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Air compressor efficiency in a Vietnamese enterprise

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ABSTRACT

Compressed air systems in a Vietnamese footwear manufacturing enterprise consume about 10% of enterprise's total electric power supply. Energy efficiency of these air compressor systems, either equipped with new and efficient compressors or old and inefficient ones, can only reach between 5% and 10%. In other words, regardless whatever air compressors were installed, energy loss from the compressor systems was over 80%. This study discovered that energy loss was due to non-optimized operations of the air compressor systems and air leakages. The objectives of the paper are to uncover energy saving potential in Vietnamese air compressor systems, demonstrate methodologies used in the auditing and assessment, share auditing and assessment results, and serve a guide on how to analyze energy efficiency in a compressed air system. This paper concludes that energy efficiency investment in air compressor systems in the Vietnamese enterprise could be extremely cost-effective. If the enterprise invests USD 84,000 in the air compressors to improve efficiency performance, the investment capital will be recovered in about six months. The net present value of the investment will be about USD 864,000 at a discount rate of 12%.

1. Introduction and literature review

1.1. Vietnamese new energy efficiency policy

In a conference on energy efficiency held by Vietnam Directorate for Standards and Quality and Washington Laboratories Association on 30th October 2008 in Hanoi, Mr Hoang Duong Thanh, specialist of Energy Efficiency Office of the Ministry of Industry and Trade (MOIT), stated (MOIT, 2008):

> Energy efficiency in Vietnam has not been encouraged. As a result, energy intensity in Vietnam is higher than that in other countries in the region. If all international codes on construction and energy utilization are followed properly, energy use can be cut down by 50% in some energy intensive sectors.

To achieve higher energy efficiency in the country, the Vietnamese government is working on better policies. As of December 28, 2008, the MOIT has been drafting a Law on Energy Conservation and Efficiency of Vietnam (MOIT, 2008). According to the draft Law, it is required that an enterprise in Vietnam with electricity consumption above 3 GWh per annum should undertake energy audit in each 5 years.

The Vietnamese government recently launched a long-term energy efficiency program: "National Program on Energy Conservation and Efficiency in the Period of 2006–2015". One of the key elements in the Program is energy audit performance in enterprises. By 2007, more than 20 pilot energy audits were carried out for enterprises.[1]

1.2. Literature review on air compressor energy efficiency

Compressed air is widely used throughout manufacturing industries, due to its cleanness, availability, and ease to use. However, compressed air is the most expensive form of energy in a manufacturing enterprise, because only about 5–10% of the input energy can be converted to useful energy for production. In other words, energy efficiency for an air compressor system in general is in a range 5–10%[2] (USDOE, 2004).

The costs of useful energy provided by air compressor systems can be divided into three parts: annualized life-cycle cost of capital investment in equipment and the whole air compressor system, operation and maintenance cost, and energy cost. Because of low energy efficiency and long time operation in air compressor system, energy cost accounts for the largest share, normally over 75% among all the three costs.

A number of governments and organizations have made great efforts to improve energy efficiency in air compressor systems.

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[1] http://www.eec.moi.gov.vn/EN/index.aspx?NewID=3499E&CateID=93.

[2] Air compressor efficiency in this article is defined as useful energy for production activities of the compressed air divided by the energy input to the whole air compressor system.

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The US government launched Compressed Air Challenge (CAC) program in January 1998 (USDOE, 2000). The objective of the CAC program was to develop and provide resources to educate the US industries to save energy and therefore to increase net profits through improved compressed air system operation. In 2003, the European Union also launched a Motor System Challenge Program, aiming at improving energy efficiency in industrial motor systems and air compressor systems. Under the support of the United Nations Industrial Development Organization (UNIDO), the Chinese government launched two industrial energy efficiency programs in 1999–2000 and 2007–2008. Improving energy efficiency for compressed air systems was a key part in both of the Chinese programs.

According to the documents of in the US Compressed Air Challenge Program, the EU Motor Challenge Program, and the UNIDO China Motor System Energy Conservation Program, improved energy efficiency in compressed air systems can lead to saving electricity in a range 30–50% (Perry and Taranto, 2003).

In 2007, the Vietnamese government initiated an energy efficiency auditing program. The objective of the program was to audit energy efficiency at Vietnamese top electricity intensive factories or enterprises. The audits were undertaken by government-selected energy service companies in Vietnam. Although about 20 selected enterprises had gone through the auditing by the end of 2008, there were not any auditing reports available to the public. Reasons might be that factory owners and the government are not willing to share business information to the public.

This paper presents a practical energy efficiency auditing and assessment for industrial compressed air systems in a Vietnamese enterprise. The objectives of the paper are to uncover energy saving potential in Vietnamese air compressor systems, demonstrate methodologies used in the auditing and assessment, share auditing and assessment results, and serve a guide on how to analyze energy efficiency in a compressed air system. This paper fills a gap of information on air compressor system energy efficiency in Vietnam. It is useful for those who want to either undertake energy efficiency auditing or invest in efficient air compressor systems in Vietnam.

1.3. Introduction to the enterprise

John316 Enterprise Vietnam is located in the southern part of Hanoi, Vietnam, about 55 km North-east of the center of Ho Chi Minh City. By driving through a high way, it takes about 50 min to travel from Hanoi, to the enterprise.

John316 started operation in Vietnam in 1995. With a capital investment of USD 12 million, the enterprise set up 6 conventional footwear production lines and hired 4500 employees, for a daily production capacity of 12,000 pairs of high quality sport shoes.

Total energy cost in the enterprise was about USD 4.7 million in 2007. Of these costs, electricity has the largest share, more than 55%, while fuel oil and diesel have the shares of about 28% and 17%, respectively. See Fig. 1.

Electricity tariffs paid by the enterprise had three tiers as of 31 December 2008. Table 1 shows these tariffs over the past six years. The tariffs have been keeping almost unchanged. Reason for this was the government control of electricity price. From 2005 to 2007, the price seemed going down, but it was due to exchange rate between the local currency and US dollars. In this study, USD 0.0522/kWh is used to calculate electricity costs. It should be noticed that industrial users in Vietnam only pay electric energy use, but not power capacity demand.

Air compressors are generally a large electricity consumer in a manufacturing enterprise. In the enterprise, there were 40 units of

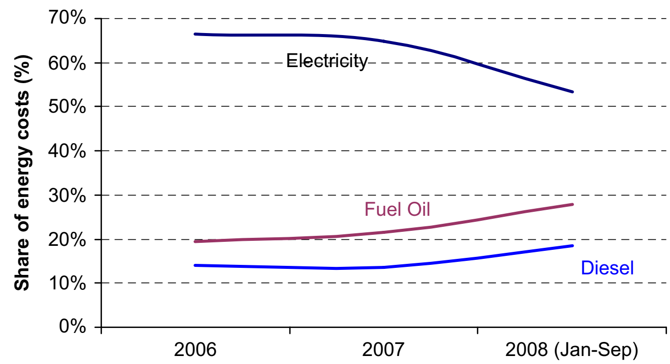

Fig. 1. Shares of energy costs in John316.

Table 1
Electricity prices in industry in Vietnam.

Time period	From 2002 to 2005 15 kV	From 2005 to 2007 22 kV	From 2007 to October 2008 22 kV
4–18 h	0.052	0.049	0.049
18–22 h	0.087	0.083	0.100
22–4 h	0.029	0.027	0.027
Weighted average	0.0521	0.0494	0.0522

air compressors (38 were in services and 2 were spare units), with 50 HP or 35 kW capacity per unit, totaling 1.5 MW. The highest electric load of 14 MW was recorded by the enterprise on June 10, 2008. This means that air compressor systems could consume over 10% of the total electric power. These air compressors were allocated in eight different sites to meet different demands in different areas of the premises of the enterprise. All the machines were made by Atlas Copo in Belgium between 2004 and 2005. They were all in very good condition. It can be seen that energy efficiency was a priority in John316's equipment procurement policy.

2. Methodology

Methodology used in this study is of more engineering than academia. The following procedures or steps are the major elements of the methodology.

2.1. Project team establishment

A project team was first established at the beginning of the auditing period. The team consisted of members throughout the plant organizations who had a stake in a particular area. Below is a list of the team members:

1. An international consulting expert (team leader–the author)
2. Energy manager from John316's parent company
3. Machine maintenance manager
4. Process quality control engineers
5. Financial officers
6. Facilities, equipment and utilities engineers
7. Air compressor managers
8. Electric motor management and repair manager
9. Process and tooling engineers
10. Procurement and logistics managers
11. Environmental and energy engineers

2.2. Walkthrough evaluation

Based on the defined objectives of the energy efficiency auditing, the team leader developed a walkthrough evaluation list for on-site inspections on the enterprise's air compressor systems. Then, the project team spent three days to conduct walkthrough evaluations. Meetings were scheduled with various plant personnel representing production, facilities, maintenance, and others to discuss air compressor system operation and performance. The walkthrough team inspected not only the actual machines and facilities, but also checked the operation logs of the air compressors and air supply systems.

2.3. On-site data measurement and recording

Following the walkthrough evaluation, the team leader listed data collection and test point locations for air compressor systems. The team developed a framework of energy efficiency auditing report which was specified to be consistent with technical objectives and business parameters. After the auditing work plan and report content were defined and agreed among the team, the team members took their individual tests and measurement tasks for on-site data collection.

Other data collection and recording included reviews and research on the historical bills paid by the financial department to utilities and energy companies. This activity involved considerably the financial and accounting managers.

Energy service companies in the local area were also contacted for quoting prices of equipment and machine spare parts. This was a particular way to get the market price information.

2.4. Cost-effective analysis

Two scenarios, with and without additional capital investment, were designed in the study to quantify the costs and benefits. To simplify the analysis, the team only took into account the marginal capital, the marginal operation and maintenance (O&M) costs and the marginal saving benefits to be brought about by the investment. An approach by the Asian Development Bank (ADB, 1997, 2002) and Brealey and Myers (1991) to identifying cost-effective projects was used in the study to calculate net present values (NPVs) of investments.

2.5. Savings calculations

Energy consumptions in relation to the two scenarios were calculated. The difference of energy consumptions between the two scenarios are energy savings. CO_2 emission mitigation via investment was also quantified.

3. Energy efficiency auditing and data collection

An audit for compressed air systems was conducted to collect data and highlight the true energy saving areas and cost reduction. The team identified best opportunities to improve efficiency and productivity with specific aims of:

1. Minimization of inappropriate uses of compressed air,
2. Minimization of pressure drops and system pressure,
3. Minimization of compressed air leaks, and
4. Maximization of waste heat recovery.

The team inspected all the eight air compressor sites in nine areas to audit energy efficiency. The audited areas included: (1) air treatment; (2) pressure levels; (3) pressure controls; (4) heat recovery; (5) load profile; (6) end-use equipment; (7) compressor package; (8) filter and dryers; and (9) air leakages.

3.1. Air treatment

In a compressed air system, air contaminants such as dirt, moisture, oil, hydrocarbons gases and bacteria aggressively attack, corrode and erode the piping system, controls, instruments and tools. Maintenance and repair costs may therefore escalate dramatically. Compressed air filters are used to remove water, oil, oil vapor, dirt, and other contaminants from a compressed air supply system.

However, air filters which are not properly used may cause over-treatment of air and therefore waste of energy. For example, a filer system in both coalescing pre-filters and particulate after-filters, offering 6–9 times the surface area found in "wrapped" or "depth-style" elements is a very good air filter system. This kind of system can reduce liquid aerosols down to 0.01 μm,[3] and particulates rating down to 0.9 μm. In the footwear manufacturing enterprise, the standard of air quality requirement is not so high. It is therefore not necessary to have both pre- and after-filters. A single filter in a machine that can take away 5 μm particulates is good enough.

Having checked the end-use pipes and machines, the author believed that the filters in the enterprise had been chosen, installed and worked well. It can remove 5 μm particulates. The audit team believed that the compressed air was treated properly, namely over-treatment of air (an indication of energy being wasted) was not perceived.

3.2. Pressure levels

The team detected the lowest possible pressure level required to operate production equipment effectively. On-site inspections showed that the off-load pressure of the air compressors were set at the level 8.16 kg/cm^2 which was close to or equal to the highest level of working pressure of the air compressors (8.16 kg/cm^2). At the end uses, the required pressures were between 1.5 and 6.5 kg/cm^2. The team actually measured the pressures at the end-use points. When in operation, the highest pressures at the end-use were between 6 and 6.5 kg/cm^2. This means that the air pressure drop between the air compressors and the end-users was about 1 kg/cm^2, which was reasonable.

3.3. Controls

The existing control system was evaluated to determine if the system was appropriate for the demand profile. The team found that the air compressor control system was not set appropriately. For example, the highest cut-off pressure of the compressors was set at 8.16 kg/cm^2, while most end-users only need 5 kg/cm^2. This implies that all the machines had to work very hard to meet artificial demand. The team's examination on motor performance for air compressors discovered that almost all of the motors were overloaded. An optimized control setting should be re-programmed to resolve this issue.

3.4. Heat recovery

The team also identified potential applications for the use of heat recovery. All the compressed air was cooled by air-fan

[3] Micron, a micrometre, a unit of length in the metric system: one millionth of a meter.

systems. No waste recovery system was installed in any of the eight air compressor systems. The team discussed with the operators and stakeholders of the air compressor houses. They did not think it was worthwhile to recover the waste heat, because there was no demand for low temperature hot water or hot air in the production process.

3.5. Load profile

The team interviewed a number of managers of production in the workshops and inspected the use of the compressed air regarding the load profile. The production processes in the enterprise, which were using compressed air, did not vary very much with load profile within individual shifts, because there were many small users in the factory. However, some workshops run day shift only and some workshops run two or three shifts. For example, in a workshop, six machines were producing compressed air for two one-shift production lines, and four machines for three-shift production lines. The six machines were always working at full load regardless one-shift or three-shift demands because of air leakage and artificial demand. If the air supply and use system did not have air leakages, the air compressors should have automatically reduced their running time in the evening or night time. Unfortunately, according to the managers and operators, all the air compressors in the enterprise were working 24 h a day regardless the time and the shifts in the workshops. This means that most of compressed air in the night shift was wasted due to air leakages in the workshops where there were only day shift or two shifts. The auditing team suggested the enterprise to separate end-users according to their time periods of demand for compressed air or individual load profiles, and to relocate the air compressors.

3.6. End-use equipment

The equipment and production processes that use compressed air were also examined to see if the use of compressed air could be replaced with other kind of energy, such as power and steam. The team did not find any air usage that could be replaced by electric power in an economic way.

3.7. Compressor package

The compressors were evaluated in terms of appropriateness for the application, general appearance and condition. The installation sites of the air compressors were evaluated in terms of its location, connection to cooling fans, and ventilation. The team did not find any outstanding issues although in one or two sites, the air compressors were too close to the air-coolers. In general, air compressor packages were well installed in the premises of the enterprise.

3.8. Filters, after-coolers and dryers

The auditing team inspected the filters, after-coolers and dryers. These devices were generally clean and suitable for operation. The housekeeping staff of the enterprise change the oil filters in every 2000 h of operation, strictly following the manual of device operation. No outstanding pressure drops across the filters were found.

3.9. Air receiver/storage

The effectiveness of the receiver tanks was inspected in terms of locations and sizes, and the receiver drain traps were also examined to see if they were operating properly. There were eight air-receive/storage tanks in the enterprise. The total volume of the tanks was estimated at about 24 cubic meters. Each of these tanks was located in an air compressor site. All the tanks were installed after the compressors before the treatment of the air. Their designs were strictly followed the demands of the air systems and therefore the sizes were matching the demands well. The receivers/tanks were all in good condition. The team did not find any outstanding issues.

3.10. More comprehensive evaluations

The team audited four whole air compressor supply and demand systems. They did not find any poor design of the system. There is no need to substantially retrofit the systems if load profile optimization is not taken into account.

3.11. Minimize compressed air leaks

Air leaks can waste energy significantly in an industrial compressed air system. Leakage can be expressed as percentage of compressor capacity lost, normally wasting 10–20% of a compressor's output. A typical plant that has not been well maintained may leak over 20% of total compressed air. On the other hand, proactive leak detection and repair can reduce leaks to less than 10% of compressor output.

According to Perry and Taranto (2003), a hole of 4 mm in diameter at the end use with a pressure of 6 bar will leak 2.12 cubic meters of compressed air per minute, which is equal to the waste of 12 kW motor's power supply. See Table 2. If this hole keeps leaking for 9 h, it will waste 108 kWh electricity. In John316, the electricity price is USD0.05/kWh. With this price, the wasted money, USD5.4/day, could be enough to pay a worker to work for the whole day!

3.11.1. Leak detection

Unlike steam leakages or water leakages, small or hidden air leakages can hardly be detected. The leaked air is invisible in the atmosphere. Thus, it is difficult to detect with naked eyes. The team randomly inspected a group of 72 machines which were using compressed air in each of the air compressor sites in the enterprise. They found that over 20 machines in each group had outstanding air leaks (outstanding here means one could hear air flow sound and feel air flow from the machines by hands) and hidden leakages. For slight or hidden air leakage detection, the best way is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks if air leaks are not substantial. In order to detect slight and hidden air leakages, the team used soap water in the following parts of the air system and machines. (See also Fig. 2):

1. Couplings, hoses, tubes, and fittings.
2. Pressure regulators.
3. Open condensate traps and shut-off valves.
4. Pipe joints, disconnects, and thread sealants.

Table 2
Compressed air system leaks power consumption table.

Hole diameter (mm)	Air consumption at 6 bar (m^3/min)	Loss (kW)
1	0.065	0.3
2	0.240	1.7
3	0.980	6.5
4	2.120	12.0

Source: Perry and Taranto (2003).

The auditing results were surprising! Air leakages were discovered in all the above mentioned devices and parts in the selected machines. The air leakage test was carried out on Sunday when all the machines in the workshops were turned off. However, after switching on the air compressors, the team could hear very loud noise in the workshops produced by the leaked air. Fig. 3 shows some of the pictures taken during the inspections.

3.11.2. Estimation of leakage

The team did the estimation of air leakages on Sunday when all the end uses were turned off. The compressor should load and unload alternatively because the air leaks will cause the compressor to cycle on and off as the pressure drops from air escaping through the leaks. In the eight tested air compressor sites in John316, when an air compressor machine was switched on, it did not stop. This means that the machine could not supply enough air to meet the leakage and establish required off-pressure level.

A revised methodology was developed by the team in this study to estimate air leakage in John316. The team switched on air compressor machines one after the other. If one air compressor could not meet air leakage and establish the system off-pressure, the second machine was switched on. If two machines were not enough, the third was put in operation, and so on. The test results showed that the maximum leakage in an air compressor system reached 86%. Weighted average leakage share of all the eight machines was 65%. See Table 3 for details. In the project economic analysis, 60% leakage was conservatively used for calculation.

Air leakages were causing overloaded motors. According to the on-site measurement, the input power of 22 out of

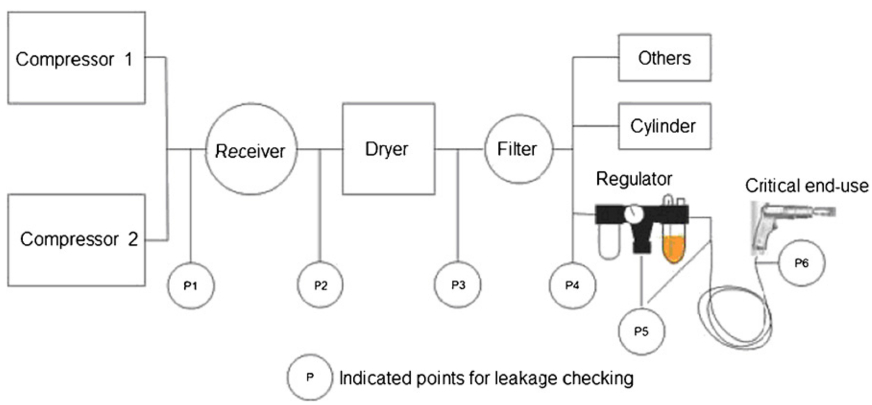

Fig. 2. Air leakage check-up points.

Fig. 3. Outstanding and hidden air leakages discovered in John316.

36 or 61% of the motors driving air compressors were overloaded (the input power was greater than 37.5 kW/unit as designed input power for each of the motors). See Table 4 for the tested results. A motor running overloaded is not efficient in using energy and its life time will be shortened considerably.

On the contrary, in a normal air compressor system where air leakage is fixed, the air system can be more easily maintained to

Table 3
Shares of air leakages in air compressor systems.

User names	Time of machine on	Time of machine off	Time of machine on again	Volume of system (M^3)	Estimated share of leak (%)
NITC	9:42	9:48	9:49	4.14	86
MAINT	21:24	21:28	21:30	16.13	67
Vinatech	13:58	14:05	14:06	6.46	88
NOS C	22:50	22:56	23:00	4.82	60
Stitching	19:03	19:11	19:15	3.99	67
NOS E	8:50	8:56	9:00	4.13	60
NOS H	10:43	10:50	10:56	10.24	54
ASS	19:15	19:20	19:26	5.23	45
Weighted average					65

Table 4
Overloaded motors of air compressors in John316.

User names	Pressure set on (bar)	Pressure set for off (bar)	Pressure at the air tank (kg/cm^2)	Pressure at the end use (kg/cm^2)	Number of machine switched on	Number of machine broken	Outstanding leakage	Hidden leakage	Power use (kW)	Power factor	Temperature °C
NITC	6	7	7	6.4	2		29	12	39.5	0.879	60
	6	7							38.7	0.876	61
MAINT	5.7	7.5	6	4	9		20	16	36.4	0.875	63
	6.6	7.7							39.6	0.88	64
	6.6	7.5							34.1	0.81	62
	5.8	6.4							37.8	0.89	64
	6.7	7.5							40.2	0.88	70
	7	8							40.5	0.88	71
	6.7	7.6							40	0.87	59
	7.3	7.9							40.3	0.88	69
	6.8	7.5							40	0.89	68
Vinatech	6.5	6.6	7	6	4	1	23	16	25.7	0.58	67
	6.5	6.7							39.1	0.872	67
	6.5	6.6							31.4	0.777	64
	8	8.6							31.4	0.752	60
	6.8	7.5							34.4	0.869	64
	6.5	6.6							34.7	0.804	63
NOS C	5.6	6.6	7	6.6	2		16	4	41.4	0.88	60
	6.1	7.1							41.7	0.89	64
	5	6							42	0.892	63
	5.5	6.5							41.3	0.88	57
Stitching	5.5	6.8	7	6.8	2		7	3	31.9	0.806	55
NOS E	6.1	7.5	7	6.8	2		16	6	40.5	0.886	60
	6.1	7.5							42	0.858	62
	6.1	7.8							40.9	0.886	61
NOS H	7.1	7.7	7.5	7.2	3		23	6	32	0.804	56
	6.9	7.6							42.8	0.884	56
	7	8							41.8	0.873	66
	7	7.7							41	0.876	62.4
	7.1	7.9							40.8	0.884	66
	6.5	7.7							36.3	0.805	67
ASS	6.6	8	7.8	7.2	4	1	15	4	14.5	0.426	55
	6.5	7.5							37.1	0.846	60
	6	8							39.7	0.75	50
	6.6	7.6							35.2	0.891	65

Note: In each of the air compressor systems, air leakage tests were conducted for 72 randomly selected machines. The numbers of leakages detected are shown in columns 8 and 9 of the above table.

reach the required point of use pressure. This will allow the compressor pressure settings to be lowered, reducing the load on the motors considerably. This will extend motor life, reduce operating expenses, and cut down energy bills.

4. Cost-effectiveness analysis

Energy saving analysis was undertaken in two most promising areas for air compressor systems: (1) optimizing load profile; and (2) preventing air leakages. Two scenarios were designed for each of the analysis areas: (1) without any energy efficiency program, in short: "without" or business as usual; and (2) with an energy efficiency program, in short: "with".

4.1. Without any energy efficiency program

John316 will keep business as usual if without any energy efficiency program for air compressors. These air compressors with a total capacity of 1.425 MW would consume 8.07 GWh electricity per annum. See "business as usual" in Table 7. At an electricity tariff of USD 0.0522/kWh, this amount of energy will cost John316 about USD 420,000 per year.

4.2. With two energy efficiency programs

In the first area (optimizing load profile), the team recommended the following ways:

1. Separate Mold Shop (Factory 3) from Maintenance. Install an additional 15 kW air compressor for this special load.
2. Relocate one air compressor from Vinatech to a venue which is close to Mold Shop (Factory 4).
3. Separate Lab & Printing room at NOS B from NOS C. Install an additional 15 kW air compressor for this special load.
4. Split NOS H into three parts: (1) new NOS H, (2) IP, and (3) Printing room at NOS I. Adding additional one 37.5 kW and another 25 kW air compressors to meet the demand of IP and Printing room at NOS I.

After this load profile optimization, air compressor relocation and addition, the load of air compressors in each of the demands will be harmonized, and air compressor system operations can optimized. See Table 7.

While preventing air leakages, the team suggested a number of measures. The first target was the joints and connections at which leaks occur most often. Stopping leaks could be as simple as tightening a connection or as complex as replacing faulty equipment such as couplings, fittings, pipe sections, hoses, joints, drains, and traps. In many cases leaks were caused by bad or improperly applied thread sealant. Non-operating equipment could be an additional source of leaks. Equipment no longer in use was isolated with a valve in the distribution system.

The second way to reduce leaks in John316 was to replace all the old plastic tubes, air guns, and broken air cylinders. The third way was to lower the demand air pressure of the system. The lower the pressure differential across an orifice or leak, the lower the rate of flow, and the lesser leakage in the air system. Thus, reduced system pressure will greatly reduce leakage rates. Stabilizing the system header pressure at its lowest practical range would minimize the leakage rate for the system.

Finally, a leak prevention education program for the workers was necessary. While auditing energy efficiency at air uses in the workshop, the team perceived a number of workers were using compressed air as a fan to cool themselves or to blow away dusts from their bodies. That was a typical improper use of compressed air. Workers in the workshop usually did not care about air leakages. Many air leak holes in the air tubes were caused by careless operations of the machines. Air leakages had little to do with the workers. An education program should be launched to educate workers that "Air in the Workshop is Not Free". After the program, a worker should have a responsibility to fix or report air leakage in his/her machine. If a leakage is found without report, a penalty should be accompanied to the user of the machine. In addition, workers who are responsible for machine maintenance should be accountable for hidden leakages. Checking and fixing air leakages should become one of their tasks in machine maintenance. These workers should check air leakages at pipe joints, couplings, regulators and cylinders every week by using professional tools such as ultrasonic detectors. With all the above measures, air leakages in workshops will be able to drop from the current 65% to about 15%. This means that the working hours of the air compressors will be cut by 50%. Table 7 shows the expected working conditions and electricity consumption by the air compressors after the two energy efficiency programs. The total annual electricity consumption by all these compressors will be cut down by 60% when compared with the business as usual scenario, only about 3.9 GWh.

It was assumed, after regrouping load and relocating air compressors, working hours for many air compressors which supply air to only one shift will greatly reduce their operation hours per day. Electricity consumption will be reduced from 8.07 to 6.89 GWh, cutting down by 1.18 GWh or 14.6%. This energy saving effect is only due to the first strategy. The second strategy is, by investing in new spare parts to reduce air leakage from more than 60% to a normal or acceptable level 10–15%. Conservatively, the second strategy will reduce about additional 50% of electricity on the basis of the first strategy of energy efficiency improvement for air compressors. As such, after capital investment in air compressors and replacing broken parts of the user machines, John316 will be able to reduce electricity consumption by 3.45 GWh (6.89 GWh $\times$ 50%) per annum.

4.3. Economic analysis for air compressors

An economic analysis was undertaken for investment in air compressors in the two strategies (or areas) mentioned above. On the basis of the enterprise's procurement records, capital investment for the first strategy to relocate air compressors and regroup air loads was estimated at USD 42,500. The costs included those to install three new air compressors at a capacity of 15 kW per unit, relocate one 37.5 kW air compressor from Vinatech to the Mold Shop, and purchase at least six filters and six dryers. Cost details are listed in Table 7.

Capital investment for the second strategy was budged at USD 41,367. That included the investment in replacing all the broken pipes, tubes, cylinders, and critical end-use tools. See Table 6. All the above two sums of investment were put in a cash flow spreadsheet to calculate project viability.

O&M costs stand for marginal operation and maintenance costs due to the new investment. It was assumed that to effectively prevent air leakages in the enterprise, new cylinders, joints, and tubes will be purchased each year to replace broken ones. The investment should be on-going. The amount of capital investment in strategy two for each year in the future is the same as that in the first year of the project.

Table 5 shows the economic analysis results of air compressor investment project. Most parameters including electricity price in Vietnam, project investment costs and savings, etc. have been discussed in the previous sections.

With these investments and maintenance, total electricity savings will amount to 4.5 GWh/yr. Each year, the investment will cut electricity bills for John316 by about USD 200,000 per year. The project will reduce over 3100 t of CO_2 per annum. The internal rate of return (IRR) is over 180% and the net present value of the investment at a discount rate of 12% for 15 years more than USD 860,000. The total investment capital will be paid back in less than half a year. Table 5 presents the results.

Table 5
Cost-effectiveness analysis for air compressors.

Average price of electricity in 2007 (USD/kWh)	0.0522	Collected on-site in the enterprise
Electricity savings from strategy 1 (kWh/yr)	1,018,080	Calculated
Electricity savings from strategy 2 (kWh/yr)	3,524,648	Calculated
Total savings of electricity (kWh/yr)	4,542,728	Calculated
Capital investment in compressor relocation (USD)	42,500	Calculated
Capital investment in preventing leakage (USD)	41,367	Calculated
Total investment cost (USD)	83,867	Calculated
O&M costs (USD/yr)	41,367	On-going replacement of broken parts
Total net saving values after first year (USD/yr)	1,95,763	Calculated
Payback period (Months)	5.14	Calculated
Life time of the newly invested technology (yrs)	15	Assumed
CO_2 emission factor (kg CO_2e/kWh)	0.7	
Discount rate (%)	12%	Assumed
CO_2 emission reduction (ton/yr)	3180	Calculated
Internal Rate of Return (IRR)	184%	Calculated
Net present value (USD)	864,023	Calculated

5. Conclusions and recommendations

Energy efficiency auditing and cost-effectiveness investment study were undertaken for John316 Co., Ltd in Vietnam. This study adopted multiple approaches and methodologies in data collection. Data sources included actual measurements of the air compressor systems, face-to-face and telephone interviews with key stakeholders, walkthrough surveys on various workshops with a focus on air compressor rooms, review of documentations of the enterprise, and check-up of the air compressor operation logs. These approaches and methodologies ensured the data to be first hand and updated. Review of energy development and planning for Vietnam was also conducted to ensure the study's recommendations to comply with the long-term energy policy of Vietnam (Tables 6 and 7).

Energy efficiency auditing showed two outstanding issues. First, the air compressor systems in the enterprise were not optimized in operation. Many air compressors were working for artificial demand. Second, air leakages were wasting over 65% of the compressed air. Because of the poor operation and air leakages, the overall energy efficiency of the air compressor systems in the enterprise was less than 5%. Investing in air

Table 6
On-site energy efficiency auditing and cost estimation on fixing air leakages in machines.

Sites of compressor	Department	No. of air compressors in each of the eight systems (sets)	Machines using air	Share of machines with leakage type A* (%)	No. of machines with leakage with type A	Cost to fix leakage type A ($)	Share of machines with leakage type B (%)	No. of machines with leakage with type B**	Cost to fix leakage type B ($)	Total costs to fix A&B ($)
NITC	NITC	2	300	90	270	1755	10	30	1773	3528
Maintenance	Roll	9	2	90	2	12	10	0	12	24
	Outsole		350	60	210	1365	40	140	8274	9639
	Phylon		171	90	154	1000	10	17	1011	2011
	CMP		49	90	44	287	10	5	290	576
Vinatech	PU	7	37	90	33	216	10	4	219	435
NOS C	NOS A	4	76	90	68	445	10	8	449	894
	NOS B		50	90	45	293	10	5	296	588
	NOS C		65	90	59	380	10	7	384	764
	NOS D		65	90	59	380	10	7	384	764
Stitching	Stitching1	1	800	90	720	4680	10	80	4728	9408
	TPU		27	90	24	158	10	3	160	318
Assembly	Assembly	6	270	90	243	1580	10	27	1596	3175
	Stockfit		117	90	105	684	10	12	691	1376
NOS E	NOS E	3	104	90	94	608	10	10	615	1223
	NOS F		92	90	83	538	10	9	544	1082
NOS H	NOS G	6	73	90	66	427	10	7	431	858
	NOS H		168	90	151	983	10	17	993	1976
	NOS I		81	90	73	474	10	8	479	953
	NOS J		85	90	77	497	10	9	502	1000
	IP		66	90	59	386	10	7	390	776
									Total	41,367

Note *,**: leak type B refers leakage at cylinders only. Leak type A includes all other leakages in a machine.

Table 7
Capital investment costs and savings for relocating and setting up new air compressors in John316.

Business as usual				Investment						After the program			Savings		
Dept.	Capacity (kW)	Work shift	Electricity use (kWh/yr)	Relocation department	Capacity (kW)	Equipment costs (USD)	Material costs (USD)	Labor & other costs (USD)	Total cost (USD)	Capacity (kW)	Work shifts	Electricity use (kWh/yr)	Electricity saving (kWh)	Cost saving ($)	CO_2 cut (tons)
NITC	37.5	3	272,700	NITC	37.5					37.5	3	272,700	0	0	0
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
MAINT	37.5	3	272,700	MAINT	37.5			500	500	37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700	Phylon,CMP,Lamination & Embroidery	37.5	10,000	8000	2000	20,000	37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	1	113,625	159,075	8431	127
				Mold shop (Factory 3)	15	1500		500	2000	15	1	45,450	−45,450	−2409	−36
Vinatech	37.5	3	272,700	Vinatech	37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	37.5	0	0		37.5					37.5	0	0	0	0	0
	37.5	3	272,700	Mold shop (Factory 4)	37.5			500	500	37.5	1	113,625	159,075	8431	127
NOS C	37.5	2	181,800	NOSC	37.5					37.5	1	113,625	68,175	3613	55
	37.5	2	181,800		37.5					37.5	1	113,625	68,175	3613	55
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
	0		0	Lab & Printing room at NOS B	15	1500	1000	500	3000	37.5	1	113,625	−113,625	−6022	−91
Stitching	37.5	2	181,800	Stitching	37.5					37.5	2	181,800	0	0	0
NOS E	37.5	3	272,700	NOS E	37.5					37.5	1	113,625	159,075	8431	127
	37.5	3	272,700		37.5					37.5	1	113,625	159,075	8431	127
	37.5	3	272,700		37.5					37.5	1	113,625	159,075	8431	127

Table 7 (*continued*)

Business as usual				Investment						After the program			Savings		
Dept.	Capacity (kW)	Work shift	Electricity use (kWh/yr)	Relocation department	Capacity (kW)	Equipment costs (USD)	Material costs (USD)	Labor & other costs (USD)	Total cost (USD)	Capacity (kW)	Work shifts	Electricity use (kWh/yr)	Electricity saving (kWh)	Cost saving ($)	CO_2 cut (tons)
NOS H	37.5	1	113,625	NOS H	37.5					37.5	1	113,625	0	0	0
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
	37.5	3	272,700		37.5					37.5	1	113,625	159,075	8431	127
	37.5	3	272,700		37.5					37.5	1	113,625	159,075	8431	127
	37.5	3	272,700	IP	37.5	10,000	3000	2000	15,000	37.5	3	272,700	0	0	0
	37.5	3	272,700		37.5					37.5	3	272,700	0	0	0
	0		0	Printing room at NOS I	15	1500		500	2000	15	2	72,720	−72,720	−3854	−58
ASS	37.5	1	113,625	ASS	37.5					37.5	1	113,625	0	0	0
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
	37.5	1	113,625		37.5					37.5	1	113,625	0	0	0
S/P	37.5	0	0	S/P	37.5					37.5	0	0	0	0	0
S/P	37.5	0	0	S/P	37.5					37.5	0	0	0	0	0
Total	1500		8,067,375		1545	24,500	12,000	6500	43,000	1567.5		7,049,295	1,018,080	53,958	814
Working hours for 1, 2 and 3 shifts are:	10	16	24	Working days per annum are	303										

compressor systems to optimize the air system and prevent air leakages becomes very promising.

A cost-effectiveness analysis was undertaken on the basis of the collected data for eight air compressor systems. Internationally acknowledged methodologies were applied. Investing about USD 84,000 in the first year and USD 41,400 in each of the forthcoming years will optimize all the eight air compressor systems and prevent air leakages. These investments will help save USD 195,700 each year. The average payback period of the investment is less than six months.

In order to achieve the energy efficiency goals, it is recommended that an energy efficiency unit be established in the enterprise. The duties of the unit include the design, development and implement of the energy efficiency programs, and management of energy efficiency database. The unit should have its own unique responsibility: promoting energy efficiency in the enterprise.

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