International Journal of Mechanical and Materials Engineering (IJMME), Vol. 5 (2010), No. 1, 87-94.

A STUDY OF ENERGY EFFICIENCY, ECONOMIC AND ENVIRONMENTAL BENEFITS OF A COOLING TOWER

R. Saidur[a], *E.A. Abdelaziz*[a], *M. Hasanuzzaman*[a] *and M.A.H. Mamun*[b]
[a]Department of Mechanical Engineering
University of Malaya, 50603 Kuala Lumpur, Malaysia
[b]Department of Mechanical Engineering
Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh
Email: hasan@um.edu.my / hasan.buet99@gmail.com

ABSTRACT

Cooling tower is one of the most important utilities in industrial and residential facilities. This paper estimates the energy efficiency, economic and environmental benefits of cooling tower. Energy-saving measures by using the high efficient motors and variable speed drive (VSD) were applied to save energy. By installing VSD in the cooling tower's fans, annual energy saving have been found to be 202,972 kWh and potential emissions reduction is about 120 ton of CO_2, 661 kg of SO_2, 312 kg of NO_x and 661 kg of CO at different cooling load. By using high efficient motor, emissions reduction are about 6.97 ton of CO_2, 38,400 kg of SO_2, 18,109 kg of NO_x and 4,601 kg of CO at 50 % load. A sizeable amount of utility bill can be saved by using high efficient motors and applying VSDs. Payback periods for different energy savings measures have been estimated and found to be economically viable.

Keywords: Energy, Efficiency, Cooling tower, Environment.

1. INTRODUCTION

Nowadays energy issue is one of the most sensitive and complicated issues in the world. Fossil fuels which are the main source of energy are depleting and rising anxiety around the world about their negative effect on the atmosphere and the environment (Gan and Li, 2008). Energy is the key input in the development and economic growth. Malaysia has experienced strong economic growth through the last decade (Saidur *et al.*, 2007; Hasanuzzaman *et al.*, 2008). Malaysian economy grew at a rate of 5 % in 2005 and the overall energy demand is expected to increase at an average rate of 6 % per annum (Saidur *et al.*, 2009a). Another study indicated that between 2000 and 2005 energy consumption grew at a fast rate of 5.6 % to achieve 38.9 Mtoe in 2005. The final energy consumption is expected to reach 98.7 Mtoe in 2030, nearly three times the 2002 (APERC, 2006) that is shown in Figure 1. Figure 2 shows sector wise energy consumption in Malaysia.

Using more energy will lead in tandem to more concentration of greenhouse gases such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxide (NO_x) and carbon monoxide (CO) which have disastrous consequences for the earth's climate like rising temperature, drought, floods, famine and economic chaos (Mahlia, 2002). The Intergovernmental Panel on Climate Change (IPCC) reported that continued emissions will lead to a temperature increase of between 1.4 and 5.8 °C over the period from 1990 to 2100. Department of Energy in USA is highlighted that global carbon emissions are rising more than 2% per year and by 2015 may be more than 50% above 1997 level, all of which because of increasing energy demand and inefficient way of utilizing energy (Mahmoud *et al.*, 2009). A key method of reducing energy's costs while retaining its benefits is to use it more efficiently. Improving energy efficiency depends on many technical, economic, institutional, and political factors (IEE, 1993). Cooling tower is commonly used in central air conditioning systems to cool the circulating warm water from the chiller condenser as well as most common equipment in the industry. There is about 75% of cooling due to the evaporative effect while the rest of 25 % is sensible heat transfer. The operation of cooling tower usually depends on the cooling load required by the chiller. Therefore, its cooling capacity could be reduced when the chiller is operating at part load. Consequently, the cooling tower fans and pumps power consumptions could also be reduced. Variable speed drives are used to control the operation of rotating devices such as fans and pumps more efficiently. It can be defined as an electronic power converter that generates a multi-phase, variable frequency output to drive a standard ac induction motor, and to modulate and control the motor's speed, torque and mechanical power output. AC drive can be described by different terms. AFD, VSD, VFD and inverters also are employed. VSD's have been used to provide significant savings in a number of applications around the world (Saidur *et al.*, 2010; Saidur *et al.*, 2009b).

The EU-funded SAVE II Project identified large-scale application of variable-speed drives as the motor systems technology having the most significant energy savings potential. Savings within the electrical drive system alone are projected to be 6 billion kWh per annum in the UK (Mecrow and Jack, 2008). Therefore, according to the Affinity Laws of speed, pressure, and horsepower, to produce 50% flow, the pump would be run at 50% speed. At this operating point, the pump would require only 12.5% of rated horsepower which is regarded as a significant energy saving (Lönnberg, 2007).

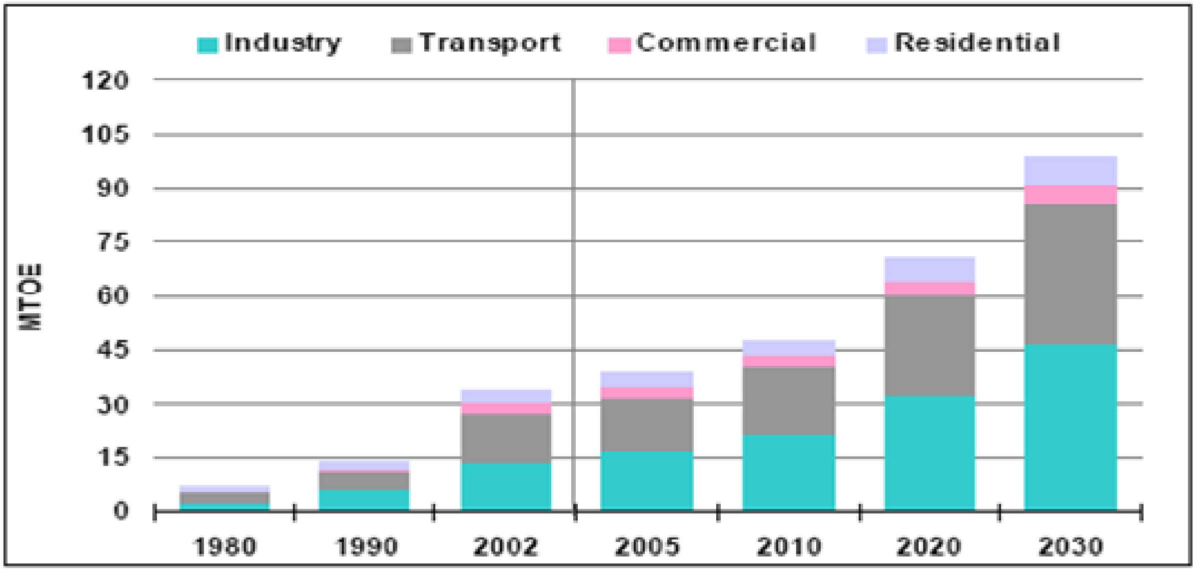

Figure 1 Statistics of energy uses in Malaysia from 1980-2030 (APERC, 2006)

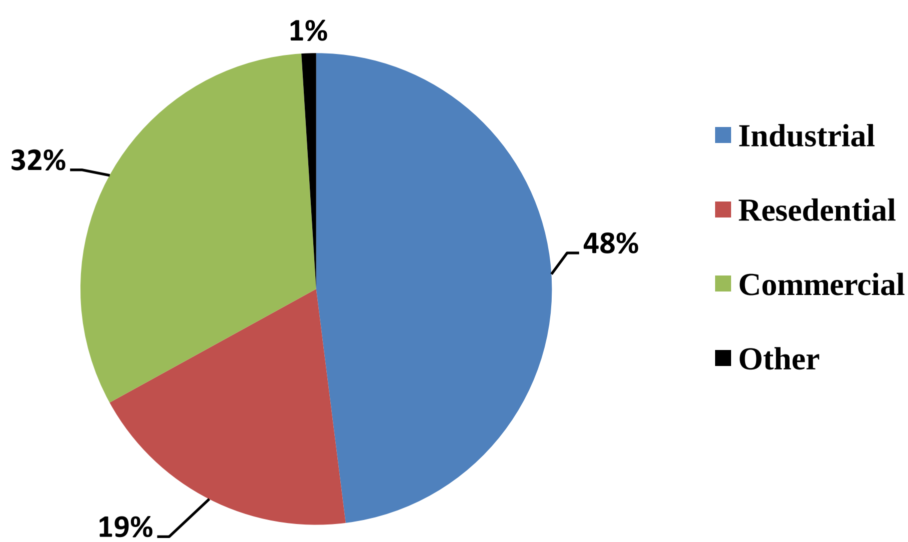

Figure 2 Statistics of energy uses in Malaysia in 2007 (Saidur *et al.*, 2009b)

Northern Foods industry in the UK has implemented VSD and achieved an annual energy saving of 769 MWh/year, over USD 45483 saving a year in electricity costs, payback period of just 10 months and annual CO_2 reduction of 338 ton. The energy saved by retrofitting a boiler system by running variable frequencies translates easily to dollars. A 50 hp motor operating at a slower speed and utilizing only 40 hp, 12 hours per day, 365 days per year, with a load factor of one and motor efficiency of 86%, will save $3,360 per year (based on $0.10/kWh) (Willems and Pipkin, 2009). In order to improve the boiler efficiency, a fan motor speed is decreased from 1450 to 255 rpm by using VSD to reduce the amount of excess air and found a reduction in stack temperature from 195 to 145 °C, increasing of the boiler efficiency 2.5%, 8000 kWh electrical energy saving in a month and payback period of 1.8 month (Ozdemir, 2004). Motor efficiency can be increased when reducing the electric power consumption for a given mechanical energy out, the motor losses must be reduced and the electric motor efficiency increased. Switching to a more efficient motors will result in energy saving, emissions reduction and bill saving.

The aim of this study is to analyze the energy use, energy savings, bill savings and emission reduction of cooling tower. Cooling tower is very common equipment in the industrial and residential sector, consumes a significant amount of energy, the efficiency improvement and reduction of losses will play a significant role in energy savings and mitigation of environmental pollution and may be useful to policy makers, engineers, industrial energy users and scientist.

2. METHODLOGY

2.1 Data collection

Data has been collected from Dewan Tunku Chancellor (DTC), University of Malaya. The information of cooling tower covered in this study has been shown as a summary in the Table 1.

Table 1 Cooling tower information

Cooling load (RT)	No of Towers	Total Fan Power (kW)	Operating hour (%)	Fan speed %
1100	2	44	5	0.98
1000	2	44	10	0.89
900	2	44	25	0.80
800	2	44	20	0.71
700	2	44	10	0.63
600	2	44	10	0.54
500	2	22	10	0.45
400	2	22	5	0.40
300	2	22	5	0.40

2.2 Variable speed drives

Many rotating systems are designed to operate at maximum load conditions. However, most of them operate at their full load only for short periods of time. This often results in many systems operating inefficiently over long periods of time. The efficiency of such systems can be improved by varying their capacity to match actual load requirements. The most common method is to modulate the speed of the motors of fans to vary their capacity using VSDs. Variable frequency drives provide continuous control, matching motor speed to the specific demands of the work being performed (Saidur, 2009).

2.2.1 Energy saving by VSD

Annual energy consumption of cooling tower's fan without using variable speed drive can be expressed mathematically from the following equation:

$$AEC_{\ BAU} = \frac{TFP_{kW} \times OPH_{\%} \times 24 \times 365}{\eta_{\ pump}} \qquad (1)$$

Annual energy consumption when using variable speed drive depends on annual energy consumption without using VSD and speed reduction ratio. This can be calculated from the following equation:

$$AEC_{\ NP} = AEC_{\ BAU} \times (FS_{\%})^3 \qquad (2)$$

Annual energy saving when using VSD is therefore the difference between annual energy consumption without using VSD and annual energy consumption when using VSD. The annual energy saving equals:

$$AES_{VSD} = AEC_{\ BAU} - AEC_{\ NP} \qquad (3)$$

2.2.2 Emission reduction by VSD

The environmental impact of the VSD is a potential reduction of greenhouse gasses or other element that have a negative impact on the environment. The common potential reductions in this study include carbon dioxide CO_2, sulfur dioxide SO_2, nitrogen oxide NO_x and carbon monoxide CO. This study is concerned with all these emissions. The emission factors of all these gases and the percentage of electricity generation based on fuel types are shown in the Table 2 and 3. The emissions reduction is a function of energy saving, percentage of fuel used and emission factor of the particular fuel. Thus emissions reduction can be calculated using the following equations:

$$AER_{CO2} = AES_{\ VSD} \times \sum(\%F \times EF_{CO2}) \qquad (4)$$

$$AER_{SO2} = AES_{VSD} \times \sum(\%F \times EF_{SO2}) \quad (5)$$

$$AER_{NOx} = AES_{VSD} \times \sum(\%F \times EF_{NOx}) \quad (6)$$

$$AER_{CO} = AES_{VSD} \times \sum(\%F \times EF_{CO}) \quad (7)$$

Table 2 Emission factors of fossil fuels for electricity generation (Mahlia, 2002)

Fuels	Emission factor (kg/KWh)			
	CO_2	SO_2	NO_x	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Gas	0.53	0.0005	0.0009	0.0005
Hydro	0.00	0.0000	0.0000	0.0000
Others	0.00	0.0000	0.0000	0.0000

Table 3 Percentage of electricity generation based on fuel types (Mahlia, 2002)

Year	Coal	Petroleum	Gas	Hydro
1994	9.30	22.30	51.70	16.70
2000	15.00	5.00	70.00	10.00
2002	14.96	4.24	65.20	15.60
2003	15.06	3.89	62.95	18.10
2004	15.24	3.56	60.80	20.40
2005	15.50	3.25	58.75	22.50
2006	15.84	2.96	56.80	24.40
2007	16.26	2.69	54.95	26.10
2008	16.76	2.44	53.20	27.60
2009	17.34	2.21	51.55	28.90
2010	18.00	2.00	50.00	30.00
2011	18.74	1.81	48.55	30.90
2012	19.56	1.64	47.20	31.60
2013	20.46	1.49	45.95	32.10
2014	21.44	1.36	44.80	32.40
2015	22.50	1.25	43.75	32.50
2016	23.64	1.16	42.80	32.40
2017	24.86	1.09	41.95	32.10
2018	26.16	1.04	41.20	31.60
2019	27.54	1.01	40.55	30.90
2020	29.00	1.00	40.00	30.00

2.2.3 Cost benefit analysis by VSD

When using VSD annual bill saving is related to annual energy saving and the unit price of energy. Payback period is the function of the incremental cost of VSD divided by the annual bill saving of VSD in a particular year. Incremental prices of VSD are shown in Table 4. The formula that associated with the above cost savings method can be calculated as:

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

Table 4 Incremental costs of VSD (Saidur, 2009)

Pump power (HP)	Incremental cost (USD)
15	4,167
20	5,316
25	6.123
30	6,835

Payback period can be expressed mathematically from the following equation:

$$PBP_{VSD} = \frac{IC_{VSD}}{ABS_{VSD}} \quad (9)$$

2.3 High efficient motor

A high efficiency motor is a motor that uses low-loss materials to reduce core and copper losses. Therefore, it generates less heat and improves the efficiency. Electric motor manufacturers seek methods for improving the motor efficiency, which resulted in a new generation of electric motors that are known as energy-efficient electric motors. Several leading electric motor manufacturers, mainly in the US and Europe have developed product lines of energy efficient electric motors (Saidur, 2009).

2.3.1 Energy saving by high efficient motors

Annual energy consumption of cooling tower's fan when using standard motors can be expressed mathematically from the following equation:

$$AEC_{std} = \frac{P_{kW} \times N_{pumps} \times OPH}{\eta_{pump,std}} \quad (10)$$

Annual energy consumption when using high efficient motors can be calculated from the following equation:

$$AEC_{hem} = \frac{P_{kW} \times N_{pumps} \times OPH}{\eta_{pump,ee}} \quad (11)$$

Annual energy saving when using high efficient motors is therefore the difference between annual energy consumption when using standard motors and annual energy consumption when using high efficient motors. The annual energy saving equals:

$$AES_{ee} = AEC_{std} - AEC_{hem} \quad (12)$$

Thus energy saving percentage (%) can be calculated as follow:

$$\% HEM_{ES} = \frac{AES_{hem}}{AEC_{std}} \quad (13)$$

The efficiencies of standard and high efficient motors at different load are shown in Table 5.

Table 5 Efficiency of standard and high efficiency motors at different loads (Saidur *et al.*, 2009b)

Motor HP	Load (50%)		Load (75%)		Load (100%)	
	$\eta_{Fan,std}$	$\eta_{Fan,ee}$	$\eta_{Fan,std}$	$\eta_{Fan,ee}$	$\eta_{Fan,std}$	$\eta_{Fan,ee}$
30	88.43	90.89	89.32	91.73	90.70	91.83

2.3.2 Emission reduction by high efficient motors

The environmental impact of the high efficient motors is a potential reduction of greenhouse gasses or other element that have a negative impact on the environment. The common potential reductions in this study include carbon dioxide CO_2, sulfur dioxide SO_2, nitrogen oxide NO_x and carbon monoxide CO. This study is concern with all these emissions. The emission factors of all these gases and the percentage of electricity generation based on fuel types are shown in the Table 4 and 5. The emissions reduction is a function of energy saving, percentage of fuel used and emission factor of the particular fuel. Thus emissions reduction can be calculated using the following equations:

$$AER_{CO2} = AES_{hem} \times \sum(\%F \times EF_{CO2}) \quad (14)$$

$$AER_{SO2} = AES_{hem} \times \sum(\%F \times EF_{SO2}) \quad (15)$$

$$AER_{NOx} = AES_{hem} \times \sum(\%F \times EF_{NOx}) \quad (16)$$

$$AER_{CO} = AES_{hem} \times \sum(\%F \times EF_{CO}) \quad (17)$$

2.3.3 Cost benefit analysis by high efficient motors

When using high efficient motors, annual bill saving is related to annual energy saving and the unit price of energy. The formula that associated with the above cost savings method can be calculated as:

$$ABS_{hem} = AES_{hem} \times UEP \quad (18)$$

Table 6 Incremental costs of high efficient motors (Saidur, 2009)

Pump power (kW)	Incremental cost (USD)
15	111
20	186
30	273
40	371
75	678

Payback period is the function of the incremental cost of high efficient motors divided by the annual bill saving achieved by high efficient motors in a particular year. Incremental prices of high efficient motors are shown in Table 6. Thus, Payback period can be expressed mathematically from the following equation:

$$PBP_{hem} = \frac{IC_{hem}}{ABS_{hem}} \quad (19)$$

3. RESULTS AND DISCUSSION

3.1 Variable speed drive results

3.1.1 Energy saving by using VSD

When installing variable speed drives in the cooling tower's fans which have already been shown in Table 3 and based on the equations (1-3), the results of total annual energy saving have been found to be 202,972 kWh.

3.2.2 Emissions reduction by using VSD

Based on the input data in Tables 2, 3, Figure 4 and equations (4-7), the results of total annual CO_2, SO_2, CO and NO_x emissions reduction when using VSD have been quantified and illustrated in Figure 3.

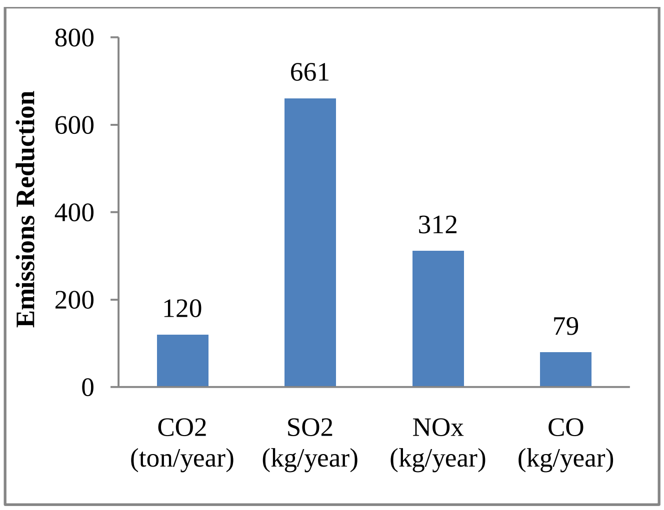

Figure 3 Total annual emissions reduction by using VSD

The results from Figure 3 show that the total emissions reduction are about 120 ton of CO_2, 661 kg of SO_2, 312 kg of NO_x and 661 kg of CO at different cooling load when using VSD. These results represent a huge amount of emissions reduction that can be achieved when applying VSD in cooling tower' fans.

3.2.3 Cost benefit analysis by using VSD

Based on total annual energy saving of 202,972 kWh and equation (8), the results of total annual bill saving with an average electricity price of RM 0.236/kWh have been calculated to be RM 47,901. Based on equation 9, VSD incremental cost of RM 22,829 (see Table 4) and total annual bill saving of RM 47,901, the average payback period have been found to be 0.95 year in each cooling tower's fan covered in this study. It can be observed that this payback period is very acceptable to boost installing VSD in this cooling tower.

3.2 High efficient motors

3.2.1 Energy saving by high efficient motors

When installing high efficient motors in the cooling tower's fan which have been shown in Table 1 and based on the equations (10-13) and Table 5, the results of total annual energy saving in kWh and energy saving percentage % of this application have been quantified and illustrated in Figures 4 and 5 respectively.

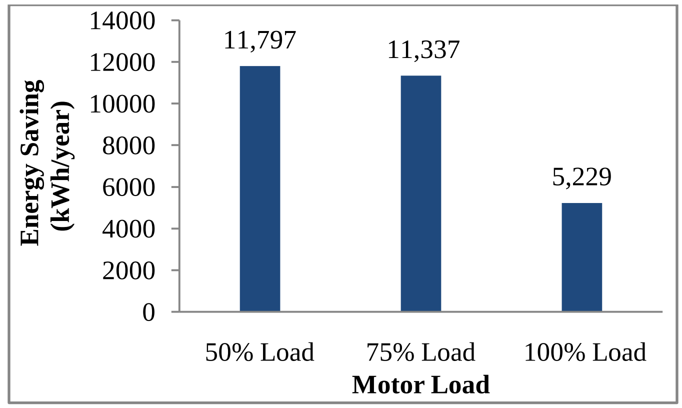

Figure 4 Total annual energy saving (kWh/year) by high efficient motors

The results from Figure 5 show that the total annual energy savings in the cooling tower depend on motors load. Annual energy saving decreased from 11,797 kWh in 50 % load to 5,229 kWh in 100 % load. These results represent a huge amount of energy saving that can be achieved when using high efficient motors in DTC cooling towers' fans.

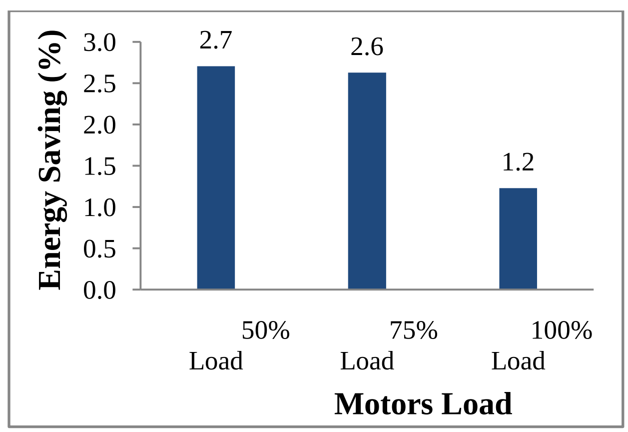

Figure 5 Energy saving percentage (%) by high efficient motors

The results from Figure 6 indicate that energy savings percentage in the DTC cooling tower when installing high efficient motor ranges from 2.71 % in 50 % load to 1.23 % in 100 % load.

3.2.2 Emissions reduction by high efficient motors

Based on the input data in Tables 2, 3, Figure 4 and equations (14-17), the results of total annual CO_2, SO_2, CO and NO_x emissions reduction by high efficient motors have been quantified and tabulated in Figure 7, 8 and 9 respectively.

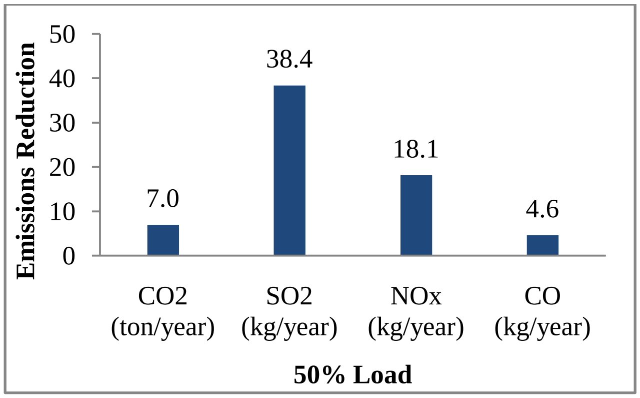

Figure 6 Total annual emissions reduction by high efficient motors at 50% loads

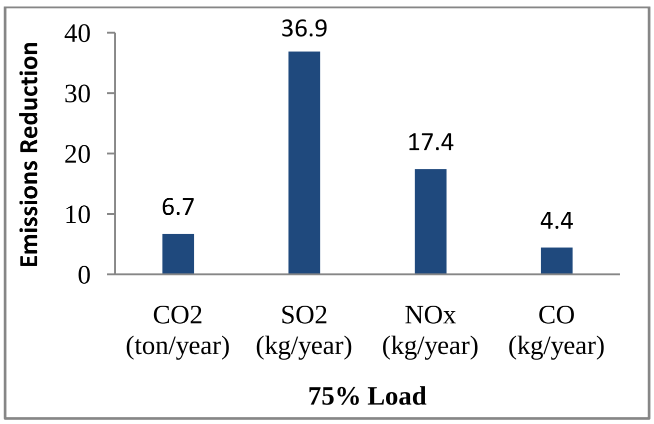

Figure 7 Total annual emissions reduction by high efficient motors at 75% load

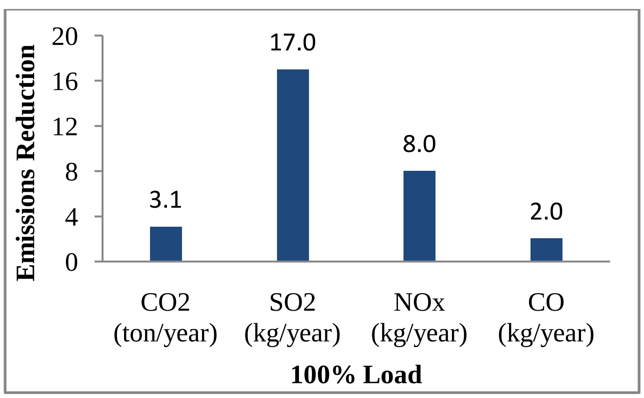

Figure 8 Total annual emissions reduction by high efficient motors at 100% load

The results from Figure 6, 7 and 8 respectively show that the total emissions reduction are about 6.97 ton of CO_2, 38,400 kg of SO_2, 18,109 kg of NO_x and 4,601 kg of CO by high efficient motors at 50 % load. These results represent a huge amount of emissions reduction that can be achieved by high efficient motors in DTC cooling towers' fans.

3.2.3 Cost benefit analysis by high efficient motors

Based on the input data of Incremental costs of high efficient motors in Table 6 and total annual energy saving Figure 4 and equations (18 and 19), the results of total annual bill saving with an average electricity price of RM 0.236/KWh and average payback period have been quantified and illustrated in Figures 10 and 11 respectively:

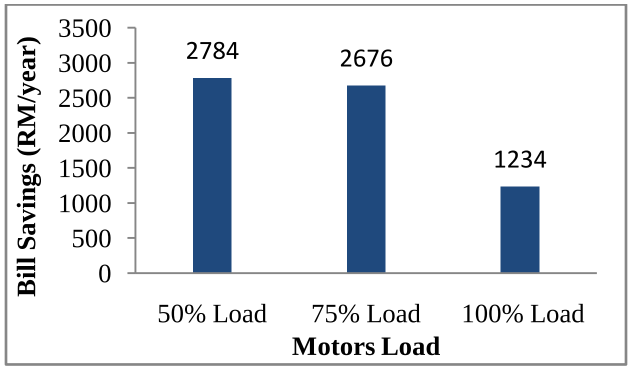

Figure 9 Total annual bill saving (RM/year) by high efficient motor

The results from Figure 10 show that the total annual bill savings by high efficient motor in the cooling tower covered in this study are about RM 2,784 in 50 % load, RM 2,676 in 75 % load and RM 1,234 in 100 % load. These results represent a huge amount of bill saving that can be achieved by high efficient motors in DTC cooling towers' fans.

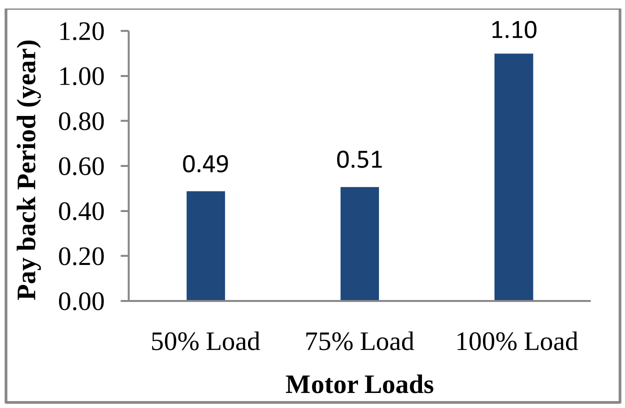

Figure 10 Average payback periods by high efficient motors

The result from Figure 10 shows that the average payback periods ranges from 0.49 year in 50 % load to 0.51 year in 75 % load and 1.10 year in 100 % load. It can be observed that this payback period is very acceptable to boost installing high efficient motors in DTC cooling towers' fans.

4. CONCLUSION

This study is concerned with an energy saving, economic and environmental analysis of a cooling tower in DTC, University of Malaya. When installing variable speed drive in DTC's cooling tower fans, it has been found that total amount of 202,972 kWh of energy could be saved annually, 120 ton of CO_2, 661 kg of SO_2, 312 kg of NO_x, 79 kg of CO could be reduced, RM 47,901 bill saving and 0.95 average payback period could be achieved when reducing the speed of these pumps in different percentage. These results indicate that VSD is an energy savings, economically viable and emissions reduction application specially when increasing the speed reduction percentage of pumps. When installing high efficient motors in DTC cooling tower fans, it has been found that total annual amount of 11,797; 11,337 and 5,229 kWh of energy could be saved in 50 %, 75 % and 100 % motors load respectively. Also it has been found that 6.79, 6.69 and 3.09 ton of CO_2 could be saved annually in 50 %, 75 % and 100 % motors load respectively. An amount of RM 2,784 bill savings and 0.49 average payback periods could be achieved when using more efficient motors in case of 50 % load. It is concluded that by applying VDS and high efficient motors a huge amount of can be saved economically as well as emissions.

REFERENCES

APERC, 2006 Asia Pacific Energy Research Centre, Energy demand and supply Outlook. http://www.ieej.or.jp/aperc/2006pdf/Outlook2006/ Whole_Report.pdf , Accessed: 15th September 2009.

Gan, P. Y. and Li, Z. 2008 An econometric study on long-term energy outlook and the implications of renewable energy utilization in Malaysia, Energy Policy, 36, 890-899.

Hasanuzzaman, M., Saidur, R. and Masjuki, H. H. 2008 Investigation of energy consumption and energy savings of refrigerator-freezer during open and closed door condition, Journal of Applied Sciences, 8, 1822-1831.

IEE, 1993 Industrial Energy Efficiency, U.S. Congress, Office of Technology Assessment, http://www.fas.org/ota/reports/9330.pdf, Accessed: 1st August 2009

Lönnberg, M. 2007 Variable Speed Drives for energy savings in hospitals. World Pumps, 494, 20-24.

Mahlia, T. M. I. 2002 Emissions from electricity generation in Malaysia, Renewable Energy, 27, 293-300

Mahmoud, A., Shuhaimi, M. and Abdel Samed, M. 2009 A combined process integration and fuel switching strategy for emissions reduction in chemical process plants, Energy, 34, 190-195.

Mecrow, B. C. and Jack, A. G. 2008 Efficiency trends in electric machines and drives, Energy Policy, 36, 4336-4341.

Ozdemir, E. 2004 Energy conservation opportunities with a variable speed controller in a boiler house, Applied Thermal Engineering, 24, 981-993.

Saidur, R. 2009 Energy consumption, energy savings, and emission analysis in Malaysian office buildings, Energy Policy, 37. 4104-4113

Saidur, R., Rahim, N. A., and Hasanuzzaman, M. 2010 A review on compressed air energy use and energy savings, Renewable and Sustainable Energy Reviews, 14(4), 1135-1153.

Saidur, R, Hasanuzzaman, M., Sattar, M. A., Masjuki, H. H, Irfan Anjum, M, and Mohiuddin, A. K. M. 2007 An analysis of energy use, energy intensity and emissions at the industrial sector of Malaysia, International Journal of Mechanical and Materials Engineering, 2, 84 – 92.

Saidur, R, Rahim, N. A, Masjuki, H. H, Mekhilef, S, Ping, H. W. and Jamaluddin, M. F. 2009a End-use energy analysis in the Malaysian industrial sector Energy, 34. 153-158

Saidur, R., Rahim, N. A., Ping, H. W., Jahirul, M. I., Mekhilef, S. and Masjuki, H. H. 2009b, Energy and emission analysis for industrial motors in Malaysia, Energy Policy, 37, 3650-3658.

Tolvanen, J. 2008, LCC approach for big motor-driven systems savings, World Pumps, November, 24-27.

Willems, D. and Pipkin, W. 2009 Does Your Boiler Need a Retrofit? http://www.fmlink.com/ProfResources/Magazines/article.cgi?AFE:afe012308a.html, Accessed: 20th October 2009