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Research Paper

Introducing innovative energy performance metrics for high-level monitoring and diagnosis of telecommunication sites

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HIGHLIGHTS

- Definition of novel performance indexes to detect anomalous energy absorptions in TLC sites.
- High level monitoring and diagnosis procedures proven effective within Energy Intelligence (EI) protocols in TLC sites.
- Clustering analysis-oriented conceivement of innovative energy metrics.
- Enhancement of big data-based diagnosis of TLC sensors and apparatus.
- Analysis and optimization of existing hardware/thermal management strategies.

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ABSTRACT

This paper aims at deepening the theme of monitoring and energetic diagnosis of telecommunication (TLC) central offices, via the development and application of innovative performance parameters, whose objective is to detect the presence of anomalous energy absorption of the electronic equipment and cooling systems. Firstly, extensive energy analysis is conducted by using the heating degree days (HDD) parameter, which is already consolidated in the field of efficient thermal management of data-centers. Secondly, properly designed indicators are added to this metric: the parameter of central utilization (PUC), which allows distinguishing the multi-use (e.g. combined TLC rooms and offices) from pure central offices; the index of cluster reliability (ICR), which evaluates the stability in time of the acquired data, and the reliability index (RI). The last parameter was specifically introduced to assess if a data center exhibits an unusual energy behavior with respect to a reference energy consumption benchmark, here defined for the group the site belongs to. The innovative contribution of the paper lies in the introduction and joint use of ICR and RI parameters, which can be set up as an effective diagnostic tool for telecommunications sites. The combined verification of current ICR and RI values allows outlining four possible scenarios, differentiated on the basis of the data reliability. Particularly, immediate determination of reliable and unreliable TLC sites is enabled, while the diagnostic potential is exploited to determine whether deeper investigation of energetic consumption trajectories is required. Specifically, the joint assessment of the ICR-RI pair was successfully applied to detecting the presence of anomalous TLC and cooling energy consumption data, as well as whether these abnormalities were due to inefficient thermal management or sensor malfunctioning.

1. Introduction

Nowadays, the Information and Communication Technology systems (ICTs) are responsible for roughly 3% of the worldwide electricity consumption [1], with an upward trend of this rate because of the impetuous development of the Internet, smart services and mobile telephony. This technical innovation requires even more powerful infrastructure in terms of features and performance. Since the current way to meet the worldwide energy requirements primarily relies on fossil fuel, ICT systems cause 2% of global carbon emission, corresponding to 1/4 of the CO_2 emissions produced by passenger cars worldwide [1]. Furthermore, the ICT sector itself is expected to play a leading role in reducing the carbon footprint of industrial processes, by e.g. replacing current TLC equipment by innovative, more efficient devices, as well as introducing intelligent energy management solutions to perform eco-friendly actions in any kind of industrial applications [2]. Such a need

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Nomenclature

CDD	cooling degree days [°C]
CF_Y	annual comparison factor [/]
CF_{Yrif}	annual reference comparison factor [/]
CO	central offices
CUE	carbon usage effectiveness [$kgCO_2 \cdot kWh^{-1}$]
DCiE	data center infrastructure efficiency
DD	degree days [°C]
E_{CLC}	climate control (thermal management) energy quota [kWh]
EEI	energy efficiency index [/]
E_{MISC}	miscellaneous energy quota [kWh]
E_{TLC}	telecommunication energy quota [kWh]
E_{TOT}	total energy consumption [kWh]
FC	free-cooler
HDD	heating degree days [°C]
ICR	index of cluster reliability [/]
ICT	information & communication technology
IT	information technology
KPI	key performance indicators
MUC	multi-use central offices
PUC	parameter of utilization of central [/]
PUE	power usage effectiveness [/]
RI	reliability index [/]
TLC	telecommunication
WSN	wireless sensor network

has been recently evaluated as one of the key actions, to be undertaken in the framework of the 20–20–20 climate change plan ratified by the European Union [3]. In this overall framework, ICT companies already started monitoring energy consumptions of data centers with dedicated sensors, so as to ensure more efficient energy usage for all services and ancillary activities. Particularly, the telecommunication company TIM (Telecom Italia Mobile) has started, since 2006, a research activity aimed at the optimization and reduction of energy consumption of telecommunication sites, by performing remote monitoring and diagnosis of TLC sites. In order to do so, a middleware platform, based on wireless sensor networks (WSN), was set-up. The WSN is based on ZigBee standard and it is deployed in TLC switching plants to monitor environmental data (e.g., internal and external temperature and relative humidity), as well as the energy consumption of servers, cooling and humidification systems, networking equipment and lighting/physical security [4]. The use of ZigBee standard in TLC environment is justified by numerous features [5], such as reliable two-ways communication, larger coverage range and extended battery lifetime. The latter two benefits with respect to competing technologies, such as infrared remote control [5], led researchers to adopt ZigBee technology to monitor inner TLC cabinet temperatures [6]. The wide availability of data guaranteed by WSNs can enable the definition and application of innovative performance parameters aimed at energy intelligence [7] purposes, such as energy monitoring and diagnosis.

Generally, the energy performance of telecommunication sites is worldwide assessed by means the Power Usage Effectiveness (refer to PUE formulation in Eq. (2)) introduced by the "The Green Grid" consortium in [8].The Green Grid, while recognizing [9] the importance of introducing further indexes aimed at improving data centers sustainability, proposed itself the use of a new metric, namely the Carbon Usage Effectiveness (CUE), to evaluate the effective carbon footprint of TLC sites. This indicator (see Eq. (3)) accounts for the energy mix adopted to generate electricity and estimates the CO_2 amount produced per each used kWh.

Upon joint evaluation of CUE and PUE, data center operators can quickly assess the sustainability of their data center, as well as determine if any energy efficiency and sustainability improvement is eventually required. In [10] the energetic efficiency index (EEI), defined as the ratio between TLC equipment and overall plant energy demand (thus EEI is nothing but the inverse of PUE), was used to evaluate the energetic performance of the plant. The knowledge of actual EEI, in conjunction with temperature monitoring, provided operators with useful information to improve energetic performance. Pelley et al. in [11] propose using total data center power to improve central offices energy efficiency; particularly, the development of specific power models for each critical data center component was proven effective in determining if: i) the energy management of existing hardware can be improved or ii) potentially costly hardware maintenance and/or replacement are eventually needed. Nevertheless, the above-mentioned xUEs metrics difficultly allow accounting for external weather conditions, which directly affect TLC cooling, thus are not effective when comparing different data centers. Therefore, properly designed indicators are added to these consolidated metrics (i.e. PUE etc.). Previous works were already devoted to propose metrics specifically aimed at improving cooling performance in TLC rooms. Particularly, the efficacy of cooling or heat removal performed by cooling systems can be judged via the capture index (CI) proposed by Van Gilder and Shrivastava [12], whereas Herrlin [13] analyzed the suitability of the return temperature index (RTI) to understand if proper air recirculation is guaranteed through the racks present into a generic TLC room or data center. Although these latter metrics were proven effective in assessing the efficacy of adopted cooling devices, none of them can be deployed to perform the high-level energy monitoring tasks, to be undertaken within comprehensive energy intelligence protocols. Thereby, main aim of this paper is to introduce energetic performance metrics that are suitable to characterize TLC sites and classify them in homogeneous groups, on one hand, and, on the other, allow verifying the reliability of acquired data both in the time and space domain. As a consequence, successful comparative analyses can be enabled among homogeneous sites, thus providing a significant contribution towards the establishment of long-lasting energy intelligence policies [14] in telecommunication environments. More specifically, the innovative metrics proposed later on, namely index of cluster reliability ICR and reliability index RI, were conceived in such a way as to account for the impact of cooling load demand. Therefore, they can be applied for the following aims: i) assessing how efficient are the thermal management strategies adopted in the TLC site under-investigation and ii) providing fast and trustable feedbacks on the reliability of the data acquisition system (i.e. the WSN). Particularly, the above introduced possible exploitations shall be considered highly valuable towards deep valorization of the large amount of data acquired and provided by the WSN, mainly aiming at successfully accomplishing the control and diagnostic tasks [15] within a comprehensive energy intelligence protocol [14]. This is a key advantage with respect to xUEs metrics and is mostly useful at the monitoring level of the mentioned energy intelligence policy or, eventually, for energy audit purposes. It is also worth mentioning that RI and ICR are non-dimensional parameters; such a feature was proven [16] to have a high potential to improve flexibility and time-adaptivity of monitoring and diagnostic tasks and procedures involving a variety of energy systems.

The paper is structured as follows: in Section 2 the energy balance to be associated to a generic TLC site, as well as the main performance metrics with their use and application are presented. Section 3 presents both the TLC sites characterization, based on HDD, PUC and EEI, and possible scenarios that may result from the joint analysis of ICR-RI metrics values. In the conclusions the potential application areas of proposed performance metrics are presented and discussed.