Energy savings in compressed air systems a case of study.

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Abstract. The compressed air applications are highly used in the industrial sector due to its easy transportation, safety, purity, cleanliness and storage capacity. In many regions, compressed air system accounts for about 10% of the industrial electricity energy bill. However, compressed air is expensive because around 30% of the consumed energy is used for these systems in an industrial facility. Energy used to be lost as leaks, pressure drops, heat, misuse, among others. Several energy efficiencies measures help to improve energy savings in companies such as: pressure reduction, reduce the inlet air temperature, use a well-calculated capacity tank for storage, control heat recovery and reduce leaks, giving potential energy savings in a range between the 20% to 60%, with a return of investment not higher than two years. As result, this document analyzes the energy efficiency measures that can be considered for compressed air systems applications, calculates the energy saving potentials, and assesses a case of study in a company in the city of Barranquilla.

Keywords: Compressed air systems; energy efficiency; energy savings.

1. Introduction.

Global energy consumption has doubled over the past four decades, and this trend will continue with an average annual increase of 1.5% in the period from 2018 to 2050 [1]. The industrial sector is consuming about 50% of the world’s energy, while other sectors such as the residential and commercial are consuming between 29 and 21% respectively [2]. In Colombia, the manufacturing sector is consuming around 30% of the total energy, making it the second most consuming sector after transportation with 40% [3, 4].

The compressed air systems (CAS) in many industries worldwide represent around a 10% of the total electricity consumption as shown on figure 1. Commonly this system is used to operate plants and instrumentation equipment due to its easy transportation, safety, purity, cleanliness, and storage capacity [5-9]. Implementing these systems differs from the activity of every organization and its adequate usage guarantees great energy savings. The major cause of energy loss are leaks, inappropriate pipeline settings, small storage, pressure drops, and inadequate usage of the system. If energy efficiency measures (EEM) are applied in these systems, it could translate into a reduced energy consumption between 20%-60%.

These factors prove that CAS can be one of the most important objectives for the EEM application in the industrial sector [10-12]. A major energy saving, and the increase of efficiency could assure other benefits such as the increase of production with a capital investment reduction, improvement of the product, decrease maintenance costs; these advantages commonly are more representative than the energy-saving itself [13 - 15]. This research main purpose is to analyze the main EEM that could be applied for CASs and its evaluation in a case of study in the city of Barranquilla.
2. Typical EEM in CASs.

2.1. Components of a CASs.

CASs has two sides defined as supply and demand sides. The compressor (which oversees the increasing pressure), a storage humid tank, a dryer, a dry storage tank, and the filters located on the supply side. While, on the demand side, the flow and pressure controls and the transportation lines deliver the amount of air to every machine based on its consumption specifications. Figure 2 shows the key elements inside a CAS.

2.2. Leaks: Identification and measurement.

The most significant cause of energy loss in the CAS is leakages. In an adequate system they are between 5% to 10% of the compressed air production [10, 22]. However, in the industry the regular range for leaks are in the range of 20% to 40% and without proper maintenance and use, it could reach up to 60% [23-25]. Commonly, leaks are found in the joints and connections of the compressed air pipelines, elbows, among others. The leakages value could be registered using two procedures: the first one is for compressors with a start/stop control and it comprises turning on the compressor when the system is without loads, the leaks can be able to pressure drops, by which the compressor will run into a load-unload cycle; according to [17, 26], the total leakage ($T_{L}$) measured in percentages are:
\[ T_L\% = \frac{T_{load}}{T_{load} + T_{download}} \cdot 100 \]  

Where:

\( T_{load} \) – Time the compressor is in load mode.

\( T_{download} \) – Time the compressor is in download mode.

Other control strategies can be as follow: a pressure gauge (manometer) is placed downstream of the receiver tank. The compressor is turned on without loads until it reaches the working pressure \( P_1 \). Then, the compressor is then turned off measuring the time \( t \) until that the system drops until a half of the working pressure \( P_2 \). It is necessary to know the system volume \( V \) including the storage tank capacity. The value of the loss flow \( L_F \) measure in \( (\text{m}^3/\text{s}) \) and can be calculated using the equation 2 as follow:

\[ L_F (\frac{m^3}{s}) = V \cdot \frac{(P_1 - P_2)}{P_0 \cdot t} \cdot 1.25 \]  

Where:

\( P_0 \) - atmospheric pressure

In equation 2, the multiplier factor 1.25 corrects the leak to the normal system pressure. The annual energy saving in a start/stop control can be expressed as:

\[ ES_L = AEC \cdot T_L\% \]  

Using other control strategies

\[ ES_L = L_F \cdot SEC \cdot OPH \]  

Where,

\( OPH \): is the operating hours in year \((\text{h/year})\).

\( SEC \): is the specific energy consumption, \((\text{kWh/m}^3)\).

\( AEC \): Annual energy consumption in the CAS.

2.3. Storage Tanks Volume

The storage tanks in a CAS have several functions including: providing storage capacity to avoid short start/stop cycles, to condense air humidity, to cover periods of pressure peaks, to keep the system’s pressure and to allow the systems control to work with more efficiency [24]. The compressed air provider companies recommend the use of two storage tanks, a humid and a dry tank. The first is placed between the dryer and the compressor while the other is located next to the dryer [25]. Sometimes, this makes more sense to have additional storage tanks near the applications with high consumption of air and intermittent usage [24]. Some authors recommend the tank volume should be between 12-120 \( \text{m}^3 \) for each cubic meter per second of air delivered by the compressor at full load as shown in figure 3 [21, 27, 28].
The annual energy saving for an adequate air receiver volume is:

\[ E_{SV} = AEC \cdot S_F \]  \hspace{1cm} (5)

2.4. Suction Temperature

Compressors are in a separate room inside the factory, or adjacent shelters, built specifically for this equipment. Most of them suck the air in that same room, at temperatures higher than the normal environment temperature, due to the heat generated by the compressor itself. The compression of the air becomes more inefficient as the suction temperature increases [29, 30], the potential savings from this concept can be calculated as:

\[ T_S = \frac{T_1 - T_0}{T_1 + 273} \]  \hspace{1cm} (6)

Where:
\begin{itemize}
  \item \( T_1 \) - average compressor air suction temperature.
  \item \( T_0 \) - average environment air temperature.
\end{itemize}

The savings produced by the reduction of the air intake temperature are calculated as:

\[ E_{S_{TR}} = AEC \cdot T_S \]  \hspace{1cm} (7)

3. Case Study

The plant analyzed is in the city of Barranquilla and it use is the glasses manufacture for the construction sector. To determine the potential savings in the compressed air systems, the efficiency measures previously discussed will be evaluated.

3.1 Leakage

The compressor has a start/stop control, so the leakage is calculated using equation (1). The corresponding measurements were carried out where it was determined that in the company the values of the leaks correspond to 33%. If we consider that a system with a proper functioning, the percentage of leakage allowed is 5%, we can state that there is a considerable saving potential in this case of 28%.

Using equation (3) potential savings could be determined, considering that the monthly electricity consumption is 10,852 kWh/month.

\[ E_{SL} = AEC \cdot T_{L\%} \]
\[ E_{SL} = 10852\text{kWh/month} \cdot 0,28\% \]
\[ E_{SL} = 3038,56\text{kWh/month} \]
If the kWh cost is 451,28 COP/kWh, the company has an annual potential saving of 16,454,896 COP.

### 3.2 Storage Tanks.

The company has an Atlas Copco GA55P compressor, which has 56 kW and handles a flow \( Q \) of 0.128 m\(^3\)/sec, the system has a storage tank with a volume \( V \) of 1 m\(^3\). The value of the relative receiver tank volume is:

\[
Q^* = \frac{V}{Q} = \frac{1 \text{ m}^3}{0.128 \frac{\text{m}^3}{\text{sec}}} = 7.81 \left( \frac{\text{m}^3}{\text{m}^3} \right)
\]

In figure 4 load/unload compressor cycles are shown. The relative consumption conditions are at 53%.

![Figure 4. Power consumption of compressor.](image)

Figure 5 shows the relative receiver tank volume for the plant. As seen that it is below the recommended value giving by manufacturers.

![Figure 5. Relative receiver tank volume for the plant.](image)

If the company buys a storage tank to achieve the relative volumes recommended by the manufacturers there would be savings in energy consumption (ESPC) caused by increasing the relative storage values of 12 % figure 6.
Figure 6. Potential savings with the required receiver tank volume.

Using equation (5) potential savings are determined as follow:

\[ ES_{TV} = AEC \cdot S_T \]

\[ ES_{TV} = 10852\text{kWh/mes} \cdot 0.12 \]

\[ ES_{TV} = 1302.24 \text{kWh/mes} \]

Considering the kWh cost, the company has an annual savings potential of 7.052.098 COP.

3.3 Temperature.

For the case study analyzed, the compressor location is not appropriated because it is located on a second floor, above the oven and next to the electric motor of the oven's fan. Temperature measurements were taken in unison inside the compressor room and the ambient temperature for a week, resulting in an average suction temperature of 10 degrees above an ambient temperature at the company, reaching a difference of 15 degrees at the most critical times. The reduction in energy consumption as a result of the reduction in air temperature is calculated as follows:

\[ T_S = \frac{42 - 32}{42 + 273} \]

\[ T_S = 3.1\% \]

We calculate the savings from reducing the inlet temperature according to equation (7).

\[ ES_{TR} = AEC \cdot T_S \]

\[ ES_{TR} = 10852\text{kWh/mes} \cdot 0.031 = 336 \text{kWh/mes} \]

Considering the cost of kWh, the company has an annual savings potential of 1.821.792 COP.

4. Conclusion.

The CASs in industry commonly consumes about 10% of the billed electricity, highlighting that they are inefficient systems where only between 10% to 30% of the produced air is used, implementing EEM such as reducing the improper use of compressed air, reducing the pressure of the compressors, lowering the air intake temperature, ensuring an adjusted storage capacity, obtaining a residual heat recovery from the air compressor and reducing leaks can provide savings in a range between 20% to 60% with a return of investment not higher than two years which makes it one of the main systems to be used by companies and countries when are considered strategies to reduce energy consumption. Also, this measure provides other benefits such as the increase of production with a lower capital investment, maintenance reduction, quality
in final product improvements, and maintenance reduction; otherwise it is important to emphasis that these advantages are better than common electricity bill savings.

The company analyzed is dedicated to glass manufacture for the building sector where was evaluated all the compressed air systems located in the production area giving all possible recommendations that could be applied energy savings. According to this research could be estimated that exist a potential energy saving of 28% if the company applies measure to reduce leakages. If a storage tank is purchased to bring the relative volumes to the recommended values by the manufacturers it can be reached potential energy savings reaching 12% and if the temperature in the compressor can be reduced to the environment it can be reached potential energy savings equal to 3.1%. The potential energy savings of the company can reach a total energy saving of 43.1% which is equal to 25.328.786 COP per year.

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