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Energy Audit of a Meat Processing Plant

Eng. Daniel Chitena
Dept of Mechanical and Industrial Eng
Palapye, Botswana

Prof. M.T Oladiran
Dept of Mechanical and Industrial Eng
Palapye, Botswana

Abstract **- The study has come up with energy saving solutions for different sections or equipment of a meat processing plant in Botswana. Much of the old original equipment at the abattoir is still in place and there exists an opportunity to lower energy consumption through the adoption of modern energy saving measures. Modern engineering instruments were used to determine the efficiencies of various manufacturing equipment so that cost-benefit analysis could be carried out. The use of premium efficient motors and variable speed drives can significantly lower motor power use. 25 motors were analysed and it was ascertained that the adoption of premium motors could save P71702 annually with payback periods of less than 3 years. An ultrasonic detector pointed out leaks in the compressed air system however a leakage test estimated that 35% of the air in the system is lost to leaks while about P11000 could be saved annually by reducing the discharge pressure. The water and energy consumption figures are benchmarked against those from modern plants. It was found that the plant's electricity and water consumption are much higher compared to modern plants. Software analysis shows that insulating certain surfaces in the plant's thermal systems can be economically viable. Installation of efficient sterilizers could save about P780000 annually in water and coal. Retrofitting light fixtures was found to have a potential to save about P66000 in electricity costs annually. Maintenance practices were scrutinised as adequate maintenance could lead to energy savings, lower overall maintenance costs and higher machine availability.**

Keywords: Energy audit, efficiency, abattoir

I. INTRODUCTION

The Industrial sector is the largest users of energy around the world [1] . In order for countries to develop and grow economically, they need a sound industrial sector and the growth is closely related with the growth in its energy consumption [2]. A systematic approach, to monitor industrial energy consumption and pin-point sources of wastage, is known as energy audit [1]. On the other hand the European Committee for Standardization defines an energy audit as a systematic procedure to obtain adequate knowledge of the existing energy consumption profile of a building or group of buildings, of an industrial operation and/or installation of a private or public service, identify and quantify cost-effective energy saving opportunities and report the findings [3]. In order to reduce energy consumption for sustainable and energy-efficient manufacturing, continuous energy audit and process tracking of industrial machines are essential. Meanwhile, industrial application of energy efficiency technologies have shown a promising potential to reduce energy consumption and associated costs [4]. First world countries have started implementing and enforcing energy saving measures within their industrial sectors. China has introduced many policies, programs, reporting requirements in support of the achievement of this goal, as its industrial sector consumes between 60% and 70% of China's primary energy [5]. Europe in 2006 launched the ESD (Energy Service Directive 2006/32/EC) aimed at reducing energy consumption by 9% in the European Union. Further they introduced stricter 20-20-20 energy savings policy in 2008 aimed at reducing energy consumption in all sectors of European society by 20% by the year 2020 [6]. The US has been at fore front energy efficiency regulation (EER) and energy research. The fundamental guidelines provided by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) are a useful reference for energy professionals worldwide. In the US, there are many other high-quality publications on energy auditing and energy management [7]. The situation in Africa is different, as the continent generally lags behind in formulating and implementing energy laws and policies aimed at enhancing energy efficiency. Therefore in African countries energy audits are not mandatory while various companies voluntarily conduct energy audits. A few published literatures on energy management and audit in Africa have been identified. These audits are mainly carried out by universities [8]. Therefore there is a need for African countries to emulate first world countries by ensuring industrial plants carryout mandatory energy audits.

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II. BACKGROUND OF THE PLANT

The company was created in 1965 to buy and slaughter livestock, promote the livestock industry and interests of livestock producers, and export the beef sector's products. Beef has made a significant contribution to the Botswana economy. In the early years of independency beef was the only foreign exchange earner. In 2013, its total beef exports were US$116.6 million, representing a world export market share of 0.3% making Botswana Africa's largest beef exporter. The company has 3 plants in Botswana located in Lobaste, Maun and Francistown. The plant studied is in Francistown, has about 200 employees and has a slaughtering capacity of 400 cattle per day.

III. THE SYSTEMATIC ENERGY AUDIT

A systematic approach is required in order to carry out energy audits effectively. Fig. *1* shows the steps taken in carrying out the audit.

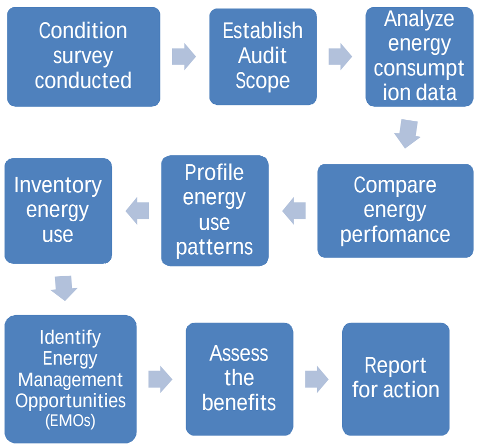

Fig. 1 Summary of the energy audit process

During the condition survey data was collected and analysed. Following the analysis the plant's energy and water consumption data were compared to benchmark figures from other abattoirs mostly from industrialised countries. The benchmark specific energy and water consumptions are shown in TABLE 1 according to the advancement of the technology in place.

TABLE 1 BENCHMARKS FOR ABATTOIRS-250KG BODIES [9]

	Traditional technology	Average technology	Latest technology
Energy (kwh/head)	5000	2500	1000
Water (L/head)	300	125	70

COWI [9] quotes rendering energy consumption benchmarks at 1800 to 7000kj/kg of rendered material such as blood meal and carcass meal.

TABLE 2 PLANT SPECIFIC ENERGY CONSUMPTION RATES

Figure	Consumption
Electricity (KWH/head)	155
Water (KL/head)	5600
Rendering (Kwh/kg)	0.11
Heat energy (KWH)	880

A. Motors

The plant's motors were studied and an inventory of the largest motors was made. Measurements and motor information was taken in order to:

1. Ascertain if the motors should be replaced with more efficient motors

2. Determine if VSDs can be installed to lower energy costs

3. Determine if the motors are overloaded so they can be replaced with smaller motors.

Other factors such as voltage imbalance, over/under voltage were checked to see if they were within IEEE standards. The maintenance program was scrutinised to check if proper maintenance practices were followed. Saidur, (2009) gives some recommendations on motor maintenance. A power meter was used to measure voltage, current, harmonics and power factor and a tachometer measured motor speed. Motormaster software was used to help determine the cost effectiveness of motor retrofits. 25 motors were studied and it was found that 23 could be retrofitted with premium motors economically with paybacks of less than three years. The retrofits could result in of P54993 in electricity savings annually.

A 40 KW blood cooker motor is considered for replacement with an ultra-efficient motor. The present motor has an efficiency of 89.8% and the proposed motor

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has an efficiency of 94%.The load factor is 0.82 and the motors are estimated to operate for 5500 hours. The differential cost of the ultra-efficient motor versus the standard motor is P3000. In order to decide the economic viability of changing the motor the payback period is computed as follows.

$$\text{Saved KWH} = \text{N.P.Lf.}\left(\frac{1}{\eta_{std}} - \frac{1}{\eta_{eff}}\right) \quad [1]$$

Where:

N is the total number of operating hours annually

P is the rated power of the motor

Lf is the average load factor

η_{std} and η_{eff} are the efficiencies of the old motor and the proposed motor respectively.

Therefore the energy saved by changing motors is calculated as follows:

$$\text{Saved KWH} = 5500.40.0.82\left(\frac{1}{0.898} - \frac{1}{0.94}\right) = 10327 \text{ KWH/yr}$$

$$\text{The payback period} = \text{P3000}\left(\frac{3000}{10327 \times 0.8}\right) = 0.36\ years$$

B. Lighting

The plant has three types of bulbs fluorescent tubes, sodium high pressure bulbs, and mercury vapour bulbs. A lightmeter was used to determine lighting levels and the areas that were overlit were recommended for delamping. The company had begun replacing its outdated T12 lamps with the more efficient and modern T8 lamps. The following retrofits were recommended:

- Replacing 250 W mercury vapour lamps with 215 W Sodium High Pressure lamps. This retrofit represents a savings of 65W per lamp including ballast savings [10]
- Replacing 40W T12 lamps with T5 lamps that use 40% less energy.
- Delamping selected lamps
- Retrofitting 65W T12 lamps with 58W T8 lamps.

In total about P69000 in electricity costs could be saved annually by employing these measures. Motion sensors and dimmers could provide significant electricity savings in areas that are scarcely occupied or are partly lit with daylight such as the storerooms, chiller rooms and the administration block. Refrigerated areas could save additional energy from the reduced heat loads.

C. Compressed air systems

The plant's air requirements are met by one 132 KW compressor. The compressor supplies production equipment such as the bone crusher blower, vacuum packaging machines, pneumatic valves, splitting saws, and dehorning tools. The compressor discharge pressure is 7.5 bar while most equipment require pressure around 6 bar.

In one audit at a Vietnamese plant 65% of compressed air was being lost to leakages [11].Therefore it is prudent to establish the leakage rate of a compressed air system. In order to determine the leakage rate all the air consuming equipment was switched off and the onload and offload times were recorded. The leakage rate was found as follows:

$$\text{Leakage rate} = \frac{\text{time loaded}}{\text{loaded time+unloaded time}} \quad [2]$$

$$\text{Leakage (\%)} = \frac{13.8 \times 100}{(13.8+24.8)} = 35\%$$

About 35% of all air produced by the compressor is lost to leaks. An ultrasonic leak detector was used to locate leaks on the air distribution system. Considering that 90% of the lifecycle costs of compressor are due to electricity costs a program to repair leaks should prove to be highly economical. About P95000 in electricity costs could be saved annually by repairing the leaks. Compressors are often oversized to meet to anticipated future air system growth and safety allowances. The demand for compressed air is highly variable and is very low on weekend as less than 5% of compressed air capacity is required. Underloaded compressors are less efficient. Therefore a modular combination of VSD controlled compressors of different sizes was recommended. The smaller compressor(s) would run during periods of low air demand. The pressure requirements of each air drawing equipment was noted to ascertain if some of the equipments pressure requirements were low enough to be supplied by blowers but almost all equipment have high pressure requirements that are above 6 bar that can only be met by compressors.

D. Thermal Systems

The plant has two boilers that supply superheated steam at 133°C to a heat exchanger and process equipment. The heat exchanger indirectly supplies hot water for cleaning, sterilisers and other uses. Sterilisers require water at 82°C and hand wash water at 42°C. Recommendations for improved efficiency include the fitting of an economiser, installation of flue gas analysers, fitting of insulation on the boiler and bare steam pipes. Blowdown is carried out periodically however sensors that test boiler water should be can be installed to lower the amount of blowdown

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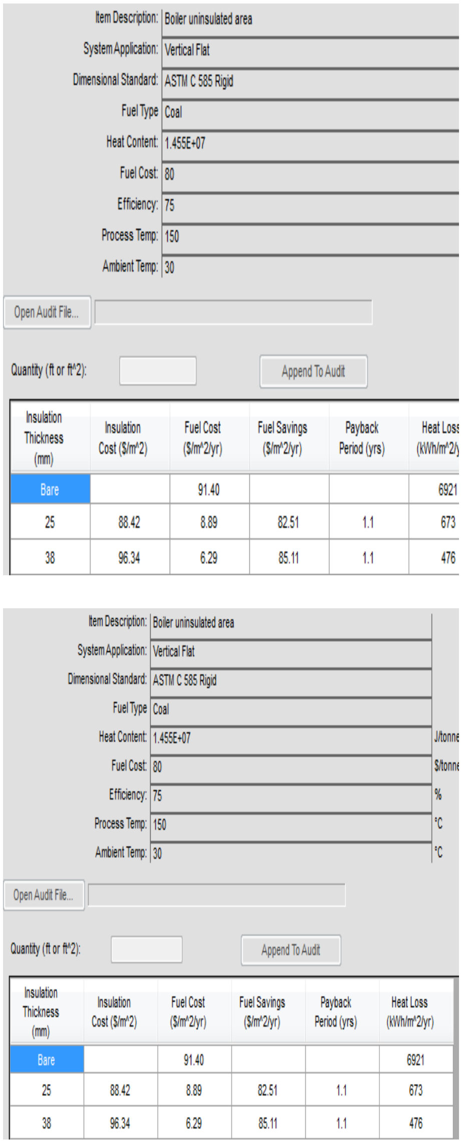
water and consequently save coal. An infrared thermometer was used to find surfaces that could benefit from insulation or added insulation and generally these are surfaces above 50°C. A software called 3E plus was used to determine the payback period of installing insulation on the surfaces that were considered. The software can give economic analysis of various types of insulation of varying thicknesses for a given surface. Software analysis shows that insulating any of the surfaces has short payback periods of between 0.5 to 4 years with a potential to save tens of thousands of pula in



Item Description: Boiler uninsulated area
System Application: Vertical Flat
Dimensional Standard: ASTM C 585 Rigid
Fuel Type: Coal
Heat Content: 1.455E+07
Fuel Cost: 80
Efficiency: 75
Process Temp: 150
Ambient Temp: 30

Open Audit File...

Quantity (ft or ft^2):

Append To Audit

Insulation Thickness (mm)	Insulation Cost ($/m^2)	Fuel Cost ($/m^2/yr)	Fuel Savings ($/m^2/yr)	Payback Period (yrs)	Heat Loss (kWh/m^2/y
Bare		91.40			6921
25	88.42	8.89	82.51	1.1	673
38	96.34	6.29	85.11	1.1	476

Item Description: Boiler uninsulated area
System Application: Vertical Flat
Dimensional Standard: ASTM C 585 Rigid
Fuel Type: Coal
Heat Content: 1.455E+07 J/tonne
Fuel Cost: 80 $/tonne
Efficiency: 75 %
Process Temp: 150 °C
Ambient Temp: 30 °C

Open Audit File...

Quantity (ft or ft^2):

Append To Audit

Insulation Thickness (mm)	Insulation Cost ($/m^2)	Fuel Cost ($/m^2/yr)	Fuel Savings ($/m^2/yr)	Payback Period (yrs)	Heat Loss (kWh/m^2/yr)
Bare		91.40			6921
25	88.42	8.89	82.51	1.1	673
38	96.34	6.29	85.11	1.1	476

Fig. 2 Insulation software analysis

E. Water Audit

Cutting water use will also help lower energy costs as all the water is pumped at pressure, while some water is heated and some will end up in the wastewater treatment facility. The 32 sterilizers in the deboning and slaughter were studied and found to use hot water (82°C) at a rate of 12L per minute while the most efficient sterilizers on the market use water at rate as low as 0.5L per minute. It was estimated that about P484000 could be saved annually in water costs and P296000 saved in heating or coal costs. Over 50% of the cold water consumed at the plant is dedicated to cleaning. However pressurized water is used for sweeping the floor. Dry cleaning before hosing could save up to 30% of water used for cleaning. The plant can adopt better hose nozzles that could save water by creating a more diverging stream at stream at higher pressure and lower flow rates as illustrated by Fig. *4*.The plant could also save water by adopting low flow shower heads, cisterns and faucets. However this strategy is most economical when the above-mentioned fittings need to be replaced with new ones.

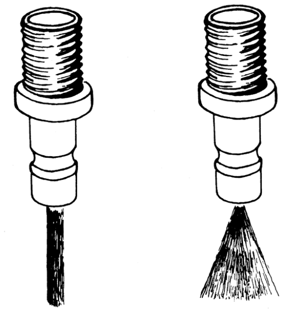


Fig. 4 Diverging angle of flow

F. Processes

Carcassmeal and bloodmeal are cooked in cookers heated by superheated steam. Hot condensate water at around 88°C is released into the sewer system while exhaust vapour is released into the atmosphere. A recommendation was made to fit an exchanger that would recover heat from the condensate and vapour and transfer it to boiler make up water. This retrofit was estimated to save about 116 tons of coal annually.

G. Pumps

The plant has three pumps that supply the plant with cold water. The pumps have old rewound motors and are manually controlled by an operator who switches them on and off depending on the demand. To improve efficiency the pumps should be fitted with a VSD that would operate the necessary number of pumps at any given point and run the motors at the ideal speeds. The

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VSD is coupled to a pressure transducer as shown in Fig. 5 and it runs the pumps depending on the pressure in the system.

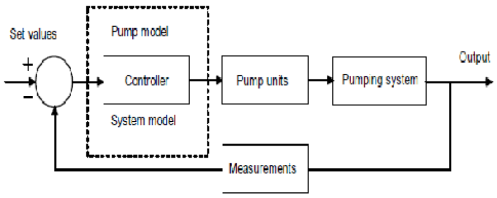

Fig. 5 Proposed water system logic

Poor maintenance practices at the plant result in significant energy losses. An example is a worn out impeller as shown in Figure 4 which would result in the pump working inefficiently and performing poorly. Replacing the existing pump motors with modern premium efficiency motors would also save a significant amount of energy.

Fig. 6 A worn out impeller

H. Refrigeration and HVAC systems

The plant has a 1200 ton refrigeration system which provides cooling power to the chillers and plate freezers and refrigerated zones namely the deboning section, storage and offal sections. Following analysis of the refrigeration system the following recommendations were made:

- The system is 27 years old and suffers from repeated ammonia leaks which have caused injury to some employees. The system needs a major overhaul or replacement
- The refrigeration temperatures in the deboning zone and the plate freezers are 5°C and -15°C respectively. However the required temperatures for the deboning section and plate freezers are can reach 7°C and -12°C respectively meaning the refrigeration system is working harder than it should and wasting energy
- VSDs should be installed on motors on the evaporators, condensers and ammonia pumps
- Doors were left open for extended periods. Door openings should be minimized to save energy especially when freezer temperatures are concerned
- It is not common for companies to recover the heat from condenser water. However this is possible and the heat can be used to heat water. In this case boiler feedwater can be preheated by condenser heat. The system currently employs open circuit condensers which release water as waste into the drainage system. A closed circuit system which recycles all the water could save a significant amount of water
- The system should be reverted back to automatic control
- The plant has old louvred windows which create infiltration resulting in higher air-conditioning load
- In hot and humid areas make up air can account for between 20-40% of the total energy consumed in air-conditioning systems [12]. Therefore a significant amount of heat can be recovered by means of heat exchangers or heat wheels.

I. Other recommendations

Some buildings' roofs are not coated resulting in them having low reflectivity and consequently higher cooling loads. A coating with high albedo needs to be applied to the necessary buildings. Thermal imaging cameras can be used to perform thermal analysis of the buildings and thermal equipment to provide the basis for recommending insulation of relevant areas. Tallow can be used to power the boiler or create biodiesel that can fuel the plants' vehicles. A compressor capacity measurement test can be used to ascertain the prevailing performance of the compressor. Compressors that are faulty or too old normally suffer a significant drop in performance therefore comparing the present capacity to the design capacity can highlight wasteful energy consumption. Experienced technicians would then determine the cause of the wastage.

FUTURE SCOPES

The author intends to publish more works on energy auditing and energy efficiency. Work on a paper on

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energy efficiency regulation is currently underway. Future works on energy auditing will focus on specific applications such pumps, compressors and motors. Case studies will conducted on companies in Botswana especially energy intensive mines. Collaborations with energy experts on future projects will be sought.

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