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Development of a multi-annual monitoring tool for energy intelligence in telecommunications

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ABSTRACT

In this study, a method for the monitoring of telecommunication central offices (COs) is proposed with the purpose of classification in terms of efficiency and diagnosis of anomalous energy consumptions. The objective is achieved through the definition of new indices based on the energy spent by the telecommunication and cooling systems, improving the outcomes of pre-existing methods. While the reliability index and the index of cluster reliability check the ratio between the telecommunication (TLC) and climate control (CLC) energy consumption, the coefficient of variation adds a check on the reliability of TLC-energy measurements. Another target of this study is to extend the analysis to multi-annual periods of monitoring, thus allowing successfully meeting the currently in-force ISO50001 standard for what concerns with the continuous monitoring of industrial plants (including the TLC sector) towards the achievement of sustainable and energy efficient enough operation. After the presentation of the method, specific central offices were selected and further analyzed to fully verify the results match the physics of the energy consumptions behavior.

Keywords: Energy intelligence, Telecommunications, Energy management, Monitoring and diagnosis, Thermal management

1. INTRODUCTION

Nowadays, considering the constant grown of greenhouse gas emissions, there is attention to reducing the environmental footprint in all sectors, including telecommunications. In fact, the global electricity requested by central offices and data centers in 2018 was an estimated 198 TWh, or almost 1% of global final demand for electricity [1] and is expected to overcome 10% by 2030 [2]. Therefore, it is contributing developing strategies to improve efficiency in this field in order to reduce the CO_2 emissions. Of course, a better management of energy leads also to economic benefits for companies that may offer their services at a lower price. In fact, many TLC companies have started deploying dedicated sensors for capillary energy monitoring, with the aim of reducing energy consumptions. The use of wireless sensor network (WSN) represents one of the promising approaches for dense environment monitoring such as data centers and central offices. Even if critical issue could arise for CO security, low-cost, nonintrusive, wide coverage, and reusability are interesting properties associated to the use of this technology [3]. Recently, relevant TLC players introduced dedicated sensors for systems' monitoring, aiming at improving COs energy efficiency [4]. Guaranteeing a wide source of data, WSN adoption makes it possible employing performance parameters for monitoring and diagnosis or, more in general, energy intelligence purposes [5] within the actual fourth industrial revolution [6]. The Power Usage Effectiveness is an index used worldwide for the assessment of the energy performance of telecommunication sites. It is defined as the ratio between the energy spent by the entire plant and the amount destined to the TLC utilities [5]. Similar indexes were proposed in [7] and [8] (i.e., the carbon usage effectiveness – CUE). The classification made by using the xUE metrics is immediate but, on the other hand, it does not make any difference between central offices and multi-use central offices, where the energy spent for ancillary devices is usually higher. The comparison factor (CF) introduced by D'Aniello et al. in [9] and reused in this work allows classifying the central offices without being affected by the possible presence of auxiliaries. In fact, it is defined as the ratio between the energy amounts spent respectively for conditioning and telecommunication infrastructures. The main aim of this paper is to develop a method for the monitoring of the TLC sites along the time. Particularly, starting from the previous efforts [9], energetic performance metrics based on indices, such as index of cluster reliability (ICR) and reliability index (RI), have been accompanied by newly defined ones, so as to achieve a higher accuracy in COs classification. More specifically, the proposed methodology allows the critical assessment of the thermal management strategies used in the TLC site and detects eventual anomalies in the acquired experimental data. Moreover, extending the monitoring period to more than two years, a key requirement of the ISO 500001 standard is satisfied.

2. MULTI-ANNUAL ENERGY MONITORING TOOL (MAEMT)

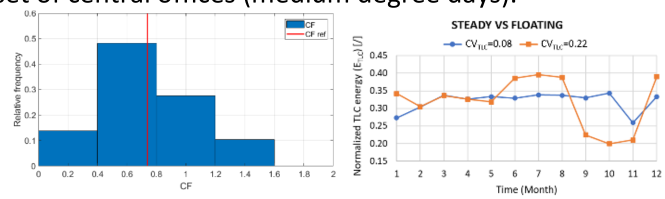
In data centers, the energy is used mainly for TLC equipment (E_{TLC}) and climate control (E_{CLC}). In fact, the electricity used by TLC infrastructures is entirely dissipated as heat, leading to the needs of cooling down the rooms. In order to detect central offices (COs) with a good management or abnormalities, suitable indices were deployed for the current analysis, as detailed below.

2.1 Comparison factor

The CF (see eq. 1) allows assessing the energy performance of the CO under-study. A low CF value means cooling system has high efficiency or low thermal load, while a high CF represents the opposite situation.

$$CF = \frac{E_{CLC}}{E_{TLC}} \tag{1}$$

While E_{TLC} is almost constant over the year, the amount of energy required for climate control (CLC) purposes (i.e., E_{CLC}) varies, achieving its peak in the summer period. Since the environmental conditions varies considerably from one climatic zone to another, COs are divided into three groups according to number of heating degree days (HDD). The more the HDD, the less the energy required for cooling. The comparison factor calculated for each data center belonging to a certain group should not be far from the average value because the climate conditions and the technologies involved are similar. If there is an important gap, the cause must be researched into the management, which can be different. A reference value of comparison factor should be calculated for each Cos group. These values are, obviously, different and it is expected to have higher values for zones where the climate is warmer. A reference comparison factor can be calculated for each year and for each climatic group [9]. Fig.1.a shows a typical distribution of the comparison factor for a certain set of central offices (medium degree days).



(a) (b)

Fig. 1: CF for a set of central offices located in places with medium degree days during year 3 (a). Exemplary TLC energy consumption trajectories (b), corresponding to steady (low CV_{TLC}) and fluctuating (high CV_{TLC}) behaviors, respectively.

2.2 Reliability index

The comparison factor can be involved in the building of other indices. The reliability index RI, calculated for each central office (CO), is the ratio between the CF and the reference CF, as shown by the eq. (2).

$$RI_i = \frac{CF_i}{CF_{i,ref}} \tag{2}$$

The subscript *i* represents the year in which the indices are evaluated. An RI value near one means stability in space, so as to be compliant to the value that many data centers manifest. A value far from one instead corresponds to a behavior very different from the reference one. Furthermore, values below 1 are representative of cases where the energy consumed for cooling is less than the average.

2.3 Index of cluster reliability

The behavior of a central office can be evaluated even over the time. The index of cluster reliability ICR is defined as the ratio between the comparison factor values relative to two different years:

$$ICR_{ij} = \frac{CF_i}{CF_j} \tag{3}$$

The subscripts *i* and *j* represent the years (or, more in general, the time periods) in which the indices are evaluated. The index is used to verify the stability over the time and, even in this case, the preferred values are the ones close to 1. In fact, a value very different from the unity means the behavior has changed too much passing from a year to another and this could be only due to a data acquisition problem or some substantial changes in the central office have been done. In multiannual analysis, there are more ways to combine *i* and *j* indices. However, the physical meaning of ICR is to verify the continuity over the time from a year to another one. So, it makes sense to compare a year (CF_i) with the previous (CF_{i-1}) or the next one (CF_{i+1}). In fact, making all the possible combinations, the number of checks would increase in a non-linear way with the number of analyzed years.

2.4 TLC energy Coefficient of variation

The method has been made more stable by introducing one more index. Since the demand of TLC services is constant, then E_{TLC} should not be fluctuating. In order to check its low variability, it has been introduced the coefficient of variation (CV) of the TLC energy, defined as the ratio between the standard deviation and the average value of E_{TLC} (see eqs. 4-6).

$$CV_{TLC} = \frac{\sigma_{TLC}}{\bar{E}_{TLC}} \tag{4}$$

$$\sigma_{TLC} = \sqrt{\frac{\sum_{m=1}^{12} \left(E_{TLC,m} - \bar{E}_{TLC}\right)^2}{12}} \tag{5}$$

$$\bar{E}_{TLC} = \frac{\sum_{m=1}^{12} E_{TLC,m}}{12} \tag{6}$$

The coefficient of variation for TLC (CV_{TLC}) energy must be as low as possible. On the other hand, E_{CLC} energy cannot be constant because, following the variation in environmental conditions over the entire year, it results in a seasonal trend. So, for E_{CLC} is not calculated the coefficient of variation. However, if CV_{TLC} does not tend to zero a problem in data acquisition (e.g., sensors malfunctioning) most likely occurred. Fig. 1.b shows two different behaviors of E_{TLC}, one very fluctuating, which cannot be fault-free (CV_{TLC}=0.22) and another one much more reasonable (CV_{TLC} =0.08). Therefore, CVTLC values higher than a safe threshold (i.e., 0.1) are assumed hereinafter indicative of a high level of irregularity in E_{TLC} consumption, due to issues in data acquisition.

While RI and CV_{TLC} are indices evaluated for every year, the ICR is a bit different because is not calculated for a single year but for a couple. When the analysis concerns two years running, there is only a value of ICR to take into account. It should be recalled that ICR is used to ensure a constant behavior in the relation between E_{TLC} and E_{CLC} during time. So, it makes sense to compare CF only with the CF of previous year and that of the following one. In other words, CF_i should only be compared with CF_{i-1} and CF_{i+1} for ICR assessment purposes.

2.5 Indices evaluation and synthesis

The procedure adopted for continuous monitoring through time is based on several indices-based checks. In case all checks are successful, then the global check result is "reliable", meaning that there are no anomalies in the data and the behavior is in line with the average one. As mentioned above, for each central office, there are more checks to do. For every year there is "check A", where ICR is evaluated backward, comparing the current CF with the value of the previous year and there is a "check B" where ICR is calculated forward, with the CF of the following year. In general, it can be said that for the *Check iA* or *Check iB*:

- The number *i* represents the year in which indices RI and CV_{TLC} are evaluated.
- The letter *A* indicates ICR is comparing CF of year *i* with the previous one (continuity with the past). The letter *B* indicates ICR is comparing CF of year *i* with the next one (continuity with the future).

Fig. 2 shows which are the checks to do in case the analysis involves a number of years ranging from 2 up to N. For example, considering the period from year 1 to year 3 (3 years), the checks required are four: 1B; 2A; 2B; 3A.

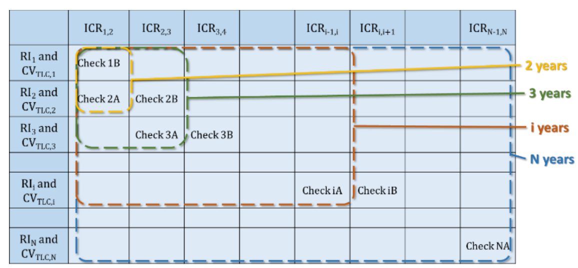


Fig. 2: List of indices goodness check for N years.

There are 2 checks for each year except the first and the last one of the considered period, where only one check is possible. This leads to the following equation, where the number of checks is a function of number of analyzed years N and has a linear behavior.

$$n_{checks} = 2N - 2 \tag{7}$$

INDEX OF CLUSTER RELIABILITY

RELIABILITY INDEX / COEFFICIENT OF VARIATION	$\lvert ICR-1\rvert > 0,5$	$ICR \sim 1$
$\lvert RI-1\rvert > 0,7$ or $CV_{TLC} > 0,1$	UNRELIABLE DATA (TIME INSTABILITY) and (NON COMPLIANCE or FLOATING E_{TLC})	UNRELIABLE DATA NON COMPLIANCE or FLOATING E_{TLC}
$RI \sim 1$ and $CV_{TLC} < 0,1$	UNRELIABLE DATA TIME INSTABILITY	RELIABLE DATA COMPLIANCE, STEADY E_{TLC}, TIME STABILITY

Fig. 3: Possible outcomes for a checking method based on RI-CV_{TLC}-ICR joint evaluation.

Once defined all the indices, the next step is the combination of them into the analysis. For every check, RI, CV_{TLC} and ICR indices are examined together. Only if all of them assume good values then the outcome of the considered check is favorable. According to the scheme shown in Fig. 3, if every index value falls within the assumed safe range, then the check gives a good outcome. On the other hand, if at least one of them is not in range, then the check cannot be considered successful.

It can be helpful having a dedicated metric index to summary all the checks done. The successful checks percentage-SCP is thus introduced:

$$SCP = \frac{\sum_i (check = OK)_i}{n_{checks}} \cdot 100 \quad (8)$$

At the end of this section, it is worth remarking that, while the PUE index assesses the efficiency without distinguishing between central offices and pure data centers, the continuous monitoring enabled by the above-introduced metrics fleet compares the energy spent on telecommunications directly with the cooling load. Moreover, it contemplates the external conditions, such as the environment temperature, allowing consistent comparisons between data center.

3. RESULTS

From the set of over 100 COs analyzed along a period of N=3 years, 2 were picked up to validate the results yielded by the RI-CV_{TLC}-ICR method (see Fig. 4). The CO 4 is an example of reliable consumptions profile. On the other hand, CO 6 is exemplary of unreliable E_{TLC} data acquisition.

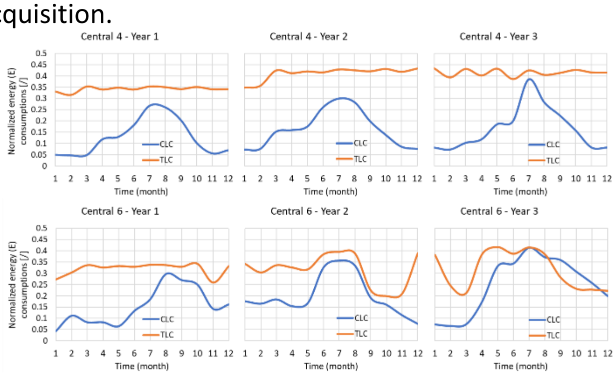


Fig. 4: TLC and CLC consumption trajectories measured for the selected COs for the proposed continuous monitoring tool.

The SCP (see eq. 8) thus achieves 100% for the central office 4 as shown by

Table 1, where also the various indices are reported. Despite a reasonable trend in the CLC energy spent by CO 6, its E_{TLC} has, clearly, a not physical behavior. This is recognized by the CV_{TLC} which, with values up to 0.26, exceeds the acceptability of 0.1 and, thus causes SCP to set to as low as 25%.

Table 1: indices values for the selected central offices analyzed over N=3 years.

CO	RI_1	RI_2	RI_3	$CV_{TLC,1}$	$CV_{TLC,2}$	$CV_{TLC,3}$	$ICR_{1,2}$	$ICR_{2,3}$	SCP
4	0.58	0.48	0.6	0.03	0.066	0.036	0.93	1.01	100%
6	0.74	0.75	1.19	0.081	0.216	0.258	0.75	0.8	25%

4. CONCLUSIONS

In this work, a method for energy monitoring and diagnosis of telecommunications centers has been presented. Starting from a previous tool with only two years coverage, this work has aimed to the extension of the analysis to periods of more years. Furthermore, the methodology was even improved by the definition of new indices. In fact, the introduction of the coefficient of variation associated to annual TLC energy consumption made the central office classification (in terms of energy management and data reliability) more accurate and effective in performing continuous monitoring of energy consumption over significantly long timeframes.

The successful validation of the presented continuous time energy monitoring method suggests its extension to similar applications, such as banks, restaurant chains or shopping malls.

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