Applied Energy 217 (2018) 266–280

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Inter-sectorial benchmarking of compressed air generation energy performance: Methodology based on real data gathering in large and energy-intensive industrial firms

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HIGHLIGHTS

- Benchmarks for energy consumption in Compressed Air Systems (CAS) are identified.
- The analysis is carried out on data available from Energy audits carried out in over 15,000 companies.
- Results of surveys regarding compressed air systems use, maintenance and monitoring practices are discussed.
- A more reliable baseline for benchmarking is proposed.
- Guidelines to improve energy performance in Compressed Air Systems are developed.

ARTICLE INFO

Keywords:
Energy efficiency
Compressed air systems
Directive 2012/27/EU
Energy benchmarking

ABSTRACT

Industrial systems management is nowadays increasingly devoted to improve the control of most critical production aspects. In this context, the performance of all the systems involved in production processes have to be measured and analysed in order to get better insights in terms of potential production and quality improvements as well as energy savings. In order to evaluate the performance of a certain system, a possible and effective way is to compare it with data from similar systems, thus to conduct a benchmark analysis. In the area of energy management, although the compressed air system (CAS) is one of the most important and energy consuming services within industrial plants, enterprises often have difficulties understanding and appreciating the entity of potential benefits coming from the improvement of its energy efficiency. The present paper aims at developing a new benchmark analysis for compressed air systems in industrial plants. The proposed methodology starts from the KPIs (Key Performance Indicators) already available in the scientific literature for CASs' energy performance and is mainly based on the analysis of a huge real dataset collected from over 15,000 energy audits made on a wide range of different companies, all related to produced quantity of compressed air and energy consumed by CASs. Collected data present some limitations and related improvements and corrective actions have been undertaken and are presented in the followings. Data analyses have been followed by complementary surveys regarding compressed air systems' use, maintenance and monitoring practices performed within several Italian enterprises and aimed at enhancing and creating a more reliable baseline for benchmarking.

1. Introduction

The uncertain condition of primary energy market, fluctuating high prices and environmental problems are driving the industrialized countries to undertake corrective measures to improve energy efficiency and reduce environmental impact [1]. Greenhouse gas emission reduction is a shared target which European Union (EU) members have worked for, developing policy instruments and sector-specific programmes [2,3]. Industrial production is responsible for about 50% of world's energy consumption and is one of the main responsible for greenhouse gas emissions [4–6]. Energy efficiency is also internationally recognised as a good practice to reach global competitiveness [7]. For these reasons, reducing energy waste through technological processes, which is to say improving energy efficiency, is one of

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https://doi.org/10.1016/j.apenergy.2018.02.139
Received 15 November 2017; Received in revised form 13 February 2018; Accepted 21 February 2018

the most important goals for EU member states [1]. In order to promote energy efficiency, Directive 2012/27/EU [8] oblige all members to issue directives and laws to achieve a 20% reduction of primary energy consumption by 2020.

Most of the energy consumption in industrial plants is related to production processes, while the rest is engaged for services that do not generate added value [9]. The compressed air generation, treatment, transport and use system is one of the most energy consuming utilities in industrial plants. In most cases compressed air system management is underestimated, even if in Europe compressed air accounts for an industrial electricity consumption between 10% and 25% of the total [10]. This scenario makes clear that evaluating efficiency as a compressed air system management goal is crucial for an industry aiming at energy saving, costs reduction, and increased competitiveness.

In Italy, Directive 2012/27/EU has been transposed in the Legislative (Lgs.) Decree No. 102 of the 4th July 2014 [11] obliging large and energy-intensive enterprises to make energy audits every four years, with first deadline for energy audits being on 5th December 2015 [1]. Energy usage evaluation can be performed in many ways using consumption and production data. In any case, it is crucial to have available data from measurements and estimates directly made on industrial plants. Energy audit is one of the most effective methods to analyse energy use in industrial sector [12]. Through in-depth analyses of all energy aspects, an energy audit allows to obtain trustworthy knowledge of the energy consumption profile of an industrial plant [4]. Carefully leading such a kind of analysis permits to identify the best opportunities to improve energy efficiency and reduce energy losses [13,14]. In order to maximise benefits, it becomes important to identify some indicators that allow to highlight the state of every energy aspects related to industrial production. To this end, energy audits should be combined to other activities related to the definition and use of key performance indicators (KPI), which provide a quantitative assessment to monitor and control the performance and support energy related actions and policies [12,15]. Among the others, the so-called energy-benchmarking is a valid method which, through the use of KPIs, allows comparing the efficiency of an organisation and its sub-systems with reference (i.e. the best available) practices and techniques. This paper starts from the experience of [1] and specifically focuses on compressed air production through the evaluation of benchmark indexes, and on the comparison of such indexes in different industrial sectors.

To the best of our knowledge, this work represents the first attempt to identify, evaluate and validate KPIs related to the energy management of CAS based on the analysis of a great amount of data, which have been gathered through an energy audit campaign and a wide-ranging questionnaire submitted to large and energy-intensive enterprises. Being the first intervention in Italian industries, the proposed methodology may have a great relevance for those organisations willing to compare their own performances with a benchmark not available before. This data driven approach allows to have more reliable and more useful results for practitioners, who can evaluate the real, rather than theoretical, efficiency of their systems compared with other similar systems in similar industrial contexts. Moreover, the proposed methodology has been developed in order to allow the analysis without additional costs for enterprises and to be easily customizable and applicable to different technical systems. This work could then represent a scientific baseline to develop new technologies able to improve energy performance and, for the same reason, also policy makers can take results as a reference to release new directives.

We developed and analysed the effectiveness of benchmark models on the basis of regression techniques. Furthermore, some lessons learned about measurement systems are indicated to simplify the next steps of the study. For the present analyses, we mainly considered the total amount of energy used by each industrial plant, the amount of energy used for compressed air production, the industrial production and the quantity of produced compressed air. The results of this study represent a starting point for the development of guidelines for the next energy audit campaign (expected in 2019) and a useful reference for all organizations wishing to evaluate and monitor the energy performance of their compressed air systems over time.

1.1. Background

Benchmarking is regarded as an effective methodology to assess energy performance and improve energy efficiency [16]. According to [17], energy benchmarking allows a complete industrial plant (or sector) energy performance evaluation against a reference one representing the best practices. A benchmark analysis can help industrial enterprises to assess its own performance compared to other enterprises belonging to the same sector and also evaluate production and energy efficiency of a specific facility in different plants. Benchmarking continuous evaluations is a necessary step for a competitive industry [18]. One of the main characteristics is the opportunity to identify and compare inefficiencies in energy use in different periods and conditions [17]. Benchmark results are also a valid starting point for the implementation of a targeted intervention aimed at improving energy performance [19].

A correct benchmarking requires data to build up the necessary indicators, thus obliging companies to install measuring systems, and a certain number of examples to define a range of methods to build the benchmarking model. Furthermore, there is not a unique method to develop a benchmark analysis; the choice of method depends on available data and obtained results [20]. Benchmarking could be achieved at different levels of complexity from basic single-factor measures up to complex econometric techniques and mathematical programming approaches [21]. In some cases, energy benchmarking has been performed on a whole industrial sector, analysing energy consumption related to CO_2 production [22], e.g. basing on data from enterprises belonging to mineral comminution industry or cement industry [23,24]. There are also some example where only a particular type of installation has been considered (e.g. wastewater treatment systems [13], ventilation systems for offices [25], thermal power plants [26], transport means [27,28] and energy consumption of commercial buildings [29]).

The success of an industrial firm derives from many aspects related to production, energy consumption and management [30,31]. Energy efficiency and production improvements are two parts of a fundamental strategy to maximize revenue and minimize costs [32]. In terms of production and energy consumption, final performance can be monitored, as already said, through the use of KPIs [12,15]. To monitor industrial energy performance, several KPIs are available. In order to have a general overview, aggregated measures are suitable. However more detailed results require the definition of specific energy drivers for the facility [33]. Usually, in a specific application field, more useful KPIs are ratios describing the relationship between an activity and the required energy [34,35].

Despite the paramount importance of compressed air generation in energy efficiency, a standard to evaluate compressed air systems performance is still missing. Furthermore, only few documents and reviews regarding energy benchmarking methodologies applied in compressed air production consider operating conditions other than nominal ones [1].

CASs are complex systems with several components, each one with very variable characteristics, which can make the overall performance radically fluctuating and the monitoring of reliable KPIs very difficult. A typical compressed air system can be divided into 3 functions: compressed air generation (compressors, air sampling systems, filters, dryers, etc.), transport (distribution network) and use (users). To get a high level of energy efficiency, all functions need to be well-designed and work at their best. Therefore, it is rather complex to define a complete framework of potential energy efficiency improvement actions for the whole system and factors influencing their effectiveness. A possible solution is to consider most influent factors of every function of