Article

Analysis of Energy Use and Energy Savings: A Case Study of a Condiment Industry in India

Khan Rahmat Ullah ^{1,*}, Marudhappan Thirugnanasambandam ² , Rahman Saidur ^{3,4}, Kazi Akikur Rahman ⁵ and Md. Riaz Kayser ⁶

¹ School of Built Environment, Faculty of Arts, Design & Architecture, UNSW Sydney, Sydney, NSW 2052, Australia

² Department of Mechanical Engineering, Bannari Amman Institute of Technology, Tamil Nadu 638401, India; mtsambandam@gmail.com

³ Research Center for Nano-Materials and Energy Technology (RCNMET), School of Engineering and Technology, Sunway University, Bandar Sunway, Petaling Jaya 47500, Selangor Darul Ehsan, Malaysia; saidur@sunway.edu.my

⁴ Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University Putra Malaysia, Seri Kembangan, Serdang 43400, Selangor Darul Ehsan, Malaysia

⁵ Idaho National Laboratory, 1955 N Fremont Ave, Idaho Falls, ID 83415, USA; kaziakik@gmail.com

⁶ Solar Energy Technologies, Western Sydney University, Penrith, NSW 2751, Australia; mdriaz.kayser@inl.gov

* Correspondence: khan2020.unsw@gmail.com or k.ullah@unsw.edu.au; Tel.: +61-(41)-6308347

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Abstract: Electric motors and boilers lead the industrial components which consume the largest portion of energy in an industry. This study explores the energy audit data of the condiment industry in India. The study mainly focuses on the estimation of the load factor, energy use, energy savings and annual bill savings with payback period of the electric motors of the plant. During the audit, it was found that there were several motors running under loaded conditions despite non-availability of variable speed drives installed in the plant. Therefore, variable speed drives are recommended to be installed to save energy by reducing the motors speed by up to 60%. According to the estimation, about 276 MWh, 551 MWh and 827 MWh electrical energy can be saved for 20%, 40% and 60% speed reduction of the motors using variable speed drives, respectively, where in most of the cases the payback period remains below 1 year. Furthermore, some suggestions are made to improve the poor power factor of running motors by using capacitor banks to save the reactive power. Besides, an estimation of energy saving is performed with a 2-ton capacity boiler. Since, there was no heat recovery system in the boiler; an air-preheater is suggested to be installed at the end of flue gas exhausting path of the boiler with the purpose of saving 68 tons of fuel per annum and having a payback period of 12 months. Moreover, a digital monitoring system, namely, “The Smart Joules” has been proposed to be installed in the plant aiming at saving about 3–5% of total energy per annum and having a payback period of 19 months. Finally, a summarization is made concluding in the fact that about 90 MWh energy and 95 tons of fuel can be saved (excluding motor energy savings) per annum by implementing proposed measures with a payback period of 15 months.

Keywords: condiment industry; energy audit; energy savings; motors; boilers

1. Introduction

The efficient use of energy with the current phenomenon of the limitations of its resources and the negative impact on environment is considered as one of the most burning issues of the current world [1]. Due to economic and technological advancement, most developing countries have been diverging from agriculture towards urbanization as well as industrialization for last few decades. This economic advancement is vastly dependent on the amount of energy consumed by a country. Insufficient energy supply is the main barrier to the economic growth for a developing country. Besides, the demand for industrial energy is growing by about 5% each year [2]. Therefore, the concept of “rational use of energy”

has been raised to reduce and optimize energy use and its limited resources, especially in industrial sectors where the rate of energy consumption is higher than any other sectors of a country [3,4].

Energy auditing is one of the most effective approaches to investigate the running energy consumption situation that leads to saving possible energy usage by means of suitable measures of an energy sector. There are several studies performed concerning energy use and energy savings considering building energy application and effects of the management structure of energy administrators on the achievement of energy efficiency [5,6], impact of non-financial factors [7], flexible measures of industrial energy systems [8], primary energy use and emissions throughout the life cycle [9], energy demand in residential sectors [10,11], energy performance of specific buildings [12,13] and multiple buildings or plants [14–16] and the effects of energy audit and energy policy on energy efficiency in industrial sectors [1–18]. For example, focusing on the energy consumption of an education institute in Rabigh City, Saudi Arabia, an energy audit was done by Sait [19]. The audit concluded that electrical energy consumption can be reduced by up to 35.3%. A detailed energy audit on small and medium scale industries in Indonesia was performed by Priambodo and Kumar [20]. They mainly focused on energy use and the respective carbon dioxide emissions of the industries, especially in textile, fabricated metals, chemicals and food industries. The following references [3,21–24], include some related audits tackling the three factors of energy use, savings, carbon dioxide emissions and their economic and environment impacts.

It is known that a large portion of primary energy is consumed by the industrial sector in India [25]. Consequently, electrical energy demand has been increasing by about 6.13% every year during the last decade [26]. For example, in the year 2006/2007, about 44.8% of total energy was consumed by the industrial sector in India [27]. Besides, a study has been done by the International Energy Agency (IEA) which indicated that this amount of consumed energy could be more than double by 2030 [28]. Along with other industries in India, the condiment sector is one of the promising industries to meet world demand. India leads the world with regards to producing condiments. About 70% of global spice is produced by India [29]. Therefore, there are a many spice factories spread out all over the country, where the electric motor is the main appliance along with boilers, water pumps and some other appliances. The motors consume a considerable proportion of the total energy of a nation. Table 1 shows the energy consumptions by motors for a few select countries of the world [30].

Table 1. Motor energy usage around the world [30].

Country	Motor Energy Usage (%)
Australia	30
Brazil	49
Canada	80
China	60
EU	65
India	70
Jordan	31
Korea	40
Malaysia	48
Slovenia	52
South Africa	60
Turkey	65
UK	50
US	75

From Table 1, we can see that the motors and their related driven systems consume major portions of the energy in an industry. Therefore, it has become a necessity to consider and analyze the cost of energy and possible savings to drive the system cost-effectively.

There are many studies done all over the world considering the energy use and energy savings in industries. For example, Christoffersen et al. [31] surveyed about 304 firms to analyze the energy management in Danish industry and proposed possible variations to improve the energy management of the concerned industries. Ozturk [32] conducted a survey on the energy consumption, energy cost and the relationship between the energy usage and textile production in the Turkish textile industry. The study focused on the effect of population growth, rapid urbanization and industrial development on energy consumption and management. Saidur et al. [33] studied the energy and emission analysis for industrial motors in Malaysia. The industrial sector consumes a massive portion of primary energy in Malaysia, where electric motors account for the largest portion of total energy used by the industrial appliances. Their study revealed that up to 3605 MWh of electrical energy could be saved by utilizing energy-efficient motors. Bala Subramanya [34] studied brick enterprises to correlate the labor productivity, energy intensity and economic performance of small enterprises in India. Besides, having a gradual economic growth in India, energy efficiency along with energy savings has become one of the major concerns of this country. A prevalent study on energy use and savings of electric motors was done by Saidur [35]. Nadel et al. [36] performed a detailed study on energy savings, policy and related technology on electric motors. An optimization along with energy audit was done by Loganthurai et al. [37] in the granite industry. The study mainly focused on the algorithm for the optimum scheduling of various machines to reduce the demand. Besides, there are many studies to save motors' energy consumption by using variable speed drives (VSDs) and capacitor banks for power factor improvement along with regular maintenance and monitoring [33,35,36]. Besides, de Almeida et al. [38] discussed several characteristics and potentials along with the barriers and policies towards using the energy-efficient motor systems in the industrial and services sectors in the European Union. Garcia et al. [39] made a comprehensive cost-benefit analysis considering various scenarios for industrial consumers' energy-efficiency standards for electric motors in Brazilian industry. Sola and Mota [40] proposed a multi-attribute decision model for portfolio selection aiming to replace technologies in industrial motor systems that lead to surpassing various organizational barriers.

Besides electric motors, boilers consume one a major part of energy in industry. In industry, boilers are used to produce steams which consume large quantities of fossil fuels. For example, primary metals, pulp and paper, food processing, petroleum refining and chemical extraction, consume fossil fuel of about 10%, 81%, 57%, 23% and 42%, respectively [41]. Hence, boiler energy use and savings have a huge effect on industrial application considering the economy and sustainability. To increase the boiler performance, maximizing heat transfer and minimizing heat losses is needed. To prevent heat losses in the boiler, special care should be taken regarding heat losses for hot flue gas, blow down losses and radiation losses [42]. About 10–30% of heat loss occurs during the flue-gas exhausting, which ranges between 150 and 250 °C [43]. Therefore, there is a huge possibility to save this energy from boilers by using advance technologies that leads to minimizing losses [44,45].

Considering land-area, population and gross-domestic-product, India, Pakistan and Bangladesh are considered the largest South Asian countries. Insufficient renewable energy policies along with inadequate energy control and management strategies are impeding achieving human development and economic sustainability [46]. Salam et al. [46] focused on the energy consumption of building sectors of some South Asian countries, where they critically analyzed the main performance indicators over a period of about 50 years to intensify the existing policies, and summarized the impacts on socio-economic development of the countries. Even though they discussed several renewable energy resources to support the energy demand in building sectors, the industrial energy consumption including policies is yet to be discussed. Sharma et al. [47] investigated the practice of energy audit in India. With the help of the Energy Conservation Act 2001, the central Government and Bureau of Energy Efficiency takes required initiatives to enhance energy-productivity in

every aspect of the economy. The study consisted of various national and international policies, standard tools and measures required for energy audit. They showed that HVAC and lighting systems might have decreased a significant amount of energy consumption for both commercial and non-commercial sectors. However, they reported that there is huge scarcity of apposite inspiration for companies to conduct energy audits as they are unaware of the advantages of it. The study mentioned that energy audits are not compulsory in India where improper economic feasibility analysis along with corresponding longer payback periods might have disinterested industries. Pandey and Prakash [48] conducted an energy audit in the pulp and paper industry in India. They estimated the electrical and thermal energy consumption of various electric pumps, boilers and lighting systems along with the reduction of CO₂ emissions, and figured out the corresponding energy saving opportunities with payback periods. The study showed that almost all suggested measures (repairment or replacement) have payback periods within 12 months, where the measures (high tension capacitor bank) required to improve the power factor yielded 30-month PBP. Their work revealed that up to 5.9% energy savings is possible, where general PBP is less than 2 years in general. However, the study would be more comprehensive and would include a smart monitoring and control system to increase the energy savings and enhance the sustainability of the plant.

From the above discussion it is obvious that, there are several attempts as well as activities performed worldwide for the energy audit, while it is not a frequent activity in developing countries like India, where the industrial energy sector is a promising sector to save a significant amount of national energy. The literature survey has documented some evidence of energy audit including perspective, policies, barriers, measures and tools; the real field energy audits are very much limited in industrial sector at India. Besides, the available studies have the abridgement discussion on adequate tools, measures and energy consumption appliances. According to the above discussion and authors' best of knowledge, there are very limited studies about motors' energy use, savings and load analysis, especially in a promising industry like condiment industry in India. This study intends to explore the energy audit data to estimate motors' energy consumptions, energy savings (using VSDs) with payback period and the required power factor improvement along with boilers' performance studies and corresponding energy savings with payback period using modern technology. Finally, an advanced system has been proposed to closely monitor processing in an effort to save energy towards achieving the economic and smooth operation of the plant. This study is expected to act as a footprint for the researchers and the industrial personnel of developing countries towards achieving future economic and sustainable industrial sectors.

2. Methodology

The methodology comprises the detailed energy audit with targeted manufacturing factory. The process includes the description of instruments used for data collection, the approaches and mathematical equations followed to estimate energy consumption and savings and the economic analysis with payback period. These are manifested as follows:

2.1. Targeted Manufacturing Factory

The targeted factory of this study is a subsidiary of Plant Lipids (P) Limited which is located in Kolenchery, east Cochin, India. The factory, namely, Lipids Condiment is one of the largest condiment producers in the world. It mainly produces chili powder, turmeric powder and processed pepper/powder. The average production of each product is shown in Table 2 below:

Table 2. List of products of the plant.

Product Name(s)	Amount (ton/Month)
Chili powder	112
Turmeric powder	390
Processed pepper	68

2.2. A Detailed Energy Audit

The audit team consisting of qualified and experienced electrical and mechanical engineers formally met with the appropriate plant personnel who are well versed with day-to-day operation as well as physical conditions of the various machines of the plant. The team was led by an expert who is a registered energy auditor with sufficient energy audit experience, where the reliability of data collection has been ensured. The total procedures followed by the audit team during audit of the plant are listed below:

- At first, the members of the audit team with their target were introduced to the manager/maintenance engineer of the plant through a kick-off meeting. A review was then made by the plant manager on the manufacturing process and energy consuming machines with operation and maintenance records to give an overall idea for the audit team.
- After the meeting, the audit team was guided by the maintenance engineer to visit the manufacturing machines in order to observe the locations, several opportunities and the accessibility of measuring points. The representatives of respective equipment operators accompanied the audit team to describe the equipment precisely.
- The operating manual of the energy consuming equipment was reviewed by the audit team to obtain specifications and operating parameters.
- Before using the instruments, they were verified for calibration status by the facility manager and were counter checked with the online instruments installed in the facility to assure the accuracy of the data measurement.

The list of the equipment used for data collection is specified in Table 3 below:

Table 3. List of the equipment and their specifications used in the audit.

Serial No.	Instruments Name	Manufacturer and Model	Measuring Range and Specifications	Purpose
1	Weatherproof multifunction clamp on ultrasonic flow meter (liquid flow only)	EESIFLO International PORTALOK 7S	ACCESSORIES: Flow meter probe Range: -30 to 100 °C Model no.: P5I7 24695, U211 Made by: SKINTOP Accuracy: $\pm 1\%$ Linearity: 0.5% Repeatability: 0.2% ACCESSORIES: 1. Current probe Range: 1/10/100 A: 10/100/100 A: 300/3000 A	Water flow measurement through pipes
2	3 phase power and harmonics analyzer	EXTECH INSTRUMENTS 382095	Model: 382097 Accuracy: $\pm 2\%$ 2. Voltage probe Made by: Chising, Model: TL88-4 Range: 600 V Accuracy: $\pm 2\%$	Electrical parameters measurement
3	Flexible CT probe	EXTECH INSTRUMENTS 382098	0 to 3000 A	Power analyzer
4	Combustion analyzer	KANE International Ltd. KANE 900 plus	Standard probe	CO ₂ , O ₂ and excess air in flue gas measurement
5	IR thermometer with wireless interface	EXTECH INSTRUMENTS 42560	ACCESSORIES: 1. Temp. probe (-30 to 300 °C) 2. Transmitter Base: Sl.no.:10079526 Accuracy: $\pm 1\%$ of reading + 20 F/ 10 °C Laser point: -50 to 1050 °C K-Type range: -50 to 1370 °C	Surface temperature measurement

2.3. Energy Audit Data

The team followed a random and compatible sampling method to collect data. For getting practically acceptable results, the basic engineering skills as well as personal experience were followed to analyze the recorded data. The measured data are primary and accurate with no obscurity. Since, the data were accurate within practically acceptable error; there is no need of any statistical tool for this case.

During the audit process, the number of equipment on the production floor was counted by the audit team. The team also noted the rated powers and operating hours (per working day) of the equipment from their technical specifications. The audit team also noted the total working days per annum by consulting with the person responsible for the production process.

Power rating and total operating time of the energy consuming machineries including power factor are the most important data which were collected during the audit. Portable power meters were used to measure the actual operating data for power consumption and power factors of the machines. Furthermore, the data were analyzed to discover the energy consumption and load factors for the electric motors used in this plant. In order to save energy for motors, the VSDs were applied by taking into account the calculated load factors.

Since, the data were taken as “Business As Usual” without making any changes in the operating situation, the data collection process by means of a meter (such as power meter, electric pliers) or experimental investigation would be the best. This may help auditors to make practically implementable and economically viable recommendations to reduce energy consumption.

Major Areas of Energy Consumption

As an energy resource, biomass briquettes are used for steam production and electricity generation to run utility systems and process machineries. The annual briquette consumption is about 1080 ton. The major portion of electricity was used in chili cleaning and grinding, which was about 34% followed by air compressors, approximately 15%. Among all the loads, the air compressor runs continuously for 24 h and consumes more electricity. The average monthly electricity consumption is 337.82 MWh based on the financial year 2013–2014. The electricity usage is shown in Figure 1.

Figure 1. Electrical load sharing of the plant.

The running electrical loads measured at each division of the plant are presented in Table 4.

Table 4. Running loads in the plant as measured during the audit.

Sl. No	Location	kWa
Process Machines		
1	Chili (Sonex) Grinding Mill sub total	23.63
2	Chili Crushing Line sub total	11.36
3	Chili Cleaning and Crushing-Axtel Line	31.28
4	Pepper Cleaning and Drying	17.05
5	Teacraft (pepper dryer)	17.27
6	Pepper milling -roller mill-1	11.18
7	Turmeric mill	24.92
8	ETO sterilizer plant	4.15
	Sub-Total	140.84
Utility		
1	Boiler	4.32
2	Air compressor	29.33
3	Vapor Absorption Machine (VAM)	4.61
4	Workshop load	2.30
5	Lighting	11.32
	Sub-Total	51.88
	Gross Total	192.72

2.4. Mathematical Formulation

To estimate different parameters such as load factors, energy consumption, energy saving, capacitors rating and payback periods (PBPs) some mathematical formulas are required which are presented within these subsections as follows:

2.4.1. Load Factor

The load factor of the motor can be calculated as [30]:

$$L = \frac{kW_a}{kW_r} \quad (1)$$

where, kW_a and kW_r denote actual capacity and rated capacity of an electric motor, respectively.

2.4.2. Estimation of Energy Use

The annual electrical energy used by the motors can be determined by the following Equation [30]:

$$AEU = n \times P \times L \times hr \quad (2)$$

where, n , P , L and hr represent number of motors, motor rated power (kW), load factor (percentage of full load) (%) and annual operating hours, respectively.

2.4.3. Estimation of Motor Energy Saving by Using VSDs

The annual energy savings of motors when VSDs are installed can be calculated as [30]:

$$AES = n \times P \times L \times hr \times S_{SR} \quad (3)$$

where, S_{SR} is the energy savings associated certain percentage of speed reduction (%).

If, the standard efficient motors are replaced by high energy efficient motors, then the annual energy savings can be determined by [49]:

$$AES = hp \times 0.746 \times L \times hr \times \left(\frac{1}{E_{std}} - \frac{1}{E_{ee}} \right) \times 100 \quad (4)$$

where, h , E_{std} and E_{ee} denote motor rated horsepower, standard motor efficiency rating (%) and energy efficient motor efficiency rating (%), respectively.

2.4.4. Estimation of Boiler Energy Savings

The heat recovered from the flue gas of the boiler can be utilized to preheat the feed water of the boiler. The heat recovery can be estimated by the following equation:

$$Q_f = m_{fg} \times c_p \times \Delta T_{fg} \quad (5)$$

where, m_{fg} , c_p and ΔT_{fg} denote the mass flow-rate, specific heat and temperature drop of the flue gases.

The efficiency of the boiler can be calculated directly by using the equation below:

$$\text{Boiler Efficiency} = \frac{\text{Enthalpy in Steam}}{\text{Enthalpy provided by fuel}} = \frac{Q(H - h)}{q * GCV} \times 100\% \quad (6)$$

where Q , H , h and GCV represent the quantity of steam generated (kg/h), enthalpy of steam (Kcal/kg), enthalpy of water (kcal/kg) and gross calorific value of the fuel, respectively. The flue gas energy analysis has been done with help of the properties of natural gas taken from the literature [36]. The costs of natural gas and oxygen trim system were considered USD 2/GJ and USD 32,000, respectively [49].

2.4.5. Economic Analysis

The annual bill savings (ABS) of motors associated with the above energy savings can be determined by:

$$ABS = AES \times C \quad (7)$$

where, C is the average energy cost (USD/kWh). Considering the VSDs are installed, the savings can be calculated as:

$$ABS_{(VSD)} = AES_{VSD} \times C \quad (8)$$

2.4.6. Payback Period

The payback period can be determined by the following equation:

$$PBP(\text{year}) = \frac{IC_{VSD}}{ABS_{VSD}} \quad (9)$$

where, IC is the incremental cost of electric motors when using VSDs has been considered as USD 80/kW based on industrial practice in India.

2.4.7. Estimation of a Capacitor Rating

It is important to determine the capacitor rating to improve the power factor. The required capacitor rating can be evaluated by the following equation:

$$CRR = P \times (\tan \phi_1 - \tan \phi_2) \quad (10)$$

where, P denotes the motor rated power (kW). Besides, ϕ_1 and ϕ_2 are the existing angle and targeted angle between the real power and apparent power, respectively.

3. Data, Result Analysis and Discussion

The various utilities employed in the units are:

- Electricity
- Compressed air
- Specific energy consumption
- Boiler

- Chilled water
- Motor
- Hot air system

3.1. Electricity

The demand for electricity of the unit is met by Kerala State Electricity Board (KSEB) grid supply and the power was drawn from 11/440 HT line with a contracted demand of 380 KVA. Considering three zones of the plant, the electrical bill analysis is shown in Table 5.

It was observed from the bill analysis (Table 5) that the average per-unit energy cost is about USD 0.091 and the average electrical power consumption per month is about 85.36 MWh. The grid power factor is maintained above 0.95 and at an average of 0.98. The zone-wise electricity consumption is shown in Figure 2.

Peak-hour electricity consumption is about 15%, which is very much on the lower side. However, the normal hour's consumption is about 51% which looks slightly on higher side. The instantly recorded power (kW), power factor (pf) and current (A) are shown in Figure 3.

During the audit it was observed that one 5 kVAR capacitor was not functioning and the automatic power factor controller was in the mode requesting it to be replaced immediately. A study on the conditions of the capacitors installed in the Automatic Power Factor Correction (APFC) panel showed that one 5 kVAR capacitor was completely derated. There is no log sheet maintained to check the capacitor on a regular basis. Therefore, it is recommended to maintain a log sheet as shown in Table 6 to check the condition of the capacitors at regular intervals at least once a day.

Table 5. Electrical bill analysis.

Bill Date	Recorded Demand (kVA)	Recorded Pf	Energy Consumption (kWh)			Total (kWh)	Total Cost (USD)	USD/kWh
			Zone 1	Zone 2	Zone 3			
03-04-2014	264.05	0.98	49,790	16,030	31,010	96,830	7135.11	0.074
04-03-2014	267.42	0.98	47,370	15,750	30,670	93,790	8470.97	0.090
04-02-2014	273.22	0.98	52,335	17,780	34,875	104,990	9312.04	0.089
07-01-2014	270.41	0.98	51,565	17,225	28,865	97,655	8867.79	0.091
05-12-2013	266.53	0.99	49,805	15,130	30,010	94,945	8547.35	0.090
05-11-2013	271.31	0.99	40,615	14,105	26,175	80,895	7521.63	0.093
04-10-2013	272.95	0.99	40,850	13,435	24,860	79,145	7374.44	0.093
03-09-2013	267.04	0.99	44,655	15,810	29,830	90,295	8208.29	0.091
05-08-2013	261.81	0.99	38,505	12,355	25,325	76,185	7104.03	0.093
04-07-2013	260.87	0.99	34,115	5705	23,135	62,955	5906.76	0.094
04-06-2013	256.46	0.99	39,000	3460	28,630	71,090	7007.64	0.099
04-05-2013	271.95	0.97	37,470	13,625	24,430	75,525	7233.53	0.096
Average	267.00	0.985	-	-	-	-	-	0.091
Total	-	-	526,075	160,410	337,815	1,024,300	92,689.57	-

Table 6. Proposed log sheet for capacitor checking and maintenance.

Date	Location	Rating (kVAR)	A Rating/Ph.	A (Actual)			% Derating	Remark (s)
				R	Y	B		
-	AFC Panel	5	6.65	0	0	0	100	Replace the Capacitor

Figure 2. Electricity consumption in each zone.

Figure 3. Recorded instant power, power factor and current.

3.2. Compressed Air

The unit consists of one screw type air compressor manufactured by Atlas Copco with an FAD 150 cfm and 30 kW capacity. One more reciprocating compressor with a capacity of 15 kW with 80 cfm free air delivery (FAD) was also available but used as a spare. Each

compressor has separate receivers attached with a capacity of 0.5 m³. The screw compressor runs for 24 h. and the operating pressure band is 7.9–8.9 bar. Compressed air was used in operating pneumatic valves and for cleaning purpose. Air lines are of galvanized iron (GI) pipes and run throughout the plant at an elevated location. A refrigerated air dryer was installed in each dryer.

3.3. Specific Energy Consumption

The specific energy consumptions estimated for the manufacture of various spice products are presented in the Table 7.

From Table 7, it is seen that the chili cleaning and crushing process has the highest energy intensity of 230 kWh/ton followed by the turmeric mill having an energy consumption of 227.84 kWh/ton.

Table 7. Specific energy consumptions.

Plant	Power (kW)	Run (h)	Energy Consumption (kWh)	Production (kg)	kWh/kg	kWh/ton
Sonex Grinding Mill, chili	26.63	16	426.08	4375	0.10	97.39
Chili Cleaning and Crushing-Axtel Line	31.28	16	500.48	2176	0.23	230.00
Teacraft- Processed Pepper	17.27	24	414.48	3870	0.11	107.10
Pepper Milling -Roller Mill-1	17.18	16	274.88	2676	0.10	102.72
Turmeric Mill	24.92	16	398.72	1750	0.23	227.84

3.4. Steam Generation and Boiler Performance Study

The unit uses saturated steam at 9 bar mainly for sterilization, VAM and hot air generation for pepper drying. Steam is generated using a shell and tube industrial boiler of capacity 2 ton/h. There is another 1 ton/h capacity boiler installed as a stand-by. At the time of audit, a 2-ton boiler was in operation. The average fuel usage per hour was about 125 kg. The average steam generation was 437.5 kg/h. The average calorific value of the fuel was 4200 (G) kcal/kg. Boiler operation details are given in Table 8.

Table 8. Boiler operation details.

Parameter	Unit	Value
Year of manufacture		1999
Type		Shell and tube
Type of fuel		briquettes
Evaporation capacity	MT/h	2
Steam pressure	bar	9
Steam condition	-	dry
Heat transfer area	m ²	Not available
Feed water temperature	°C	28
Flue gas temperature	°C	260
Condensate return temperature	°C	75
Is there any waste heat recovery installed		No
Type of draft		Induced
Feed water TDS	ppm	300

The boiler was operated for 24 h a day as well as blow down was done three times a day and the boiler is under AMC with the manufacturer. The condensate return was not used as feed water and instead it was collected in a tank and kept unutilized.

A detailed study on the 2-ton boiler was made. The observed data are presented in Table 9.

The instant performance study shows that the boiler was operated at load of less than 25%. The boiler can be efficient from an economic perspective if it is operated at least at

more than 60% of its rated capacity. The excess air is estimated at 27% based on the flue gas analysis.

Table 9. Boiler performance study.

Parameter	Unit	Value	Recommended Value
Boiler type		Shell and tube, Two-pass Thermax	
Made by			
Rated capacity	ton/h	2	
Steam generation	ton/h	440	
Boiler loading	%	22	
Steam pressure	bar	9	
Steam condition	-	Dry saturated	
Steam enthalpy	Kcal/kg	670	
Feed water temperature	°C	28	>80
Feed water enthalpy	Kcal/kg	28	
Flue gas temperature	°C	260	180
Fuel type		Briquette	
Fuel consumption	kg/h	125	
GCV	Kcal/kg	4200	
Feed water TDS	ppm	300	3000
O ₂ % in the flue gas	%	4.5	8
Excess air	%	27	<30
Stoichiometric air required	kg/kg of fuel	11	
Energy recovered through air preheater	kg/h	Nil	Proposed to install
Thermal efficiency based on direct method	%	56.14	
Condensate recovery		Nil	
Air preheating		Nil	

3.4.1. Condensate Recovery

At present the plant collects the condensate from the plant and is stored in a tank and not used as boiler feed water. The heat recovery and the efficiency of the boiler were calculated using Equations (5) and (6), respectively. The measured parameters on condensate, fuel and cost saving potential are presented in Table 10.

Table 10. Energy saving opportunity in boiler through condensate recovery.

Parameter	Unit	Value
Condensate temperature	°C	75
Quantity collected	Lit/shift	1990
Heat in condensate	Kcal	149,250
Calorific value of fuel	Kcal/kg	4200
Fuel equivalent (utilized)	kg/shift	35.53
Boiler efficiency	%	56.14
Fuel equivalent input	kg/shift	63
Operation duration/shift	h	8
Number of shifts in a day	-	3
Fuel saved per day	kg	189
Annual fuel saving for 360 days	ton	68
Cost of fuel	USD/ton	73.17
Annual cost saving	USD	4975.61
Water recycled	kL/annum	716
Cost of water	USD/kL	1.30
Annual cost saving due to water recycling	USD	931.38
Total cost saving (fuel + water)	USD	5907
Approximate investment for installing additional collection tank, pump and piping to take the condensate to feed water tank	USD	5691.06
PBP	Months	12

By implementing these measures, the plant can reduce the boiler operational cost by approximately USD 5853.66 per annum. The water saving would be 78 kL and fuel saving would be 68 ton per annum.

3.4.2. Improving the Load on Boiler

Steam generation in boiler at present of study was only 22% of its capacity. The plant uses a 2-ton boiler to generate steam at an average of 440 kg/h keeping the 1-ton boiler as a stand by. The under loading of the boiler causes energy loss and it was observed that during the sudden requirement of steam, the feeding of fuel in the 1-ton boiler becomes laborious and cannot meet the requirement. Therefore, it was suggested to install a semi-automatic fuel feeding system to cope with the problem of fuel feeding (see Figure 4).

Figure 4. The current situation and suggestion for boiler performance improvement.

Optimum boiler efficiency occurs at 65–85% of full load. As the steam demand falls, so does the value of the mass flow rate of the flue gases through the tubes. This reduction in flow rate for the available heat transfer area helps to reduce the exit flue gas temperature by a small amount, reducing the sensible heat loss. However, at below 50% load, most combustion appliances need more excess air to burn the fuel completely and this would increase the sensible heat loss. Operation of a boiler at low loading should be avoided. It is practically impossible to estimate the quantum of fuel saved by increasing the boiler loading; however, there will be significant reduction in the fuel requirement by increasing the load on boiler.

By referencing the graph above (Figure 5) it is clear that boiler should not be operated at less than 25% loading and the maximum boiler efficiency occurs at a load of nearly 50%. Optimum efficiency occurs where the efficiency curve meets the exit gas temperature curve. In the present case, the loading was 22% and the corresponding boiler combustion efficiency falls below 90%. By improving the load to nearly 50% by using the 1-ton boiler, the efficiency could be improved by 1%. The present fuel consumption at 90% efficiency was 125 kg/h and if the efficiency were improved by 1% the new fuel consumption would be around 123 kg/h. Thus, the annual fuel saving would be approximately 17 ton of briquettes. The corresponding cost saving would be USD 1243.90. The investment required for installing a semi-automatic fuel feeding system would be approximately USD 3252.03. The PBP for the investment would be 31 months.

Figure 5. Performance curve of packaged boiler.

3.5. Compressed Air System Performance

The performance study was conducted on air compressors and the outcome of the capacity test is presented in Table 11.

Table 11. Capacity assessment test on air compressors.

Type	Power (HP)	Rated cfm	Running h	Actual cfm	Generation Efficiency (%)	Operating Power (kW)	Actual Power (kW)	Internal Leakage cfm
Screw Type	50	150	24	145	96	9	29.33	10
Reciprocating	20	80	Stand by	56	69	8	14	24

It was observed (see Figure 6) from the test that the screw compressor works at 96% generation efficiency and reciprocating compressor works at 69% generation efficiency. However, the leakage was arrested immediately by calling the maintenance contractor as shown in the picture below.

Figure 6. Leakage valve maintenance during audit.

Detailed analysis of arresting compressed air leakage is presented along with potential cost saving in Table 12.

Table 12. Air compressor performance analysis.

Parameter	Unit	Value	Recommended
Type	-	Screw	
Make	-	Atlas Copco	
No. of compressor	-	1	
Type of loading	-	Intermittent	
Application	-	Pneumatic valve and cleaning	
Set pressure (max)	bar	8.9	
Set pressure (min)	bar	7.9	
Rated power	kW	30	
Rated FAD	cfm	150	
Running load	kW	29.33	
Loading on compressor	%	97.76	
FAD actual	cfm	145	@ > 95% generation
Specific power consumption	kW/cfm	0.20	
Leakage observed	cfm	10	@ 6% within generation point
Energy lost per day	kWh	48	
If leakage is arrested cost saving would be per day	USD	4.34	
Annual energy saving	MWh	17.28	
Annual cost saving	USD	1561	
Investment for leakage minimization	USD	813	
Payback	Months	6	

Together with the leakage, which was observed at the generating point, there were other opportunities to reduce the energy consumption as set out below:

- Conduction of a complete leakage test in the air lines,
- Replacing the existing GI pipes with friction free aluminum pipes to reduce pressure drop,
- Grouping of cleaning points and using a separate low-capacity compressor so that air leakages can be eliminated and the use of high-pressure air can be avoided as below,
- Replacing the unused valves in receivers and other areas to avoid leakages through defective valves as shown in the Figure 7 below.

Figure 7. The unused valve which needs to be replaced to avoid leakages.

Implementing the above measures, the air compressor operating pressure band could be reduced to 6–6.5 bar. If the pressure band is reduced, the power consumption goes down to 25 kW and thus saving 4 kW. Furthermore, the loading time will also get reduced. The expected saving per annum, assuming 70% loading hours per day, would be reduced to 68 kWh per day. The annual electricity saving for 360 days would be 24,480 kWh. Therefore, the corresponding cost saving would be approximately USD 2211.38 per annum. The major investment would be replacing the compressed-air pipes. Assuming a budget provision

of USD 4065.04 for the replacement of air pipes, the PBP for the investment would be approximately two years (23 months).

3.6. Motor Survey

A sample motor performance survey was conducted on various motors installed in the manufacturing machines and utility system. The measured electrical parameters for motors as well as in panels are presented in Table 13. The table contains various parameters of the electric motors such as rated power, actual power, power factor, load factor, energy use, energy saving using VSDs for three different percentages (20%, 40% and 60%) of speed reduction of the motors and their corresponding annual bill savings with payback periods. Some of these parameters were directly measured and the rest were calculated by using Equations (1)–(4) and Equations (7)–(10). It may be noted that there were no VSDs installed in the plant, therefore the suggestion was made to save energy using VSDs. It is evident from the table that the payback period decreases with the increase of percentage of speed reduction using VSDs and the payback periods for most of the motors are around 1 year.

It was also observed from the survey that most of the motors have good power factors. The motor running in the hammer mill has a low power factor (pf) because of its intermittent loading on the mill. Besides, in the case of panels, the motors used in the cooling water pump, cooling tower fan, workshop panel reading, roller A, roller B, boiler total panel, water pump and DM pump have lower power factors. To improve pf it is suggested to add capacitors in these panels to improve pf to 0.99, thus reducing cable losses by reducing the line current. The rating of capacitors to be added in these panels is listed in Table 14.

3.7. Study on Pepper Dryer Hot Air System

From the study on pepper dryer hot air system, the study observed the followings:

- (i). The peppers' hot air and cold air blower system consists of one steam heater with blower for hot air generation and two cold air blowers to supply cooling air to cool the dried pepper. It was observed during the audit that:
- (ii). Hot air blower and cold air blowers suction line was 80% choked.
- (iii). No significant air flow was measured in these blowers.
- (iv). Flow rate from dryer was measured of about 551 kg/.
- (v). Cooler surfaces were insulated.
- (vi). The steam temperature was measured of about 110 °C and the air temperature was measured of about 60 °C.
- (vii). In the cold air blower suction end the filter was completely choked and there was no significant air flow observed in the blower.
- (viii). The loads measured in each blower were:

Cold air blower-1	1.71 kW
Cold air blower-2	2.17 kW
Hot air blower	2.39 kW

Table 13. Load details with energy use, savings and corresponding payback periods on motors and panels.

Motor's Location	HP	kW _r	pf	kW _a	Load Factor, L (%)	AEU (MWh)	Annual Energy Savings, AES (MWh)			Annual Bill Savings, ABS (USD)			Payback Period, PBP (Months)		
							20%	40%	60%	20%	40%	60%	20%	40%	60%
Chili (Sonex) Grinding Mill															
Pulverizer-2	30	22.38	0.99	16.60	74.16	96.94	19.39	38.78	58.17	1727.93	3455.86	5183.79	12	6	4
Pulverizer Blower	7.5	5.60	0.99	4.07	72.79	23.77	4.75	9.51	14.26	423.66	847.31	1270.97	12	6	4
Chili Crushing Line															
Conveying Blower	15	11.19	0.98	6.75	60.30	39.42	7.88	15.77	23.65	702.62	1405.24	2107.87	15	7	5
Cyclon and R.A.L.V.	7.5	5.60	0.98	4.62	82.51	26.98	5.40	10.79	16.19	480.91	961.81	1442.72	11	5	4
Chili Cleaning and Crushing-Axtel Line															
Conveying Blower	25	18.65	0.98	16.38	87.84	95.66	19.13	38.26	57.40	1705.03	3410.06	5115.09	10	5	3
Hammer Mill	30	22.38	0.96	8.70	38.85	50.81	10.16	20.32	30.49	905.60	1811.20	2716.81	23	12	8
Blower	5	3.73	0.98	3.64	97.68	21.26	4.25	8.50	12.76	378.90	757.79	1136.69	9	5	3
Water Scrubbers ID Fan	5	3.73	0.99	3.40	91.15	19.86	3.97	7.94	11.91	353.91	707.83	1061.74	10	5	3
Pepper Cleaning and Drying															
Main Panel	31	23.13	0.85	17.05	73.75	149.36	29.87	59.74	89.61	2662.16	5324.31	7986.47	8	4	3
Tea craft (Pepper Dryer)															
Dust Collector	7.5	5.60	0.97	5.25	93.75	45.99	9.20	18.40	27.59	819.73	1639.45	2459.18	6	3	2
Hot Air Blower	7.5	5.60	0.97	2.39	42.66	20.94	4.19	8.37	12.56	373.17	746.34	1119.51	14	7	5
Vacuum Sucking Motor	7.5	5.60	0.84	4.75	84.84	41.61	8.32	16.64	24.97	741.66	1483.31	2224.97	7	3	2
Cold Air Blower -1	3	2.24	0.90	1.71	76.54	14.98	3	6	9	267.00	534.00	801.00	8	4	3
Cold Air Blower-2	3	2.24	0.94	2.17	97.06	19.01	3.80	7.60	11.41	338.82	677.64	1016.46	6	3	2
Pepper Milling -Roller Mill-1															
Roller A	10	7.46	0.69	3.41	45.74	19.91	3.98	7.97	11.95	354.95	709.91	1064.86	20	10	7
Roller B	10	7.46	0.74	3.62	48.53	21.14	4.23	8.46	12.68	376.81	753.63	1130.44	19	9	6
Blower	7.5	5.60	0.99	4.15	74.12	24.24	4.85	9.69	14.54	431.98	863.97	1295.95	12	6	4
Turmeric mill															
Pre-grinder	20	14.92	0.99	12.30	82.44	71.83	14.37	28.73	43.10	1280.33	2560.67	3841.00	11	5	4
Sonex Mill	50	37.3	0.94	12.62	33.83	73.70	14.74	29.48	44.22	1313.64	2627.29	3940.93	27	13	9
Eto Sterilizer Plant															
Water Pump	1	0.746	0.75	0.64	85.36	5.61	1.12	2.24	3.36	99.93	199.86	299.79	7	3	2
Vacuum Pump	5	3.73	0.86	3.52	94.27	30.84	6.17	12.33	18.50	549.61	1099.21	1648.82	6	3	2
Boiler															
Water pump	5	3.73	0.51	1.94	52.03	16.99	3.40	6.80	10.20	302.91	605.82	908.73	12	6	4
D M pump motor	1	0.746	0.72	0.43	58.23	3.77	0.75	1.51	2.26	67.14	134.28	201.42	10	5	3
Compressor															
Atlas Copco Compressor	40	30	0.91	29.33	97.76	256.93	51.39	102.77	154.16	4579.53	9159.07	13,738.6	6	3	2
LG Screw Compressor	20	14.92	0.90	9.28	62.20	81.29	16.26	32.52	48.78	1448.96	2897.93	4346.89	10	5	3
Chilling Plant															
Cooling water pump	5	3.73	0.65	2.27	60.74	19.89	3.98	7.95	11.93	354.43	708.87	1063.30	10	5	3
Cooling tower fan	5	3.73	0.51	2.34	62.83	20.50	4.10	8.20	12.30	365.36	730.73	1096.09	10	5	3

Table 14. Recommended rating of capacitors to improve pf in panels.

Sl. No	Location	Load (kW)	Pf (Old)	Pf (New)	Capacitor Power Rating, CPR (kVAr)	Suggested Rating (kVAr)
1	Cooling water pump	2.27	0.65	0.99	2.33	3
2	Cooling tower fan	2.34	0.51	0.99	3.61	4
3	Workshop panel reading	2.3	0.53	0.99	3.35	4
4	Roller A	3.41	0.69	0.99	3.09	4
5	Roller B	3.62	0.74	0.99	2.77	3
6	Boiler total panel	1.94	0.59	0.99	2.38	3
7	Water pump	1.94	0.51	0.99	3	3
8	D M pump motor	0.43	0.72	0.99	0.35	1

It was recommended to implement the following to improve the dryer performance and reduce the power consumption:

- Regular cleaning of steam heater coil and improve air flow.
- Removing the insulation from cooler surfaces.
- Isolating the dryer area from cooler area by providing partition strips.
- One cooler having the suction near steam trap fan can be removed.
- Cleaning the suction filter of the second cooler fan and improve air flow. This flow can be split and connected to the cooler.
- The steam heater was placed at the suction end of the hot air blower. It was recommended to place the steam heater on the delivery side of the steam heater.
- The higher velocity of air at delivery end of the blower will enhance the heat transfer rate and improve efficiency of heat utilization.
- At present, the blower handles hot air thus reducing flow rate due to hot gas. If the blower handles cold air, the specific energy consumption will decrease, and flow rate will increase (see Figure 8).

Figure 8. The current and proposed position of heat exchanger to increase the performance.

By rectifying the steam heat exchanger arrangement, the hot air temperature could be increased to 90 °C. There is a possibility to increase the drying speed and thus increase the production to 1000 kg/h from the dryer for the same energy consumption. With these measures implemented, one cold air blower would be sufficient to supply cold air and the other blower could be removed as shown in the Figure 9 below.

Figure 9. The suggestion to remove one blower for energy saving.

By removing one blower, the expected power reduction is 1.71 kW and the annual reduction in electricity consumption would be 14.77 MWh. The corresponding cost saving would be USD 1333.33. Investment for the proposed measure is very nominal and PBP will be immediate.

3.8. Cooling Tower Fan

An FRP cooling tower was installed in the plant to cool the condenser water coming from VAM. The fan is driven by a 5 HP motor and the power drawn was measured of about 2.73 kW. The fan maintains a single speed and runs 24 h a day. It was recommended to switch off the fan based on cooling water outlet temperature particularly during winter and rainy seasons. By installing a commercially available cooling tower fan energy saver, fan operation could be optimized and an energy saving of 10% per annum is possible. Thus, the fan energy consumption could be reduced by 2358 kWh per annum. The corresponding cost saving would be USD 211.38. The cost of the energy saver is approximately USD 122 and PBP for the investment is about 7 months.

3.9. Improving Monitoring and Control of Energy Consumption

Close monitoring and controlling of energy consumption help to benchmark and fix target energy consumption in various production activities as well as in utility systems. This leads to a conservative estimation of 3–5% energy saving per annum. To do that, the plant can install sub-meters with GPRS modem for remote measuring and monitoring of electricity consumption in the following panels:

- Main panel
- Turmeric plant
- Chili plant
- Pepper plant
- VAM
- Air compressors

The schematic diagram of the smart metering system is shown in the Figure 10 below:

The various electrical parameters from the above meters will be collected remotely to a central PC. The data will be analyzed by the new energy analysis software tool named “SMART JOULES” to provide an insight into the electrical energy consumption pattern. The tool has various features as follows:

- Hourly energy consumption in a graphical form with values.
- Profile/trend chart for pf and KVA.
- A comparative chart on hourly/monthly/yearly energy consumption along with cost.

- Prediction feature to estimate future demand.
- Mail alerts in case of nearing target values of energy consumption.
- Feature to enter production/fuel consumption/water consumption data manually.
- Generate report on specific energy/fuel/water consumption and energy saving potential in case of low power factor.

Figure 10. The proposed digital monitoring system using Smart Joules software.

The Smart Joules software can be integrated into the production monitoring software already installed in the plant.

The energy saving estimation using “The Smart Joules” software is presented in Table 15.

Table 15. Energy saving estimation by installing “Smart Joules”.

Parameters	Unit	Value
Present annual energy consumption	kWh	1,024,300
Cost of energy	USD	0.091
Estimated energy saving	%	3
Estimated annual energy saving in absolute value	kWh	30,729
Annual cost saving	USD	2764.23
Investment for “Smart Joules” for connecting 30 energy meters and one software license	USD	4471.55
Payback period	months	19

Smart energy meters with GPRS modem can be installed quickly and connected to the PC through the Internet. It avoids cabling and works maintenance-free forever.

3.10. Energy Conservation Options and Recommendations

The various energy conservation opportunities are listed with recommendations in Table 16.

Table 16. List of energy saving options with recommendations.

Area	Recommendations	Estimated Energy Saving (MWh/y)	Estimated Fuel Saving (Ton/y)	Estimated Cost Saving (USD)	Estimated Investment (USD)	Payback (Month)
Boiler Section	Condensate Recovery	-	78	5902.44	5691.06	12
	Installing fuel feeding system to improve the loading and efficiency of boiler	-	17	1243.90	3252.03	31
Air compressor	Arresting air leakage within compressor and receiver system	17.28	-	1560.98	813.01	6
	Revamping pipelines, grouping cleaning points and reduce pressure bad	24.48	-	2211.38	4065.04	24
Pepper dryer	Improve maintenance of suction side of cold air blowers and install steam heater at delivery section. Remove one cold air blower	14.77	-	1333.33	Nominal	Immediate
Cooling tower	Installing cooling tower fan energy saver	2.35	-	211.38	121.95	7
Energy Monitoring and Control	Installing smart metering system	30.73	-	2764.23	4471.55	19
Total		89.61	95	15,227.64	18,414.63	15

4. Conclusions

Using the energy audit acquires prominent value in the field of industry as it gives us a clear idea about recent energy consumption along with possible energy savings. The present study represents a detailed energy audit in a condiment plant in India. The audit consists of the energy use and possible energy savings of various electric motors along with two boilers installed in the plant. The major findings of this study are summarized below:

- The process of chili cleaning and grinding causes the highest energy consumption (about 34% of total energy) and highest energy intensity (230 kWh/ton) followed by air compressors, approximately 15%, and the turmeric mill, about 227.84 kWh/ton, respectively.
- The average electrical power consumption per month is about 85.36 MWh, where the grid power factor is maintained above 0.95 and at an average of 0.98.
- The nonfunctioning capacitor (5 kVAR) would be replaced by APFC panel to improve the power factor of the system.
- Energy savings from electric motors can be obtained by using VSDs to ensure maximum energy savings of about 827.10 MWh per annum with PBP below 1 year (in most cases) if the speed of the motors is reduced by about 60%.
- The measures considered for condensate recovery of the boilers leads to a reduction of the boiler operational cost by approximately USD 5853.66 per annum, where the water and fuel saving would be 78 kLand 68 ton per annum, respectively.
- The enhancement of boilers loading (from 22% to 50%) enables an annual fuel saving of approximately 17 ton of briquettes, where the PBP of the measures taken is found to be about 31 months.
- In the case of the panel, the motors used in the cooling water pump, cooling tower fan, workshop panel reading, roller A, roller B, boiler total panel, water pump and D M pump have lower power factors (between 0.51 and 0.74) which causes huge energy

losses. Therefore, capacitors of required ratings are suggested for all these motors to enhance the power factor by up to 0.99.

- (h) An air-preheater has been suggested to be installed at the output of the boiler to extract the heat from exhausting flue gas which is vastly suitable to preheat the input steam. This measure enables about 68 tons of fuel savings per annum with a PBP of 1 year.
- (i) A digital system using “The Smart Joules” software has been proposed to be installed in the plant which will monitor the whole energy system of the plant. This managed to save about 3–5% of total energy per annum with the PBP about one and half years.

Therefore, it can utterly be concluded that there are several areas including related tools and measures occupied in the industries, where prospective measures along with the upgradation as well as inclusion of new technologies offers enormous potentiality to minimize energy consumption by dispelling energy loss that leads towards economic and sustainable energy consumption by industrial sectors. Therefore, this study will help researchers and industrial personnel of developing countries towards achieving economic and sustainable industrial sector status in the future.

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Abbreviations

The following abbreviations are used in this manuscript:

ABS	Annual Bill Savings
AES	Annual Energy Savings
AEU	Annual Electrical Energy
APFC	Automatic Power Factor Correction
CRR	Capacitor Rating Required
FAD	Free Air Delivery
IEA	International Energy Agency
L	Load Factor
PBP	Payback Period
PF	Power Factor
Q_f	Heat Recovery
VAM	Vapor Absorption Machine
VSD	Variable speed drive

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