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Assessment of Detailed Energy Conservation Potentials: The Case of the Ethiopian Leather Industry

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ABSTRACT

One of the most crucial components in any industrial operation is energy. However, the supply is not limitless. One of the key ingredients in cement production is energy, whose cost share ranges from 8 to 15% of overall production costs in developed nations but is much more in undeveloped nations. Therefore, the objective of this extensive research was to carry out a thorough energy conservation audit at the Sheba leather factory, located in the city of Mekelle, in the north region of Ethiopia. The specific objective of this research was to analyse the patterns of power consumption, identify energy-saving techniques, as well as to propose energy-saving recommendations for their implementation. It was obtained using primary and secondary data from the industry personnel. As a result, a total of 19 recommendations for energy saving were found and were forwarded for consideration. These recommendations have the potential to save a total of about $ 29900 annually, but their implementation would cost close to $ 15900, with a payback period of seven months. These recommendations also cover the utilities of the boiler, motors, blower, air compressors, cooling tower, and lighting. In order to lower their energy use, economic benefits are also considered.

Keywords: Electrical energy, energy audit, energy savings, economics, leather, thermal energy

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INTRODUCTION

Cement production requires significant

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energy; the global cement industry is estimated to consume 2% of all primary energy used globally (Bhukya & Basak, 2014). Since becoming one of Africa's fastest-growing economies in recent years, Ethiopia has experienced a consistent increase in cement production. Next to the beverage and textile industry, leather is the second largest production in Ethiopia (Ramakrishna, 2014; Tesema & Worrell, 2015). Ethiopia is one of the Sub-Saharan African nations in the continent's eastern region. After Nigeria, Ethiopia has the second-highest population in Africa.

One of the people's primary needs is energy, which is the foundation of global progress and will continue to increase by at least one-third by 2035. Africa has seen enormous economic growth and increasing demand for energy (Fawkes et al., 2016; Gebreslassie et al., 2022). While this is happening, the instability in fuel costs has inspired development in African countries, particularly countries like Ethiopia, to concentrate on energy security and decrease their use of conventional fuels. Energy conservation is a fundamental first step in tackling the energy shortage and environmental degradation. Industrial energy audits aim to lower energy costs by lowering operating costs and raising profits. In Ethiopia, most garments and leather companies do not use energy conservation schemes, mainly because there are no measures in place to ensure that energy-efficiency measures are implemented (Al-Ghandoor et al., 2008; Benhelal et al., 2013; Önüt & Soner, 2007).

Therefore, many developing nations focus on increasing cost benefits by establishing energy efficiency in all process and production industries. In 2010, the United Nations Industrial Development Organization (UNIDO) employed sector-specific performance indicators to assess the energy efficiency potential of various industrial sub-sectors (Mulatu et al., 2018; Singh et al., 2023).

Any country's economic success depends on a number of key factors, including energy. Developing countries like Ethiopia have relatively little scientific data, especially in the major energy-consuming sectors like textile and leather factories, where there is a lack of clear data on the energy efficiency as well as power consumption patterns of the various factory processes. In addition, no research-based data can support further studies on the effective utilisation of both electrical and thermal energy as well as the implementation of renewable energy and waste to energy wherever possible. In view of the economic aspect, once we know or identify the amount of energy loss and where it has happened, it will help to show the decision makers to correct (to reduce the loss) or reuse it by finding another mechanism (Edenhofer et al., 2012; Tesema et al., 2015).

Therefore, the purpose of the existing study was to carry out a thorough, detailed energy audit and analyse the major energy-consuming processes of the Sheba leather industry in this pilot project. The factory is situated 45 kilometres away from Mekelle, the regional capital of Tigray, near the town of Wukro. The region is renowned for being the best source of hides and skins, particularly goatskin.

During the preliminary energy audit in the Sheba factory, the electrical and thermal energy consumption was around 33.14% and 66.86%, respectively, but the cost of thermal and electrical energy was recorded to be about 32.94% and 67.06%, respectively. Therefore, we advised a detailed energy audit to identify the source of the plant's energy issues.

SIGNIFICANT OF THE AUDIT PROCESS

In the audit process, the recommendations are proposed based on field measurement with achievable Energy Conservation (ENCON) proposals under no cost/low cost and cost investment categories. Moreover, the minimisation of present energy costs would be optimised by adjusting and optimising energy usage.

OBJECTIVES OF THE AUDIT

The main objective of this energy assessment was to assess the types of energy resources being extensively utilised, the technologies implemented, and the energy consumption with regard to the energy required by different factory utilisations to implement conservation measures. It has been achieved by:

a) Assessing the present pattern of energy consumption in each plant of the factory
b) Relating energy inputs and production output
c) Identifying potential areas of thermal and electrical energy economy
d) Minimising thermal energy wastages in major areas and optimising thermal energy distribution in end usage
e) Identifying immediate (especially no/low cost) improvements/savings
f) Identifying energy conservation opportunities and proposing possible applications of renewable energy sources

MATERIALS AND METHODS

Methodology

A comprehensive energy audit has been conducted in two stages in the Sheba leather factory: pre-audit phase I and detailed audit phase II. Physical measurement was used for most of the approaches in this investigation in the various processes of the factory (Da Cunha, 2007; IEA, 2020; Sony & Mekoth, 2018). The energy auditing was conducted at the key processes of Tannery Plant and Shoe Plant. In the detailed energy audit, the production process was evaluated through observations, interviews, and a register book of industry personnel and physical measurements of all major utilities using advanced instruments to analyse the energy utilisation of the entire industry.

Data Processing

The following expressions (Equation 1) were used to determine the energy measurements with respect to each utility, as shown below:

Boiler

The following expression can be used to compute the percentage of fuel savings when the boiler's operating pressure is reduced (Berry et al., 2006):

$$\left[\frac{\mathrm{h}_{9\text{ bar}} - \mathrm{h}_{7.5\text{ bar}}}{\mathrm{h}_{9\text{bar}}}\right] x100 \qquad (1)$$

where "h" is the enthalpy of the corresponding steam pressure

The following heat transfer formula (Equation 2) is used to calculate the amount of heat lost from the bare hot water pipeline:

$$hxAx\Delta T \qquad (2)$$

where h = Convection heat transfer coefficient (W/(m^2°C))

A = Surface area of the pipeline (m^2)

ΔT = Temperature difference (°C)

The thermodynamic relation (Equation 3) shown below can be used to calculate the waste heat recovery from the flue gas and the heat content in the hot water of the boiler (Equation 4) (Berry et al., 2006):

$$Q_{fg} = m_{air} x C p_{air} x \left(T_{hotair} - T_{ambair}\right) \qquad (3)$$

$$Q_{water} = m_w x C p_w x \left(T_{hw} - T_{cw}\right) \qquad (4)$$

Compressors

Equation 5 can be used to calculate anticipated power usage during bandwidth reduction.

$$\left[\frac{P2^{0.36}-1}{P1^{0.36}-1}\right] \qquad (5)$$

where P_2 and P_1 are cut off and cut in pressure, respectively

In compressed air systems, leaks are the primary source of energy loss. The following method was used during the leakage test, as stated below:

Step 1: The compressor was set up to work under the required operating pressure.

Step 2: All machine valves were shut off, and the required sections were permitted access to compressed air.

Step 3: The time spent loading and unloading compressed air during the flow was measured and registered.

Step 4: The work from step 3 was carried out 3multiple times to obtain average values for a precise output. The percentage of air leakage is estimated by Equation 6.

$$\text{\% of Air leakage quantity} = \left[\frac{load}{(load+Noload)}\right] x100 \qquad (6)$$

Motors, Fans & Blowers

Actual measurements of the voltage, current, and power factor for motors, fans, blowers, and compressors were taken using a power analyser. The Specification of the instruments used in the study is summarised in Table 1.

Economics Analysis

This study employed the simple payback period (SPP) method to analyse energy economics. SPP is a first approximation used in economic analysis to determine the time (in years) needed to recover the initial investment (First Cost), taking into account solely the net annual savings representing the returns on investment. Typically, the basic payback period is determined as follows (Equation 7):

$$Simplepaybackperiod = \frac{Firstcost}{Yearlybenefits - Yearlycosts} \qquad (7)$$

Table 1

Specification of the instruments

Instruments Name	Make	Range	Uncertainty
Infrared temperature measuring instrument	TESTO 830-T4	-30 to + 400°C Type K (NiCr-Ni)	± 0.5°C + 0.5% of m.v.
Light intensity measuring instrument	TESTO 540	0 to 99999 Lux	± 3 lux or ± 3% of m.v.
Digital pressure manometer	TESO 510i	-150 to 150 hPa	± 0.05 hPa
For non-contact and mechanical measurement	TESTO 470	+1 to +99999 rpm	± 0.02% of m.v.
Vane anemometer	TESTO 410i	0.4 to 30 m/s	± (0.2 m/s + 2% of m.v.)
Flue gas analyser	TESTO 300 O_2	0 to 21 vol.%	± 0.2 vol.%
	TESTO 300 CO	0 to 4,000 ppm	± 5% of m.v. (400 to 4,000 ppm)
	TESTO 300 NO_x	0 to 3,000 ppm	± 5% of m.v.(100 to 3,000 ppm)
	TESTO 300 CO_2	± 0.2 vol.%	0.1 vol.%
Power analyser	PCE-PA 8000 PF (power factor), kWh, KVAh, kVARH, PF	Voltage: 10–600 Current 0.2–1200	± 0.01% V ± 0.05% A

ENERGY PROFILE OF THE COMPANY

Energy Utilisation Status of the Sheba Industry

Each plant's thermal and electrical energy bills were compiled to assess the factory's present energy consumption status. Transformers with the 1250 kVA and 800 kVA capacity were connected to meet the Tannery plant's electrical load requirements. For the Shoe plant, the 800 kVA transformers were connected to meet the Shoe plant's electrical load requirements. The transformer details are summarised in Table 2.

Table 2
Technical details of transformers

No	Connected plant	Transformer Details (kVA)	Qty	Operation days/week	hrs/day	No. of days/yr	Total hrs/y
1	Tannery plant	1250 (rated voltage HV 15000V/48.11A, LV 400V/1804.2)	1	6	16	317	5075
		800 (rated voltage HV 15000V/30.79A, LV 400V/1154.7)	1	6	16	317	5075
2	Shoe plant	800 (rated voltage HV 15000V/30.79A, LV 400V/1154.7)	1	6	8	317	2535

From May 2019 to April 2020, the Sheba factory used 0.865 million kWh of electricity supplied by the Ethiopian Electricity Utility (EEU). The energy share pattern of the thermal and electricity is given in Table 3 and graphically illustrated in Figure 1. An overall power factor of 0.85 was maintained in the factory.

Table 3
Energy usage pattern

No	Energy Source	Type of Energy	Unit	Annual Consumption	Direct Energy Equivalent 10^6 MJ/y	% Share	
1	EEU	Electrical	kWh	865500	3.1	32.71	33.14
2	DG		kWh	11250	0.04	0.42	
3	Steam Boiler	Thermal (FO)	Lit	155991	6.3	66.48	66.86
4	DG	Thermal (Diesel)	Lit	890	0.036	0.38	

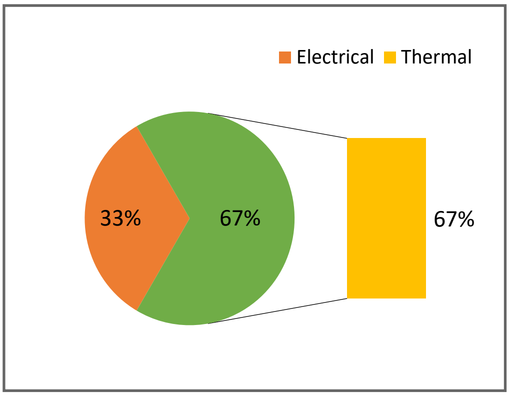

Figure 1. Graphical view of energy consumption pattern (MJ/Annum)

The expenditure incurred annually towards the above-cited energy usage is given in Table 4 and Figure 2. As illustrated in Figure 1, thermal energy is used for steam generation at around 6.3 x 10^3 MJ per annum, which is shared to 67% of total energy consumption. It indicates that thermal energy consumption is high for the dyeing section.

From (the EEU) electricity bill every month, it was noted that the Tannery Plant's power factor penalty and maximum demand penalty were around $ 315 and $ 72, respectively. Similar penalties for power factor and maximum demand for the shoe production plant were around $ 63 and $ 200, respectively. The increase in the unit cost may be due to an excess penalty in the power factor and maximum demand reached.

Table 4
Energy cost pattern

No	Energy Source	Type of Energy	Unit	Annual Consumption	Cost ($)	Total Cost Incurred ($/y)	% Share	
1	EEU	Electrical	kWh	865500	0.041	35485.5	32.51	32.94
2	DG		kWh	11250	0.041	461.25	0.43	
3	Steam Boiler	Thermal (Furnace oil)	Lit	155991	0.471	73471.76	66.64	67.06
4	DG	Thermal (Diesel)	Lit	890	0.528	469.92	0.43	

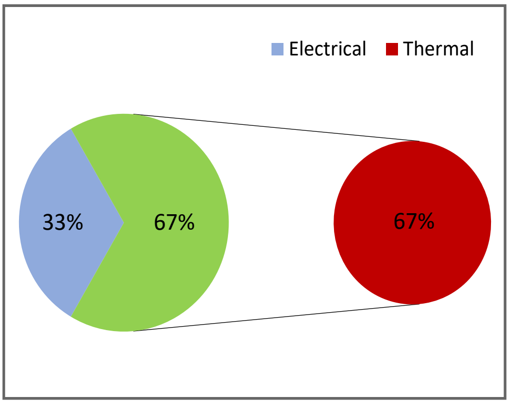

Figure 2. Graphical view of energy cost pattern ($/Annum)

Energy Consumption Distribution

The details of the electricity bill for May 2019 to April 2020 were obtained, and the variance in all parameters was reviewed month-wise. Figure 3 depicts the electricity consumption distribution pattern for the entire plant. The tannery plant consumed roughly 72%, while the shoe manufacturing factory consumed less, roughly 28%.

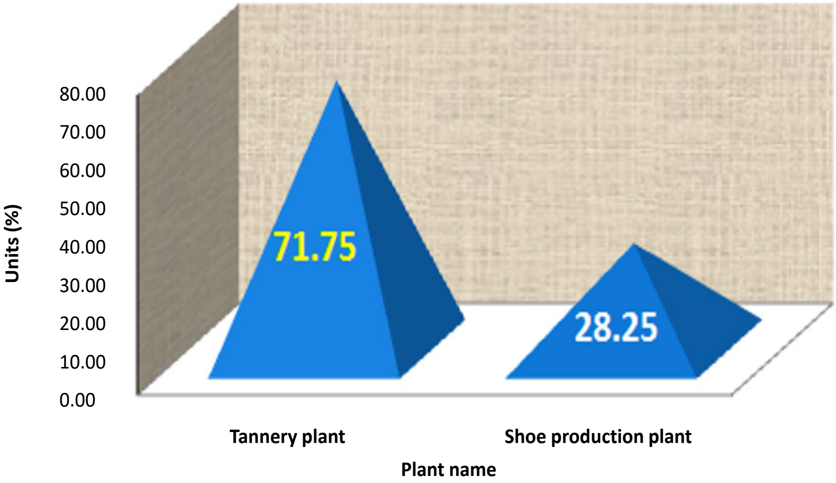

Figure 3. Electricity consumption distribution pattern for the entire plant

The monthly average specific energy consumption for the Tannery plant is shown in Figure 4. It is to be observed that the monthly average specific energy consumption was around 1.02 kWh per square foot of leather.

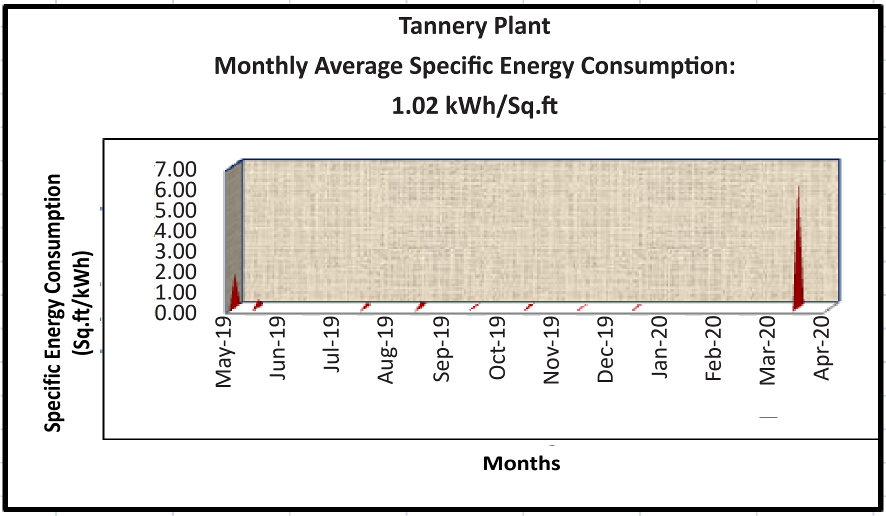

Figure 4. Specific energy consumption for the Tannery plant

The variation in unit cost between May 2019 and April 2020 is depicted in Figure 5. The average monthly unit cost for the Tannery plant was $ 0.04.

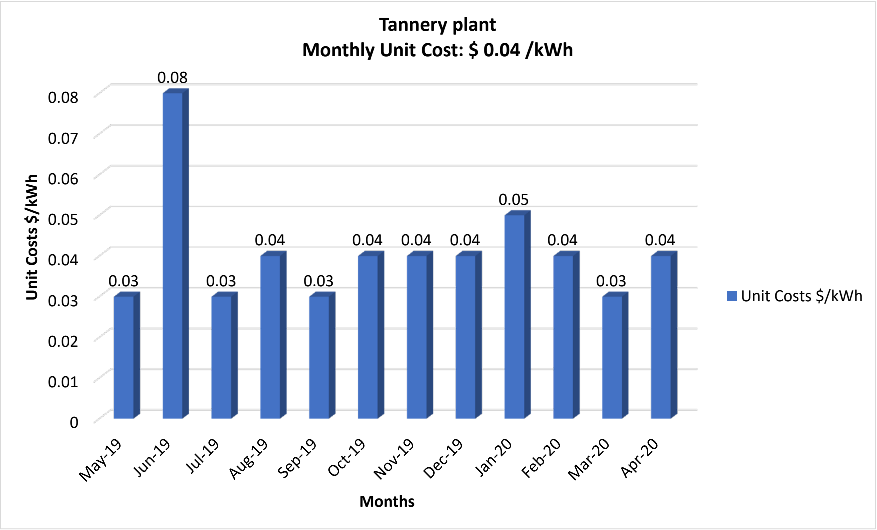

Figure 5. Average unit cost per month for Tannery plant

Figures 6 and 7 show the specific energy consumption and unit cost for the shoe production plant, respectively. The specific energy and unit cost has been computed, and it was observed to be around 4.59 kWh per Shoe pair and $ 0.04 per unit.

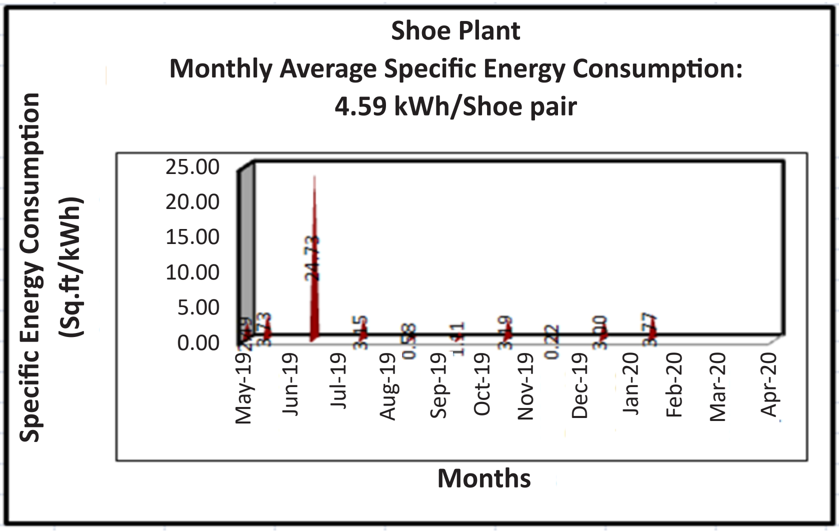

Figure 6. Specific energy consumption for Shoe production plant

From Figure 8, the overall average unit cost for the factory was $ 0.04 per kWh. It is to be observed that the actual calculated unit cost is more than 33% when compared to that of EEU unit cost. The consolidated specific energy consumption is summarised in Table 5.

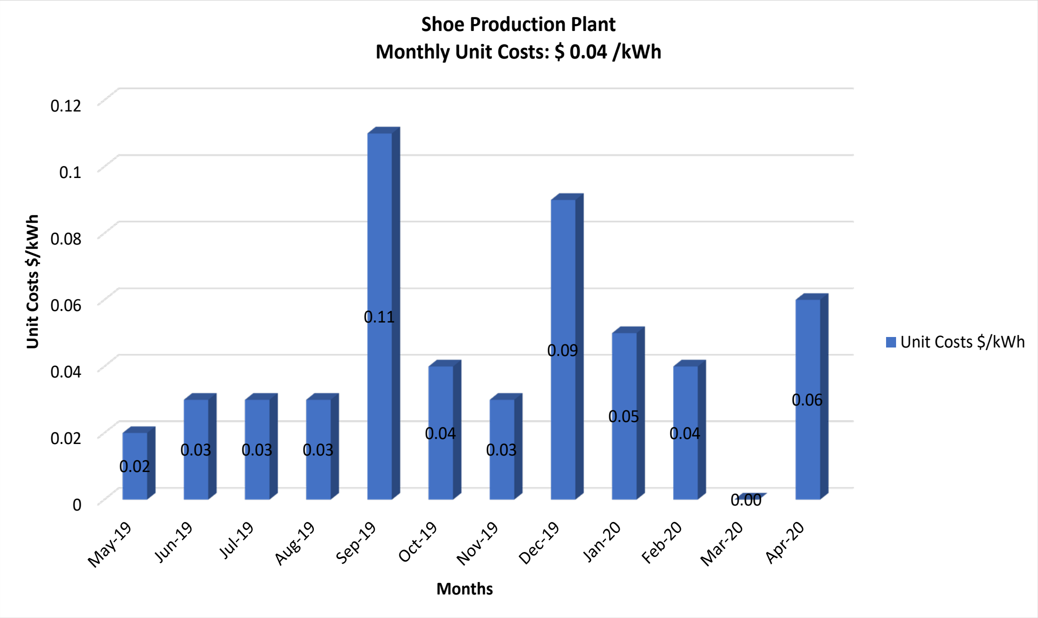

Figure 7. Average Unit cost per month for shoe production plant

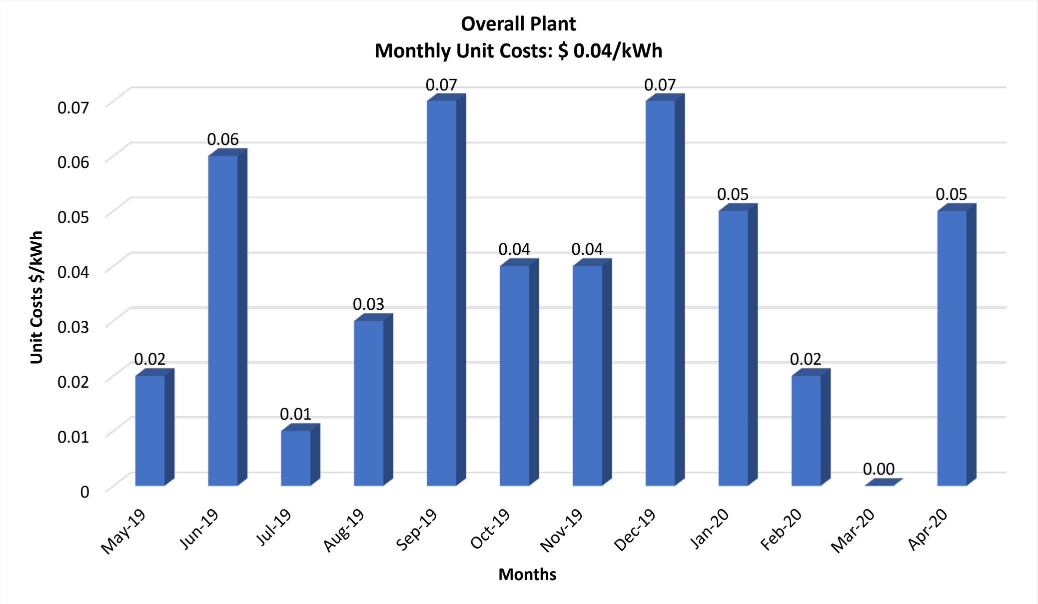

Figure 8. Average unit cost per month for the entire plant

Table 5
Energy efficiency level

No	Plant/Process	Specific energy consumption
1	Tannery	1.02 kWh/sq. ft of leather 0.03 lit of FO/sq. ft of leather
2	Shoe production plant	4.59 kWh/pair of shoes

RESULTS AND DISCUSSIONS

Based on the investment, payback duration, and other benefits, the identified recommendations shall be ranked in a phased manner.

Nil Investment Recommendations

Optimisation of the Operating Steam Pressure. Two furnace oil-fired boilers are installed at the Sheba factory to supply steam at 2.5–10 bar, and one boiler is kept on standby. The boiler was operated between 590 and 760 kg/h against the rated capacity of 2.8 tonnes per hour (27–30% loading), and oil consumption was recorded at around 53 lit/hr (51.8 kg/h). The boiler produces steam to hot water generation for Re tanning drums for the hide and skin section at 35–60°C. During the steam audit, the boiler's current pressure setting ranged from 2.5 to 10 bar (on average, 6.25 bar), but the process only required a maximum steam pressure of 4 to 6 bar. It shows that steam was produced at a higher pressure than was required by the process, which results in increased fuel consumption (20). Therefore, it is advised to run the boiler pressure at the boiler house between 2.5 and 6.5 bar (on average, 4.5 bar). With no additional cost, this would result in significant fuel savings. Making the mentioned changes to the pressure setting will result in an annual savings of more than $ 370.

Operating Pressure Reduction for Screw-type Air Compressors. The compressors at the company are installed in two places to provide the required quantity of air for the Hide and Curst production plant and the Shoe Production plant to perform various process requirements. It was noticed that the air requirement of the whole plant is a maximum of 6 bars for its operation, considering both the tannery and shoe production plant. Thirdly, the compressed air pipe size ranges between 3” and ½” in diameter.

Thus, the pipeline distance and smaller pipe diameter are expected to add to the pressure drop in the pipeline. Therefore, adjusting the compressor's pressure setting bandwidth is advised to lower power usage. Tables 6 and 7 provide the suggested pressure setting and estimated power savings for three compressors.

Table 6
Operating pressure settings for hide and crust production plant air compressor

Identification	Existing pressure bandwidth (bar)		Proposed pressure (bar)		Measured energy consumption (kW)	Expected energy consumption (kW)	Process requirement (bar)
	Cut in	Cut out	Cut in	Cut out			
Comp-1	6.5	7.5	6.2	6.8	16.08	15.03	6 bar only
Comp-2	6.6	7.6	6.2	6.8	16.87	15.76	
Total					32.95	30.79	

Table 7
Proposed pressure settings for shoe production plant air compressor

Identification	Existing pressure bandwidth (bar)		Proposed pressure (bar)		Measured energy consumption (kW)	Expected energy consumption (kW)	Process requirement (bar)
	Cut in	Cut out	Cut in	Cut out			
Comp-3	8	8.5	6.2	6.8	22.49	20.30	6 bar only

With the suggested pressure setting for the three units, the energy usage can be decreased from 164 kW to 147 kW, saving almost $ 3150 annually without any additional investment.

Reduction of Compressed Air Leakages in the System. Two compressors are operating to provide the air supply for the hide and crust production plant, and one compressor is located around the Shoe production plant to fulfil the compressed air demand for various process requirements. Compressors are well known to be important energy consumers. Compressed air must be used optimally and sensibly, only allowing minimum unavoidable leakages. However, 10% of the production of pressurised air is often allowed because more than that would be very difficult to stop. A leakage test was carried out in the Hide and Crust section and shoe production plant to ascertain this. Some of the leakage spots in the pipelines and the quantity of air leakages from the respective plant are shown in Figure 9 and Table 8, respectively.

From the total quantity of compressed air supplied of 14.04 m^3 per minute, 8.64 m^3 per minute was leaked. Therefore, with a permissible 10% leakage, nearly 7.2 m^3 per minute air leakage could be arrested, resulting in a total cost saving of $10,334 per year with zero investment.

Figure 9. Photographic image of leakage points

Reduction of Compressor Air Intake Temperature. Two air compressors used to deliver compressed air for the hide and crust production plant are housed beside the boiler room, where high heat losses are available. All these compressors operate based on Load–No Load mode. During the detailed audit, it was observed that the compressor air suction was kept within the room. The two compressors were kept adjacent to the boiler room. The partition between the boiler shed and the compressor shed is not fully closed; hence, the boiler side radiation was transferred to the compressor house. The temperature within the shed was between 5°C and 6°C higher than the ambient air temperature outside, which was 310°C (Da Cunha, 2007; Rossiter & Jones, 2015).

Table 8
Details of leakage quantity at various plants

Identification	Trials	I	II	III	Average	Compressor loading (%)	Measured FAD (m^3/min)	Quantity of leakage (m^3/min)
Hide and crust plant								
Comp-1	Load	220	210	221	217	60.69	5.88	3.55
	Unload	140	142	135	139			
Comp-2	Load	243	240	245	243	62.87	5.85	3.68
	Unload	142	145	143	143			
Shoe production plant								
Comp-3	Load	100	105	98	101	61.09	2.31	1.41
	Unload	60	65	68	64.5			
						Total	14.04	8.64

It has been established that every 3°C rise in the suction air temperature would increase the compressor power consumption by 1%. Hence, it is suggested to provide ventilation for the suction duct at the hide and crust production plant compressor room. In addition, the partition full partition must be made between the boiler shed and the compressor shed to prevent heat transfer from the boiler shed. Therefore, if ventilation is provided, the motor power usage of 144 kW might be lowered by 2%, saving at least $ 140 annually as a result of the extremely minimal investment, the payback period would be quite low.

Small Investment Recommendations

Proper Insulation of Steam Lines. In the boiler house, during the insulation survey, it was observed that the steam pipelines at certain locations were either improperly insulated or left bare. The average surface temperature of these bare steam pipelines was measured as 105°C. This higher temperature leads to considerable heat loss to the surroundings. The total area of the inefficiently insulated surfaces at the various steam line locations was estimated to be 1.2 m^2. Therefore, it was suggested to insulate the bare hot water pipelines with an investment of $145 and a straightforward payback period of 9 months to reduce convection heat loss and obtain cost savings of $ 200.

Proper Insulation of Hot Water Storage Tank. The factory consumes hot water of around 124,900 litres per day for various processes in the Tannery plant. Raw water at 21°C is heated by saturated steam at 300°C in the heat exchanger between 35°C and 55°C according to hot water demand for each process and stored in the storage tank. It was observed during the study that the entire top portion of the storage tank cover was not insulated and left bare. The entire hot surface of the top portion was simply exposed to the atmosphere. The surface temperature of this top cover varied from 30–45°C. This higher temperature results in considerable heat loss to the surroundings.

It was therefore recommended to appropriately insulate the leftover top portion of the storage tank cover to reduce convection heat loss with an expenditure of $ 150 and a simple payback period of 6 months to reduce convection heat loss and gain cost savings of $ 285.

Utilisation of Exblow Gun for Cleaning Purposes. One of the regular tasks in any industry is using compressed air for cleaning applications. Huge air at low pressure (2.5 ksc) is needed for cleaning applications, whereas compressed air at 6.0 bar is employed for cleaning applications in practically all industries. During the study, compressed air from Compressor No. 1, 2, and 3 was used for all types of cleaning purposes in Tannery and Shoe production plants, respectively. About 18% of compressed air generation is estimated to go for cleaning. It can be reduced to less than 7.5% by optimising the utilisation.

Thus, Exblow Guns were advised to be installed in air cleaning hose pipelines to supply cleaning air at 2.5 bar, which is lower than the 6.5 bar pressure. Depending on the amount of air utilised for cleaning, an air consumption reduction of between 70% and 75% can be achieved (Kingston & Baghzouz, 1994). A $ 185 investment might result in an annual savings of around $ 2150. This results in a maximum payback duration of 1 month.

Replacement of Cast Aluminium Blades with FRP Blades. Cooling tower performance was evaluated for potential energy conservation measures during the detailed energy audit. The industry has 2 cooling towers (CT) for water cooling using a vacuum dryer machine installed in the hide and skin section. The blades of cooling tower fans were found to be made of cast aluminium. Cooling water circulation pump-rated power was recorded as 5.5 kW and 11 kW for skin and hide vacuum dryers, respectively. In order to save energy, it is currently popular to swap out the traditional metal blades on cooling tower fans with blades made of fibre-reinforced plastic (FRP). Therefore, changing the cooling tower fan's present aluminium blades for lighter, properly profiled fibre-reinforced plastic blades is advised. An investment of about $ 300 may result in annual savings of approximately $ 150. A maximum payback duration of 24 months results from this.

Medium Investment Recommendations

Arresting of Steam Leakages. Steam leaking is an obvious indication of waste and needs to be prevented. Latent and sensible energy is lost as a result of steam leaks (Bureau of Energy Efficiency, 2018; Rossiter & Jones, 2015). The employees at the factory would do well to consider the expenses and issues associated with steam loss issues. During the study, steam leakages have been noticed in 5 places, especially in bends, couplings and valves. In a few locations, the steam leaked through the holes on the pipe surface, possibly due to erosion. Hence, replacing the faulty valves and fittings and arresting the Steam Leakages is recommended. Considering the size of leakage points and steam pressure, it was anticipated that about 1.8 kg/h steam would leak from these five identified points. It may be possible to replace bends, T joints, valves, and couplings to save $ 5925 annually with a $ 570 investment and a 1-month payback period.

Installation of Temperature Indicator Cum Controller (TIC) in Cooling Tower. In the Sheba factory, two cooling towers (CT) are operated and powered by 4 kW aluminium blades to supply cooling water to the skin and hide sections. The cooling tower is designed to operate at 9°C and 11°C for skin and hide sections. However, the outlet water temperatures from the cooling tower were observed to be around 20 to 22°C as needed for both sections. It was observed that due to erratic weather variations in the winter season, the outlet water temperatures would go below 10°C. Hence, operating the cooling tower fan only when required is recommended. Hence, operating the cooling tower fan as and only when required is recommended. It can be achieved by installing a Temperature Indicator Cum Controller (TIC) at the cooling tower water outlet port to sense the temperature continuously and activate the cooling tower fan whenever the water temperature exceeds its set limit (Kingston & Baghzouz, 1994). It would result in appreciable cost savings of $ 385 per year with an investment of $ 430, which gives a payback period of just 14 months.

Installation of Automatic Star-delta-star Starter in the Part-loaded Motor. Power measurements were taken at various locations in the motors. At present, all motors are connected to a star-delta-star starter. Irrespective of the loading of the motor, it goes into Star mode and changes over to Delta-Star mode. The Auto Star-Delta-Star starter is a device with a built-in load sensor which senses the load continuously, and whenever the load goes below 40%, it automatically changes over to Star connection and reverts to Delta mode when the load goes above 40% (Bureau of Energy Efficiency, 2018; Zeitz, 1997).

While the motor operates and loads less than 40%, the iron losses will be more dominant than the current related to copper losses (Ganguly et al., 2016). As a result, the iron losses would be at their lowest since the applied voltage is lower when the motors are linked in star mode. Besides, a considerable power factor improvement would be possible in the star mode connection. Therefore, it is recommended to install Auto Star-Delta-Star Starter for the identified motors since their load varies between 15–40%. A significant amount of kVA would be saved with this technique. With an expenditure of $ 640 and a payback period of about 1 month, this implementation would result in more than $ 2,090 annual savings.

Installation of Servo Stabiliser in the Lighting Feeder. During the lighting audit, the lighting voltage used was 220 V in each lighting feeder located at various sections, and the overall lighting load was 17.06 kW. A reduction in supply voltage by 15% can result in a drop in power consumption by around 15% and an insignificant drop in illumination level by about 3–4% (Bureau of Energy Efficiency, 2018).

By installing a servo stabiliser and keeping the lighting voltage at 205 V, it is possible to optimise the voltage level in the lighting feeder and save significant energy. This technique has been successfully implemented in various companies, and substantial savings have been achieved. The investment required for a 25 kVA servo stabiliser and fitting is nearly $ 715; hence, the cost-saving benefits are around $ 2,980 and a payback period of around 3 months.

Waste Heat Recovery from the Boiler Flue Gas. The Sheba plant has an oil-fired furnace boiler capacity of 2.8 tonnes per hour. It was noticed that an electric heater filament capacity of 5 kW preheated the furnace oil. At a flow rate of 0.324 kg/s, the flue gas exits the boiler from the boiler at a temperature of around 290°C to the atmosphere. If we installed a heat exchanger to recover this heat, huge savings would be attainable. Hence, it is recommended to install an oil preheater to recover the heat from the flue gas to preheat the furnace oil. If preheated is supplied by waste heat recovery of flue gas, but the combustion would be better, and the energy input requirement would also be lesser as the preheated oil brings in a certain quantum of energy (Ganguly et al., 2016).

Therefore, around 17.2 thousand units can be saved by replacing the 5 kW electrical filament by preheating the inlet air through the outgoing hot flue gas. The approximate $ 1,430 investment for a recuperator with ceramic plates and installation resulted in cost savings of $ 715 in a payback period of less than 24 months.

Large Investment Recommendations

Replacement of Thermodynamic Steam Traps with Floating Ball Steam Traps. In the Sheba leather factory, thermodynamic steam traps (TDS) let out the condensate in the steam line (22). There are 6 steam traps installed in the steam pipelines for 6 machines in the skin and hide section. The Features and advantages of a floating ball steam Trap (FBS) over a TDS trap are detailed in Table 9. Therefore, using FBS instead of TDS traps, about 1.5–2% of steam that goes out along with condensate can be saved. Hence, replacing all the TDS Traps with FBS traps is recommended in a phased manner. It would yield a noticeable cost save of $ 8,900 per year with an investment of $ 2,570, giving a payback period of just 4 months.

Table 9

Features and advantages of floating ball steam trap

No	Feature	Advantages
1	Single moving part	Easy maintenance and low spare part cost
2	Easily accessible cover	In-line maintenance
3	High surface quality float	Long service life
4	Easy access to discharge orifice	Great reaction to the changes in the steam load
5	Float departs from the orifice as a rotating	Constant condensate discharge
6	Float and orifice	Not affected by back pressure
7	The orifice is well placed underwater level	No steam leakage
8	Contains thermostatic venting equipment	Quick service without steam lock
9	Built-in strainer	Prevents dirt
10	Prevents steam locking	Preferred where the steam lock is possible and increases the system efficiency

Installation of VFD to the Dust Extraction Blower. A Variable Frequency Drive (VFD) converts standards 3 ϕ Alternate Current (AC) power input at 415 V, 50 Hz into an adjusted voltage and frequency output that controls the speed of an AC motor. VFDs were designed to ensure efficiency improvements even under part loads by reducing speed. Generally, power consumption is proportional to cubic speed [$P \alpha N^3$] (Ganguly et al., 2016). In the Sheba factory, the dust extraction Induced Draft (ID) fan is installed on the skin buffing floor with a rating of 45 kW. It sucks dust from the buffed leather in the buffing machines and discharges it to the collector. There are 9 buffing machines, and one de-dusting machine operates according to the production schedule. During the study, the power consumption of this blower was observed to be 17 kW against a rated power of 45 kW. The fan's power consumption differs daily depending on the customer's requirements. It is quite obvious that this fan would be operating on a varying load (35–85%) directly influenced by the dust accumulation. Regardless of machine operation, the dust extraction fan operates continuously.

It is therefore recommended to install a VFD to this ID Fan and make it operate at a higher efficiency level by adjusting the fan power requirement according to the dust loading in the machines. An investment of about $ 2,900 may result in annual savings of approximately $ 740. This results in a payback time that is no longer than 47 months.

Installation of VFD for Fume Extraction Unit. In the hide and skin of the section to provide a good quality chemical spray over the hide and skin in both sections, the chemicals are sprayed by the Forced Draft (FD) fan over the layers of leather as well as heated by steam to a temperature of 100–110°C. These processes are carried out by spraying various pre-mixed chemicals continuously through multi-hole nozzles in the closed cabin. This results in the emission of dense fumes from the closed spray cabin. These fumes are exited from the tanks through headers provided on the sides of the cabin. A blower arrangement sucks the fumes out and lets them into the atmosphere. Since the spray process is intermittent, it was observed that fumes generation is also intermittent. However, while spraying chemicals, the blower keeps exiting the fumes to atmospheric air during non-spraying) continuously. The loading of the motor varies from 45 to 65%.

It is recommended to install a Variable Frequency Drive (VFD) for the blowers of the fume extraction units of the skin and hide spray machine. The VFD can be put in a closed loop with a pressure sensor control at a point near the hollow hood (A chemical sensor that senses the inlet of the fume can also be used). The sensor would sense the fume's presence and signal the VFD. The VFD would actuate the motor and vary the speed of the blower based on the quantum of fume emitted. Upon installation of VFD, it is anticipated that about 30% of present energy consumption can be saved. It could save nearly $ 5,400 per year with an investment of around $ 5,830. It brings to a payback period of a maximum of 13 months.

CONCLUSION

An energy conservation study was carried out in the Sheba leather factory in Mekelle in northern Ethiopia. The plant has all types of utilities and technologies at work, suggesting that it is operating fairly efficiently. However, the management still looks for avenues to reduce energy consumption to a lesser value. Hence, the management has requested the help of the Centre for Energy, Mekelle University, Ethiopia, to conduct a detailed energy audit and suggest ways to reduce energy consumption. The following are the recommendations as summarised below:

a. 19 proposals have been identified for possible energy savings
b. An energy-saving potential of about \$ 29,900 / year can be realised by implementing these proposals
c. The implementation would require a one-time investment of about \$15,900 to reap the benefits and be paid back in about 7 months.
d. Of the total savings identified, \$14,000 can be realised without significant investment.
e. CO_2 Reduction is possible by implementing energy-saving proposals around 52.70 tons of CO_2/y

The list of conservation suggestions and their technological and economic viability are provided in Table 10.

Table 10
A summary of recommendations for energy conservation

No	Energy Saving Proposal	Investment Required (\$)	Annual Savings (\$)	Payback Period months
Nil Investment Proposals—4				
1	Optimisation of the operating steam pressure	Nil	370	0
2	Operating pressure reduction for screw-type air compressors	Nil	3150	0
3	Reduction of compressed air leakages in the system	Constant Maintenance	10334	0
4	Reduction of compressor air intake temperature	Negligible	140	0
	Total	**0**	**13994**	**0**
Small Investment Proposals—4				
1	Proper Insulation of Steam Lines	145	200	10
2	Proper Insulation of Hot Water Storage Tank	150	285	06

Table 10 *(Continue)*

No	**Energy Saving Proposal**	**Investment Required ($)**	**Annual Savings ($)**	**Payback Period months**
3	Utilisation of a blow gun for cleaning purposes	185	2150	01
4	Replacement of the existing cast aluminium blades with FRP blades	300	150	24
	Total	**780**	**2785**	**0.28**
Medium Investment Proposals—5				
1	Arresting of steam leakages	570	5925	01
2	Installation of temperature Indicator Cum controller (TIC) in cooling tower	430	385	14
3	Installation of automatic star-delta-star starter in the part-loaded motor	640	2090	04
4	Installation of servo stabiliser in the lighting feeder	715	2090	03
5	Waste heat recovery from the boiler flue gas	1430	715	24
	Total	**3785**	**12095**	**04**
Large Investment Proposals—3				
1	Replacement of thermodynamic steam traps with floating ball steam traps	2570	8900	04
2	Installation of VFD to the Dust Extraction Blower	2900	740	47
3	Installation of VFD for fume extraction unit	5830	5400	13
	Total	**11300**	**15040**	**09**

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