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Article

Electrical Energy Consumption and Energy Conservation of Rice Mills in the Northeastern of Thailand

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Abstract. Modern rice mills have increased in size and now operate with improved technological milling systems and tend to use electrical energy increase. The aim of this research was to determine the Electric energy consumption (EEC) and energy conservation of rice mills. Ten rice mills in the Northeastern of Thailand were studied. The results showed that average of EEC of the rice mills was 1,183,271 kWh/yr, and a Specific energy consumption (SEC) of 19.50 kWh/ton. The average Energy cost (EP) was 141,452 USD/yr, and the average specific energy cost (SEP) was 2.37 USD/ton. This EEC was dependent on rice quality, production quantity, and the wattage of the electrical machines operated in the rice mills.

The whitening polishing machine used the highest EEC at 33.17%, with 21.60% EEC used for mist polishing machine. Bran separator, other equipment, air compressor, hulling machine, husk separator, meal separator, and sieve separator consumed the energy of 11.68, 8.86, 6.67, 6.54, 5.72, 4.75, and 1.01%, respectively. The improvement of the EEC in rice mills must focus on the equipment which has the highest the EEC. There are 3 systems where energy can be saved in rice mills, including the power supply systems, the motor systems, and the air compressor systems that can be reduced average cost 4,518.363, 3,313.162 and 936.687 USD/yr, respectively. (1 USD = 34.650 THB as of 23/09/2016.)

Keywords: Rice mills, electrical energy consumption, tooling process.

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1. Introduction

Thailand is a major global rice cultivation and exporter. Eleven million tons of rice were exported with a total value of 5,050 million USD [1]. In Thailand, rice is a staple crop which is very important for all aspects of economic, social, and political activities.

The rice industry consumes high energy to transform rice in the paddy fields to the finished product. P. Suntivarakorn et al [2] studied guidelines on energy management in Khon Kaen province of the Northeastern of Thailand and found that 70.71% of the province's energy was consumed by logistics and industry. Therefore, rice mills have a core role in the Thai rice industry. The Northeastern of Thailand contains the highest number of rice mills. These mills have increased in size, with improved milling systems and productivity. The EEC to produce the finished rice product is high, and electricity is a major cost in the milling process [3].

Rice mills operate continuously and using many equipment. All equipment work together harmoniously from the paddy cleaning stage through to final packaging, and all the stages use electrical energy. A. Chaoumead [4] studied energy consumption in Thai rice mills in the central of Thailand and results showed that the rice mill motors consumed 80 to 85% of the total electrical energy.

In the past, rice mills used steam power to produce energy, but now electrical motors drive all the milling systems. The value of the rice husks is also higher now than in the past as it can be mixed with bagasse, rice straw, and water hyacinth to make charcoal briquettes [5]. Therefore, the husks can be used as an energy source for the milling process, which has electricity production costs between 0.058 and 0.208 USD/kWh [6]. Motor efficiency, tooling duty, production layout, and product quality all require large amounts of EEC [7]. The EEC of rice mills shows an increasing tendency; therefore, the aim of this research was to determine the EEC and energy conservation of rice mills in the Northeastern of Thailand. This research was performed as a guideline for mill owners to understand the EEC of each tooling requirement in their rice mills. This information can also be used for enhanced decision making on electricity energy saving, and streamline electrical energy usage for each tooling process in rice production.

2. Methodology

Ten rice mills in the Northeastern of Thailand were selected for this study in the following provinces: Amnat Charoen, Mukdahan, Maha Sarakham, Khon Kaen, Yasothon, Nakon Phanom, Roi Et, Nong Khai, and two rice mills in Udon Thani. The mills used only electricity energy and they were installed with electric transformers with the minimum of 250kVA to the maximum at 1,175kVA [8, 9, 10] or the production capacity more than 100 ton per day. Data were collected with the inquiry and measurement of electric power transmission system, electric motors and air compressor system.

Power consumption is calculated

$$P = \sqrt{3} \times V \times I \times \cos\theta \qquad (1)$$

where V = Voltage (V)
I = Current (A)
cosø = Power factor

Calculation of Electric energy consumption of motor:

$$\text{EEC (kWh/yr)} = (\text{Power consumption} \times (\text{d/yr}) \times (\text{h/d}) \times (\text{working ratio})) \qquad (2)$$

where d/yr = Machines and equipments running day or the rice mill running day
h/d = Running hours of system or machines
working ratio = Power factor of machines as not over than 1, 100% running

Energy charge was calculated by electrical consumption (as unit or kWh) for each month and types of tariff:

$$\text{energy charge} = (\text{on peak power units} \times \text{on peak tariff rate}) + (\text{off peak power units} \times \text{off peak tariff rate}) \qquad (3)$$

Demand charge was calculated by power requirement (kW), average 15 minutes of the maximum period for each month and types of tariff:

$$\text{power requirement} = \text{on peak power requirement} \times \text{on peak tariff rate} \tag{4}$$

Power factor (PF) is the PEA charge by based on the power factor of the maximum kVAR that is calculated from the excess over than 61.97 percent of maximum electricity requirement in the rate of 1.618 USD per kVAR (please check the current kVAR).

$$\text{Excess of kVAR} = \text{kVAR} - (0.6197 \times \text{power requirement})$$
$$\text{PF} = \text{Excess of kVAR} \times \text{kVAR Rate} \tag{5}$$

Monthly service fee = 9.011 USD

Fuel adjustment charge (Ft) is adjustment rate follow by fuel price, logistic and production costs at 0.016 USD/unit (please check the current Ft rate):

$$\text{fuel adjustment charge (Ft) rate} = \text{power units (both of on peak and off peak)} \times \text{Ft rate} \tag{6}$$

Vat 7 %:

$$\text{Tax} = (\text{energy charge} + \text{demand charge} + \text{Power factor} + \text{monthly service fee} + \text{Ft}) \times 7/100 \tag{7}$$

The total payment to the PEA:

$$\text{energy charge} + \text{demand charge} + \text{Power factor} + \text{monthly service fee} + \text{Ft} + \text{tax} \tag{8}$$

Calculation of energy cost:

$$\text{EP (USD/yr)} = \text{average EP x EEC} \tag{9}$$

where Average EP = The electrical energy used (USD/kWh)
EEC = Electric energy consumption (kWh/yr)

Calculation of SEC and SEP:

$$\text{SEC (kWh/ton)} = \text{EEC (kWh/yr)} / \text{Actual production (ton/yr)} \tag{10}$$
$$\text{SEP (kWh/ton)} = \text{EP (USD/yr)} / \text{Actual production (ton/yr)} \tag{11}$$

2.1. Measurement of Electrical Energy Consumption of Rice Mills and Equipment

Install power quality analyzer on the electric control cabinet of the electric power transmission system, air compressor system and equipment's rice mills. Measurement the electric current, voltage and the electric power factor on every 1 minute a day. The data of analysis were EEC, EP, SEC and SEP and calculated using equation 2, 9, 10 and 11 respectively.

2.2. Electrical Energy Saving for Equipment in Rice Mills

The improvement for power reducing of rice mills were 3 methods that consist of power saving in electric power transmission, electric motor and air compressor improved in amount of 5, 9 and 9 plants respectively. The EEC testing was analysis both of before and after improvement and continue for EEC, EP, SEC and SEP testing is shown in Fig. 1.

Fig. 1. The measurement of electrical energy consumption of rice mills.

3. Results and Discussion

3.1. EEC of Rice Mills

The rice mills were divided by electricity user type into two groups. There were 7 mills of time of use (TOU) type and 3 mills of the normal rate type. Both groups had a different electricity energy demand. For the TOU group, the electricity power demand value was 3.836 USD/kW, the value of electrical energy on Peak was 0.106 USD/unit and off Peak 0.063 USD. For the normal rate group, electricity power demand value was 5.664 USD/kW, while the value of electrical energy was 0.078 USD/unit [11]. As the electricity requirement of the normal rate is increased every 1 kW, that will be over cost about 5.664 USD/kW while the electricity requirement of TOU will be 3.836 USD/kW only. That is the reason that the cost of TOU at nighttime between 22.00 pm to 09.00 am will be cheaper than daytime at 09.00 am to 22.00 pm. Therefore, choosing the electricity user type affected the EEC.

The total production of the ten rice mills varied from 33,967 to 129,632 ton/yr, with the average at 55,481 ton/yr. Their electricity power peak value was between 148 and 749 kW, and the average electricity power peak was 362 kW. The EEC value costs were between 529,200 and 3,789,600 kWh/yr, with an average of 1,183,271 kWh/yr. Their SEC was between 15.58 and 29.23 kWh/ton, with the average at 19.50 kWh/ton. The electricity EP of the rice mills were therefore between 69,331 and 408,998 USD/yr, with an average of 141,452 USD/yr. The electrical energy value per production quantity was between 1.63 and 3.16 USD/ton, with an average of 2.37 USD/ton. The EEC varied according to the rice quality and quantity. The higher electricity quantity required to meet demand caused heavy duty on the electrical motors, and if overtime work exceeded the Provincial Electricity Authority specific time, then this resulted in higher electrical power cost, follow as Table 1.

Table 1. The electrical energy and cost of the rice mills.

Location	**Actual production**	**Electric power**	**EEC**	**EP**	**SEC**	**SEP**
(Province)	**(ton/yr)**	**(kW)**	**(kWh/yr)**	**(USD/yr)**	**(kWh/ton)**	**(USD/ton)**
Amnatcharoen	78,444	746	1,643,700	228,309	20.95	2.91
Mukdahan	45,003	458	813,528	116,790	18.08	2.60
Maha Sarakham	63,087	327	1,342,307	158,256	21.28	2.51
Khon Kaen	129,632	749	3,789,600	408,998	29.23	3.16
Yasothon	39,748	259	659,420	81,652	16.59	2.05
Nakhon Phanom	35,469	204	567,526	74,032	16.00	2.09
Roi Et	45,064	406	1,083,420	131,710	24.04	2.92
Nong Khai	33,967	160	529,200	68,573	15.58	2.02
Udon Thani 1	41,799	148	688,388	76,866	16.47	1.84
Udon Thani 2	42,598	160	715,620	69,331	16.80	1.63
Average	55,481	362	1,183,271	141,452	19.50	2.37

3.2. EEC of Equipment of Rice Mills

The EEC of rice mills is important information that can be used as guidelines for energy saving to reduce costs and increase profits for the milling entrepreneur. The proportion of EEC for each equipment is shown in Fig. 2 and Table 2.

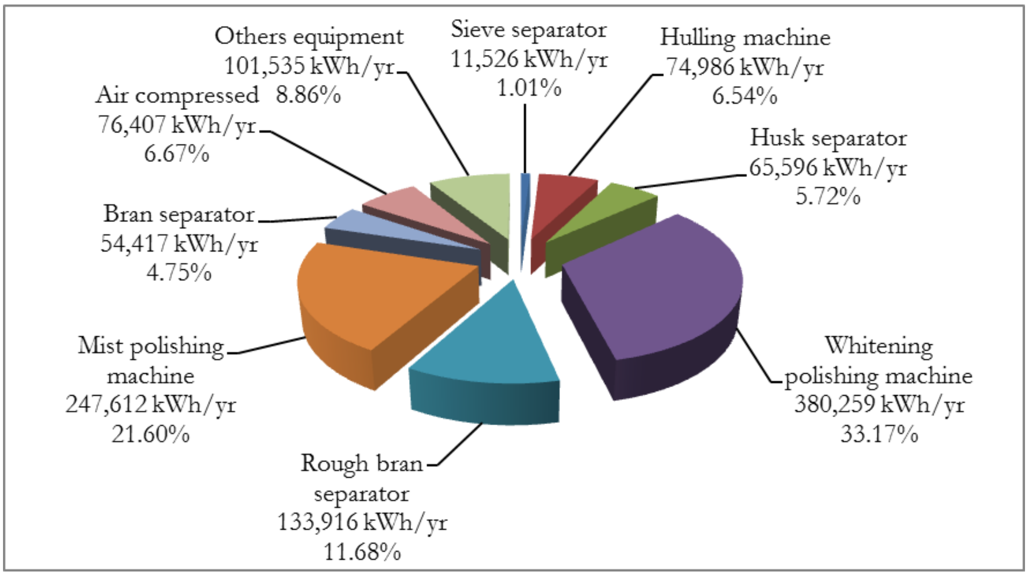

Fig. 2. The proportion of power consumption for each tooling process.

Table 2. The energy consumption of the equipment.

Equipment	EEC (kWh/yr)	EC (USD/yr)
Sieve separator	11,526	1,400
Hulling machine	74,986	9,056
Husk separator	65,596	7,972
Whitening polishing machine	380,259	45,090
Rough bran separator	133,916	15,171
Mist polishing machine	247,612	30,449
Bran separator	54,417	6,879
Air compressor	76,407	9,148
Others equipment	101,535	12,315

Figure 2 shows that the whitening polishing machine use the highest EEC at 33.17% of the total. Second equipment is taken by the mist polishing machine at 21.60%. The remaining equipment such as rough bran separator, others equipment, air compressor, hulling machine, husk separator, bran separator, and sieve separator consumed EEC of 11.68, 8.86, 6.67, 6.54, 5.72, 4.75, and 1.01%, respectively. For the whitening polishing machine was the highest, which correlated with the results of W. Ekasilp. et al. [12] because, the whitening polisher has many large motors which require high electricity consumption. The sieve separator on the other hand has smallest motors, and therefore lowest EEC of the equipment. Therefore, guidelines to develop or improve the whitening polishing machine should be concentrate on the highest EEC first.

From Table 2 Power consumption of the device was analysis by Power Quality Analyzers (Chauvin Arnoux C.A. 8332B) and found that the sieve separator had motor power between 1.5 and 3.7 kW, and consumed an average electricity of 11,526 kWh/yr costing 1,400 USD/yr. The sieve separator requires a large space so that paddy rice can be easily loaded. Heavier loads on the motor use more electricity and take longer for cleaning, so we would expect an increase in the EEC.

The hulling machines have their own electrical motors powered between 5.5 and 7.5 kW. The EEC for the hulling process averaged 74,986 kWh/yr, with average electricity power costs of 9,056 USD/yr. Because the grain cracker is high speed in the peel off, that is also affect to high energy demand [13]. Moreover, the excess grain which is fed into the machine could not peel off easily [14] As a result to re-peel off and increasing of the power consumption

The husk separation from the rice grains used powered motors from 11 to 18.5 kW. This process had an average electricity consumption of 65,596 kWh/yr, and an electrical power value average of 7,972 USD/yr. Due to the big fan motors and duration of motors running needs high power to startup. It cause to result of the power in baht per unit increased. This is accord with the study of J. Nissayan and A. Artnaseaw [15] found that the husk separation by air blower type is the energy consumption rate about of 16.8 unit per ton of paddy. Which is less than the husk separation by air suction type that use generally in the rice mills 30%.

The whitening polishing machine used a power motor between 15 and 37 kW. Their EEC averaged 380,259 kWh/yr, and their electrical energy value averaged 45,090 USD/yr. Owning to before arranging the rice into the rice whitener, entrepreneurs will provide rice to the temperature drops. Therefore, the grain has a high rate of resistance to fracture, and low fracture seeds, but electricity consumption [16] and the power of the whitening process was increased as well.

The rough bran separator used power motors rated between 11 and 18.5 kW. This process had an average EEC of 133,916 kWh/yr, and average electrical power value cost of 15,171 USD/yr. Due to the similar principle of the husk separation and length tube to suck rice bran is quite a long that can be affected to need high power which is related to the study of J. Nissayan and A. Artnaseaw [15].

The mist polishing machine used a power motor between 18.5 and 37 kW. The EEC averaged 247,612 kWh/yr, and the electrical energy value averaged 30,449 USD/yr. Because of the low speed of large motors usability in polishing rice and water spraying to reduce the temperature of the polished rice, It will be cause of resistance to fracture but high electricity consumption [4, 16].

The bran separator used a power motor between 11 and 18.5 kW. This process used average electrical energy of 54,417 kWh/yr, with average electricity energy value at 6,879 USD/yr. Because of it is to spray water to reduce the temperature of rice. That is the result of soft bran splitting to difficult. Therefore, it makes electrical energy in the processing is too high. [4, 15, 16].

The air compressed system for rice packing and color sorting used a power motor rated between 3.7 and 30 kW. This process consumed average electrical energy of 76,407 kWh/yr, and had an average electricity energy value at 9,148 USD/yr. Due to the air compressor in the rice mill is pressure more over setting than to use. [17] Then, an electrical energy using and power energy cost is too high.

All the tooling energy requirements were inspected and measured while the rice mill was operating. However, some tooling parts which consumed electrical energy could not be measured, such as the lighting systems, air conditioners, bucket conveyor, and sieve motors for size separation. These all had an EEC average value of 101,535 kWh/yr, with electricity energy costs at 12,315 USD/yr.

3.3. The Electrical Energy Conservation of Equipment in Rice Milling

3.3.1. The Electrical Energy Conservation in Electric Power Transmission

As shown in Table 3 the energy conservation in transformer system of the rice mill. The power factor of processing is value at lower than 0.85. That is the result to reduced ability to distribute an electricity and heating in a distribution line. The rice mills for this study were added to the power factor is higher by capacitors installing. There are results to reduced power loss, makes use of electrical energy and including fines power factor decreased as well. [18, 19] The adjustment of the power factor found that EEC before improving has average of 46,318.17 kWh/yr while after adjusted average of 31,987.17 kWh/yr, fines power factor averaged 0.05 USD/ton, which is represent to an average energy savings about of 0.23 kWh/ton and average savings in amount of 0.114 USD/ton.

Table 3 Average data for the electrical energy conservation in electric power transmission.

Province	EEC (kWh/yr)		Forfeit PF	Saving	
	Before	After	(USD/ton)	SEC (kWh/ton)	SEP (USD/ton)
Yasothon	24,411.75	15,707.01	0.035	0.22	0.098
Mukdahan	25,293.90	20,436.12	0.060	0.11	0.076
Maha Sarakham	14,023.30	6,971.50	0.003	0.11	0.020
Amnatcharoen	154,875.00	108,066.00	0.070	0.60	0.223
Roi Et	12,986.88	8,755.20	0.070	0.09	0.152
Average	46,318.17	31,987.17	0.05	0.23	0.114

3.3.2. The Electrical Energy Conservation in Electric Motors

The energy conservation in electric motors system of the rice mill by reducing the speed of the large motor such as the whitening polishing machine and mist polishing machine. Which the rice mills for this study were installed VSD, to reduce the power surge when the motor has starts up and also reduce the speed for suitable of application. The result showed that EEC of the rice mill was reduced accordingly [13, 20, 21] by EEC value before update was 134,184.45 kWh/yr while after the improvement was about of 106,700.13 kWh/year. This is representing to an average energy savings about of 0.57 kWh/ton and savings in amount of 0.071 USD/ton, as shown in Table 4.

Table 4 Average data for the electrical energy conservation in electric motors.

Province	EEC (kWh/yr)		Saving	
	Before	After	SEC (kWh/ton)	SEP (USD/ton)
Yasothon	59,884.11	43,653.65	0.41	0.051
Maha Sarakham	406,310.40	322,329.60	1.33	0.157
Amnatcharoen	89,853.75	69,968.32	0.25	0.035
Roi Et	105,857.28	82,429.06	0.52	0.063
Nakhon Phanom	27,014.40	15,120.00	0.34	0.049
Nong Khai	57,285.00	41,760.00	0.46	0.059
Udon Thani 1	76,230.72	67,679.37	0.20	0.023
Udon Thani 2	245,280.42	200,762.52	1.05	0.101
Khon Kaen	139,944.00	108,974.04	0.24	0.026
Average	134,184.45	106,700.13	0.57	0.071

3.3.3. The electrical energy conservation in air compressor.

As shown in Table 5, the energy conservation in air compressor of the rice mill. Due to the production process is pressure more over setting than to use and air leak in the system cause of the power consumption increasing. Then, the reducing of pressure and check at leak points will be the result to decreased electricity consumption. [17, 20, 22, 23] In the other hand, reducing the pressure that can be showed that the EEC value before the improvement was 45,176.79 kWh/yr while after the improvement was 38,066.60 kWh/yr. This is representing to energy savings up to 0.15 kWh/ton, and savings in amount of 0.020 USD/ton.

Table 5 Average data for the electrical energy conservation in air compressor.

Province	EEC (kWh/yr)		Saving	
	Before	After	SEC (kWh/ton)	SEP (USD/ton)
Yasothon	592.42	137.22	0.01	0.001
Mukdahan	48,014.44	22,752.64	0.56	0.081
Maha Sarakham	11,729.97	9,480.16	0.04	0.004
Amnatcharoen	10,944.15	6,504.75	0.06	0.008
Roi Et	63,689.09	52,328.42	0.25	0.031
Nakhon Phanom	13,270.90	10,928.48	0.07	0.010
Nong Khai	139,862.82	130,409.16	0.28	0.036
Udon Thani 1	42,693.12	39,653.37	0.07	0.008
Khon Kaen	75,794.21	70,405.24	0.04	0.005
Average	45,176.79	38,066.60	0.15	0.020

4. Conclusion

The electrical energy used by the rice mills is variable and depends on rice quality and quantity. Rice mills that require high productivity to meet demand may overload their electric motors, and overtime working of TOU or the normal rate will be the high energy cost, therefore, it is also the increasing of electrical power requirement.

The whitening polishing machine had the highest EEC, followed by mist polishing machine, Rough bran separator, others equipment, air compressed, hulling machine, husk separator, bran separator, and sieve separator respectively. Therefore, to improve EEC in rice mills it is best to focus on the equipment with the highest energy consumption.

The guidelines for electrical energy saving for each tooling process in rice mills can be divided into three power saving sections: electric power transmission, the electric motor system, and the compressed air system.

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Appendix

EEC	=	Electric energy consumption	
EP	=	Energy cost	
SEC	=	Specific energy consumption	
SEP	=	Specific energy cost	
PEA	=	Provincial Electricity Authority	
TOU	=	Time of Use Rate	
		Peak 09.00 am to 22.00 pm	Monday to Friday, Royal ploughing ceremony
		Off peak 22.00 am to 09.00 pm	Sunday to Friday, Royal ploughing ceremony day
		and off peak 00.00 am to 24.00 pm	Excluding holiday compensation