fan power reduced from 2.24 kW to 0.2 kW per CRAC) with net cooling capacity 24.9 kW each. Using simultaneously the three new CRACs at 40% partial load and raising the room temperature to 24°C, savings can reach 67,978 kWh/year. Accounting for the capital and maintenance costs of the new CARC units, chiller and blanking plates, the payback period is ~9 years.

4. Conclusions

Data centers are amongst the most energy consuming facilities. Various resources are available to support the design and operation of high performance DCs. An energy audit of two large Hellenic facilities provided the necessary data to asses various measures to reduce energy consumption for artificial lighting by adjusting their time schedule through BEMS, implementing new cooling approaches (e.g. CRACs and free cooling chillers in DC-2), increasing the supply temperature of chillers and CRACs in both DCs and assessing additional energy savings using CFD simulations. The investigated EEMs can improve the PUE by 0.38 points (from 2.49 to 2.11 in DC-1) and 0.23 points (from 1.89 to 1.66 in DC-2) and increase the DCiE by 7%.

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