Motor Systems Energy Efficiency Supply Curves

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ABSTRACT

Motor-driven equipment accounts for approximately 60% of manufacturing final electricity use worldwide. A major barrier to effective policymaking, and to more global acceptance of the energy efficiency potential in industrial motor systems, is the lack of a transparent methodology for quantifying the magnitude and cost-effectiveness of these energy savings. This paper presents the results of original analyses conducted for five countries and one region to begin to address this barrier. Using a combination of expert opinion and available data from the United States, Canada, the European Union, Thailand, Vietnam, and Brazil, bottom-up energy efficiency supply curve models were constructed to estimate the cost-effective electricity efficiency potentials and CO_2 emission reduction for three types of motor systems (compressed air, pumping, and fan) in industry for the selected countries/region. Based on these analyses, the share of cost-effective electricity saving potential of these systems as compared to the total motor system energy use in the base year varies between 27% and 49% for pumping, 21% and 47% for compressed air, and 14% and 46% for fan systems. The total technical saving potential varies between 43% and 57% for pumping, 29% and 56% for compressed air, and 27% and 46% for fan systems.

Introduction

Motor-driven equipment accounts for approximately 60% of manufacturing final electricity use and are ubiquitous in industrial facilities worldwide. A major barrier to effective policymaking, and to more global acceptance of the energy efficiency potential of motor systems, is the lack of a transparent methodology for quantifying this potential based on sufficient data to document the magnitude and cost-effectiveness of these energy savings by country and by region (McKane, et al. 2008).

This paper and supporting analyses represent an initial effort to address this barrier, thus supporting greater global acceptance of the energy efficiency potential of motor systems, through the construction of a series of motor system efficiency supply curves, by motor system and by country studied. It is important to note, however, the limitations of this initial study based on available data and expert opinion. The purpose of this research is to provide guidance for national policy makers and is not a substitute for a detailed technical assessment of the motor system energy efficiency opportunities of a specific site. Further, while it is important to acknowledge that the methodology employed blurs real variations that may exist in system performance from one industrial sector to another within a country, it is consistent with the level of precision possible with the available data. The authors seek to refine the study findings through further collaboration with other researchers.

The approach used in this study to develop the energy conservation supply curves (in this paper called "motor system energy efficiency supply curves) is different from the one often used in prior studies. Because of data limitations for industrial motor systems at the country-level, detailed bottom-up data typically used for developing a CSC was not available. To overcome this problem, an innovative approach was developed that combines available data with expert opinion to develop energy efficiency supply curves for the motor systems. This approach is explained in detail in the next section.

Methodology

For the Phase 1 analyses, six countries/region were selected that represent varying sizes and levels of industrial development, and for which industrial energy use by sector and some information about motor system efficiency practices were available. These initial six are the United States, Canada, the European Union, Thailand, Vietnam, and Brazil.

Country-specific data was collected in parallel with the motor system expert consultation. After receiving expert input and completing collection of the country-specific data, the Motor System Energy Efficiency Supply Curves were constructed based on the methodology explained below. For a more detailed explanation of the methodology and data (country-specific and system-specific data) used in the study, refer to UNIDO (2010).

Experts Input

Following a literature review to develop a base case of information, a data collection framework was developed to obtain expert input to supplement the existing data. Input was received from thirteen motor system experts, including at least four experts for each of the three systems analyzed (compressed air, fans, and pumping). A Delphi-type approach was used in which several iterations of expert opinion were used to refine the final inputs to the analyses. Defining Three Base Case System Efficiency Scenarios (LOW-MEDIUM-HIGH): The approach used was to establish three base case energy efficiency scenarios (LOW-MEDIUM-HIGH) for each of three system types- pumping, compressed air, and fan systems- based on previous research and the experts' opinion. The first step in establishing a base case was to create and test a unique list of system energy efficiency practices representative of each of three efficiency scenarios for each system type. Tables that provide the list of practices defined for each base-case efficiency level for the pumping, compressed air and fan systems can be found in UNIDO (2010).

The experts were then asked to provide a low to high estimated range of the system energy efficiency (expressed as a %) they would expect to see when assessing a system in an industrial market with the characteristics given for each efficiency scenario. A range of efficiency was requested, rather than a single value, to better align with the variations that are likely to be found in industrial settings.

Data Preparation and Assumptions

As mentioned before, the experts were asked to assign system efficiency, expressed as a range, for LOW-MED-HIGH efficiency base cases. Table 1 below is the consolidated results, including the base case values used in calculating the cost curves. *There was a high degree of agreement among experts for each system type regarding the range of system energy efficiency that would be expected to result from the list of characteristics assigned to the three base cases*. As can be seen, for compressed air and fan systems, we used the average values (average of low and high values) for the LOW-MED-HIGH efficiency base case. However, for pumping systems, we used the low end of the values because application of the energy efficiency measures to the low end values provided an outcome more consistent with experts' opinions. This helped to compensate for lack of interactivity between measures in the analysis, which seemed to be a particular issue for the pumping system measures.

After defining the base case efficiencies for each motor system, we assigned a "base case" to each country of study for the purpose of providing a reference point for the current (pumping, compressed air, or fan) system performance in that country based on the information available for that country. Expert judgment was used for this purpose. Table 2 shows the base case efficiencies assigned to each country for each motor system type.

Table 1. Consolidated System Efficiency for LOW-MED-HIGH Efficiency Base Case

Motor System type	**System efficiency**			
	low end (%)	**high end (%)**	**Average (%)**	**used in our**
Pumping systems				
Low level of efficiency	20.0%	40.0%	30.0%	**20.0%**
Medium level of efficiency	40.0%	60.0%	50.0%	**40.0%**
High level of efficiency	60.0%	75.0%	67.5%	**60.0%**
Compressed Air systems				
Low level of efficiency	2.0%	5.0%	3.5%	**3.5%**
Medium level of efficiency	4.8%	8.0%	6.4%	**6.4%**
High level of efficiency	8.0%	13.0%	10.5%	**10.5%**
Fan systems				
Low level of efficiency	15.0%	30.0%	22.5%	**22.5%**
Medium level of efficiency	30.0%	50.0%	40.0%	**40.0%**
High level of efficiency	50.0%	65.0%	57.5%	**57.5%**

Table 2. Base Case Efficiencies Assigned to Each Country for Each Motor System Type

	Pumping	**Fan**	**Compressed air**
US	MED	MED	MED
Canada	MED	MED	MED
EU	MED	MED	MED
Brazil	MED	Low	Low
Thailand	MED	Low	Low
Vietnam	Low	Low	Low

Determining the impact of energy efficiency measures. A list of potential measures to improve system energy efficiency was developed for each system type and sent to the experts for review. Ten energy-efficiency technologies and measures for pumping systems (US DOE, 2006), ten measures for the fan systems (US DOE, 2003), and sixteen measures for compressed air systems (Compressed Air Challenge and the US Department of Energy, 2003) were analyzed. For each group of measures, we asked experts to provide their opinion on a low to high range of energy savings likely to result from implementation of each measure, taken as an independent action, expressed as a % improvement over each of the LOW-MED-HIGH base cases.

The experts were also asked to provide cost information for each measure, disaggregated by motor size range. The size ranges were selected based on categories developed for the most detailed motor system study available (US DOE, 2002). For the purpose of this study, the term “motor system size” refers to the aggregate motor HP or KW for that system. In addition to the energy efficiency improvement cost, the experts were also asked to provide the useful lifetime of the measures, disaggregated into two categories of operating hours (between1000hrs and 4500 hrs per year and more than 4500 hrs per year). While the installed cost of any given measure is highly dependent on site conditions, the “typical” cost data given by experts was reasonably well correlated for most measures and system sizes, with the exception of systems larger than 1000 hp or 745 kW. Because these wide variations in cost for these systems imposed additional uncertainty on the final results, we decided to exclude them from the final analysis. This reduced the total energy savings potential estimated in some instances, most notably for compressed air systems in the U.S. where these large systems constitute 44% of the total. Because the goal of the analysis is to assess the total potential for energy efficiency in industrial motor systems in the base year assuming 100% penetration rate, the estimated full cost of the measures analyzed was used rather than the incremental cost for energy efficient measures. Therefore, the energy savings is based on the assumption that all the measures are installed in the base year.

Table 3 depicts the typical % improvement in efficiency over each base case efficiency (LOW-MED-HIGH) as well as an estimated typical capital cost of the measure, differentiated by system size for the pumping system. The similar tables for compressed air and fan systems can be found at UNIDO (2010). The base year for all countries/region except the EU was 2008. For the EU, year 2007 was used as the base year based on industrial energy use data availability. Country-specific data was collected from various sources.

US DOE (2002) data and additional inputs from the international experts were used to determine 1) the motor systems electricity use as a % of total electricity use in each industrial sector and 2) each system (pump, compressed air, and fan) electricity use as % of overall motor system electricity use in the sector. The data received were consolidated and used in the analysis for all countries.

In some instances, the initial list of measures included several measures that would be unlikely to be implemented together. For example, it is likely that matching pumping system supply to demand would include one of the measures below, rather than all three.

1.4.1 Trim or change impeller to match output to requirements
1.4.2 Install pony pump
1.4.3 Install new properly sized pump

For this reason, in situations for which there appear to be groupings of several proposed solutions to address a specific problem, the experts were asked:

- Are these measures “either, or” rather than “and” solutions?
- If the measures are “either, or” (in other words they are alternative measures and cannot be implemented at the same time), which one is the most typical or common?

For compressed air systems, heat recovery can be extremely beneficial to improving the energy efficiency of the system because this measure has the potential to address the energy lost through heat of compression (typically 80% of input energy); however, its applicability is dependent on a suitable use for the resulting low grade heat. Compressed air system heat recovery was not included in the final analyses because it would need to be added to the base case rather than applied as a % improvement and consensus could not be reached concerning its potential across countries and climates.

Information was also sought concerning the dependence of energy savings resulting from implementation of each measure on maintenance practices. Altogether, there were twenty (20) measures identified as highly or moderately dependent on maintenance practices, with 60% (12) of them also meeting the cost-effectiveness threshold for four or more countries.

The dependence of so many cost-effective motor system energy efficiency measures on effective maintenance is one indicator of the potential benefits from implementing an energy management system (EnMS), and hints at the potential impact from implementation of the future ISO 50001- Energy management systems. A principal goal of the standard is to foster continual and sustained energy performance improvement through a disciplined approach to operations and maintenance practices.

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Construction of Motor System Efficiency Supply Curves

The Conservation Supply Curve (CSC) used in this study is an analytical tool that captures both the engineering and the economic perspectives of energy conservation. The curve shows the energy conservation potential as a function of the marginal Cost of Conserved Energy (Meier, 1982). The Cost of Conserved Energy can be calculated from Equation 1.

$$\text{Cost of Conserved Energy} = (\text{Annualized capital cost} + \text{Annual change in O\&M costs}) / \text{Annual energy savings} \qquad \textbf{(1)}$$

The annualized capital cost can be calculated from Equation 2.

$$\text{Annualized capital cost} = \text{Capital Cost}*(d/(1-(1+d)^{-n}) \qquad \textbf{(2)}$$

d: discount rate, n: lifetime of the energy efficiency measure.

In this study, a real discount rate of 10% was assumed for the analysis. After calculating the Cost of Conserved Energy for all energy efficiency measures, the measures are ranked in ascending order of Cost of Conserved Energy. In CSCs an energy price line is determined. All measures that fall below the energy price line are identified as “Cost-Effective”. That is, saving a unit of energy for the cost-effective measures is cheaper than buying a unit of energy. On the curves, the width of each measure (plotted on the x-axis) represents the annual energy saved by that measure. The height (plotted on the y-axis) shows the measure’s cost of conserved energy.

Calculation of the annual energy savings and the cost of conserved electricity. The calculation and data analysis methodology used was the same for all three motor system types included in these analyses (i.e. pumping, fan, and compressed air systems). The detail of the calculation of energy saving and cost are not presented in this paper because of lack of space and can be found at UNIDO (2010).

Labor adjustment factor for the cost of measures. Typical capital costs of installing the selected measures were acquired from several experts for each motor system type. These costs include both materials and labor. However, most of these experts are in the U.S., Canada, and European countries and based their cost estimates on the typical costs for those locations. Since most of the energy efficiency measures considered in this study are system improvement measures, a significant portion of the cost is the labor for implementing the measures.

Table 3 Expert Input: Energy Efficiency Measures, % Efficiency Improvement and Cost for Pumping Systems

No.	Energy Efficiency Measure	Typical % improvement in energy efficiency over current Pump system efficiency practice			Expected Useful Life of Measure (Years)	Typical Capital Cost (*US$*)				
		% Improvement over LOW eff. base case	% Improvement over MED eff. base case	% Improvement over HIGH eff. base case		≤50 hp	>50 hp ≤100 hp	>100 hp ≤200 hp	>200 hp ≤500 hp	>500 hp≤1000 hp
						≤37 kW	>37kW ≤75kW	>75kW ≤150kW	>150kW ≤375kW	>375kW ≤745kW
1.1	**Upgrade System Maintenance**									
1.1.1	Fix Leaks, damaged seals, and packing	3.5%	2.5%	1.0%	5	$1,000	$1,500	$2,000	$2,500	$3,000
1.1.3	Remove scale from components such as heat exchangers and strainers	10.0%	5.0%	2.0%	4	$6,000	$6,000	$9,000	$12,000	$15,000
1.1.3	Remove sediment/scale buildup from piping	12.0%	7.0%	3.0%	4	$3,500	$3,500	$7,000	$10,500	$14,000
1.2	**Eliminate unnecessary uses**									
1.2.1	Use pressure switches to shut down unnecessary pumps	10.0%	5.0%	2.0%	10	$3,000	$3,000	$3,000	$3,000	*
1.2.2	Isolate flow paths to nonessential or non-operating equipment	20.0%	10.0%	5.0%	15	$0	$0	$0	$0	$0
1.3	**Matching Pump System Supply to Demand**									
1.3.1	Trim or change impeller to match output to requirements	20.0%	15.0%	10.0%	8	$5,000	$10,000	$15,000	$20,000	$25,000
1.4	**Meet variable flow rate requirement w/o throttling or bypass ****									
1.4.1	Install variable speed drive	25.0%	15.0%	10.0%	10	$4,000	$9,000	$18,000	$30,000	$65,000
1.5	**Replace pump with more energy efficient type**	25.0%	15.0%	5.0%	20	$15,000	$30,000	$40,000	$65,000	$115,500
1.6	**Replace motor with more energy efficient type**	5.0%	3.0%	1.0%	15	$2,200	$4,500	$8,000	$21,000	$37,500
1.7	**Initiate predictive maintenance program**	12.0%	9.0%	3.0%	5	8000	$8,000	$10,000	$10,000	$12,000

* This measure is not typical for large pumps, but it is a good practice for all pumps in parallel applications.

** For pumping systems dominated by static head, multiple pumps may be a more appropriate way to efficiently vary flow

To address the disparity in labor costs in the developed and developing countries studied in this report., a Labor Adjustment Factor (LAF) was created for the three developing countries/emerging economies, i.e. Thailand, Vietnam, and Brazil. This LAF was calculated for each energy efficiency measure. A detailed explanation of the methodology and the calculated LAFs for Thailand, Vietnam, and Brazil is provided in UNIDO (2010).

The LAF was multiplied by the calculated CCE (both preliminary and final). This resulted in lower CCEs for the measures in the three developing countries compared to that of developed countries. The results after applying the LAF appear to more closely approximate to real world conditions.

Results and Discussion

It should be noted that the energy saving potentials are the total existing potentials for the energy efficiency improvement in the studied motor systems in the base year. In other words, the potential presented here is for the 100% penetration rate. The authors are aware that 100% penetration rate is not likely and, in any event, values approaching a high penetration rate would only be possible over a period of time. Conducting the scenario analysis by assuming different penetration rates for the energy efficiency measures was beyond the scope of this study, and it could be the subject of a follow up study.

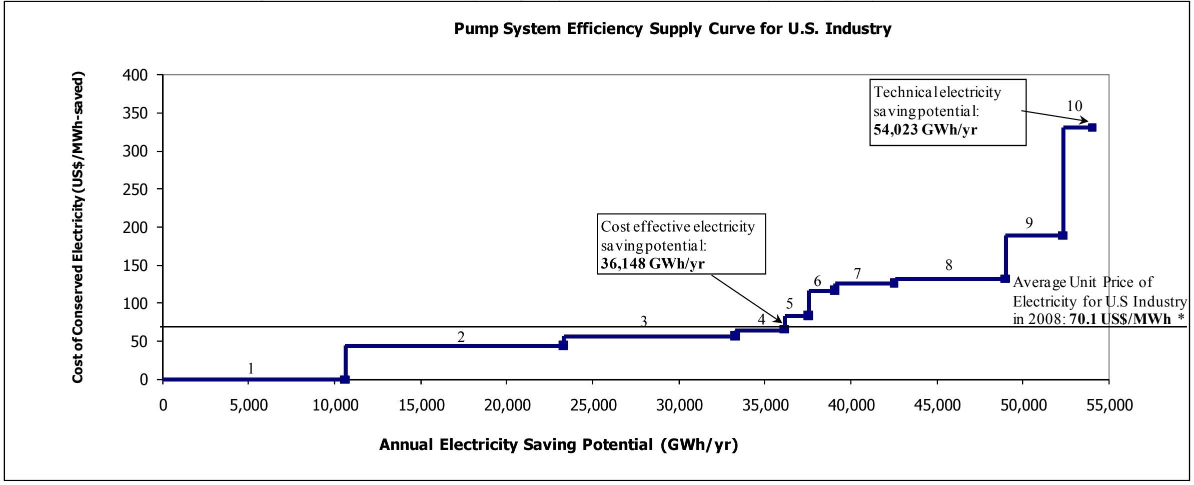
Pumping System Efficiency Supply Curves

Figure 1 presents the Pumping System Efficiency Supply Curves for the U.S. Similar figures and tables for the industrial pumping systems in other countries studied can be found in UNIDO (2010). The name of the measures related to each number on the supply curve is given in the table below the figure along with the cumulative annual electricity saving potential, final CCE of each measure, cumulative annual primary energy saving potential, and cumulative CO2 emission reduction potential (Tables 4-5). In Table 5, the energy efficiency measures that are above the bold line are cost-effective (i.e. their CCE is less than the unit price of electricity) and the efficiency measures that are below the bold line in the tables and are shaded in gray are not cost-effective. The results of pumping system efficiency supply curves show that in the developed countries (U.S., Canada, and EU) out of 10 energy efficiency measures only 3 to 5 measures are cost effective, i.e. their cost of conserved energy is less than the average unit price of electricity in those countries. On the other hand, in the developing countries, more energy efficiency measures fall below the electricity price line (7 to 9 measures). This is mainly because of the application of labor adjustment factor to the cost of the measures for the developing countries which will reduce the CCE significantly.

Furthermore, Table 6 shows that in all countries studied except Vietnam, the total technical energy saving potential is around 45% of the total pumping system energy use in the base year for the industries analyzed. The reason for this similarity is that all countries except Vietnam fall into the MEDIUM base case efficiency (see Table 2). Because Vietnam falls into LOW base case efficiency, the share of total technical energy efficiency potential compared to the total pumping system energy use is higher than that of the other five countries/region, at approximately 57%.

For cost-effective potential, however, the story is different. The three developed countries have the cost-effective potential of 27% - 29% of the total pumping system energy use in the base year for the industries analyzed. Although Thailand and Brazil have a MEDIUM base case efficiency (similar to the developed countries), their cost-effective potential is higher – equal to 36% and 43%, respectively – due to the application of a labor adjustment factor in the calculation of CCE. As a result, the CCE is lower, allowing more measures to fall below the electricity price line. For Vietnam, the cost-effective potential is much higher than other countries (49%) due to the combination of a LOW efficiency base case and the application of labor adjustment factor.

Figure 1. US Pumping System Efficiency Supply Curve



NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 4. Total Annual Cost-Effective and Technical Energy Saving and CO_2 Emission Reduction Potential for US Industrial Pumping Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for pumping system in US industry (GWh/yr)	36,148	54,023
Share of saving from the total pumping system energy use in studied industries in US in 2008	29%	43%
Share of saving from total electricity use in studied industries in US in 2008	4%	6%
Annual primary energy saving potential for pumping system in US industry (TJ/yr)	396,905	593,171
Annual CO_2 emission reduction potential from US industry (kton CO_2 /yr)	21,786	32,559

*In calculation of energy savings, equipment 1000 hp or greater are excluded

Table 5. Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Pumping System Efficiency Measures in US Ranked by Their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 emission reduction Potential from Industry (kton CO_2 /yr)
1	Isolate flow paths to nonessential or non-operating equipment	10,589	0.0	116,265	6,382
2	Install variable speed drive	23,295	44.5	255,784	14,040
3	Trim or change impeller to match output to requirements	33,279	57.0	365,405	20,057
4	Use pressure switches to shut down unnecessary pumps	36,148	65.7	396,905	21,786
5	Fix Leaks, damaged seals, and packing	37,510	84.1	411,855	22,607
6	Replace motor with more energy efficient	39,084	116.9	429,138	23,555
7	Remove sediment/scale buildup from piping	42,523	126.3	466,906	25,628
8	Replace pump with more energy efficient	48,954	132.2	537,516	29,504
9	Initiate predictive maintenance program	52,302	189.0	574,280	31,522
10	Remove scale from components such as heat exchangers and strainers	54,023	330.9	593,171	32,559

*In calculation of energy savings, equipment 1000 hp or greater are excluded

Table 6. Total Annual Cost-Effective and Technical Energy Saving Potential in Pumping Systems in Studied Countries

Country	Annual Electricity Saving Potential in Industrial Pumping System (100% penetration) (GWh/yr)		Share of saving from total Pumping system energy use in studied industries in 2008	
	Cost effective	Technical	Cost effective	Technical*
U.S	36,148	54,023	29%	43%
Canada	9,929	16,118	27%	45%
EU	26,921	38,773	30%	44%
Thailand	2,782	3,459	36%	45%
Vietnam	1,693	1,984	49%	57%
Brazil	4,439	4,585	43%	45%

*In calculation of energy savings, equipment 1000 hp or greater are excluded

Compressed Air System Efficiency Supply Curves

For compressed air systems, figures and tables similar to those shown above for the pumping system were developed for all countries studied (see UNIDO 2010 for details). Based on these analyses, "Fix Leaks, adjust compressor controls, establish ongoing plan" and "Initiate predictive maintenance program" are the top two most cost-effective measures for the compressed air system across studied countries, except for the EU for which "Install sequencer" displaces "Initiate predictive maintenance program" in the top two. On the other hand, "Size replacement compressor to meet demand" is ranked last with the highest CCE across all countries studied.

Table 7 shows the cost effective as well as technical potential for energy saving in compressed air system. For Thailand, Vietnam, and Brazil with LOW base case efficiency (see Table 2), the share of total technical energy efficiency potential for industrial compressed air systems relative to total compressed air energy use is higher than that of developed countries. However, the share is relatively lower for Brazil than for Thailand and Vietnam, and the share in the US is relatively lower than for Canada and the EU. Further analysis was conducted which demonstrated that this is likely due to the relatively higher proportions of large compressed air systems in the US and Brazil because of the mix of industries.

The three developed countries have the cost-effective potential of 21% - 28% of the total compressed air system energy use in the base year for the industries analyzed compared to the three developing countries with a cost-effective potential of 42% - 47%. As with pumping systems, this difference is due to the LOW efficiency base case and the application of a labor adjustment factor, allowing more measures to be cost effective (below the energy price line).

Table 7. Total Annual Cost-Effective and Technical Energy Saving Potential in Compressed Air Systems in Studied Countries

Country	**Annual Electricity Saving Potential in Industrial Compressed air System (100% penetration) (GWh/yr)**		**Share of saving from the total Compressed air system energy use in studied industries in 2008**	
	Cost effective	**Technical**	**Cost effective**	**Technical***
U.S	20,334	28,403	21%	29%
Canada	4,707	7,498	26%	41%
EU	18,519	24,857	28%	38%
Thailand	3,741	4,381	47%	55%
Vietnam	1,609	1,970	46%	56%
Brazil	6,069	6,762	42%	47%

*Excludes equipment 1000 hp or greater from calculations, resulting in understatement of-US and Brazil potentials

Fan System Efficiency Supply Curves

For fan systems, figures and tables similar to those shown above for the pumping system were developed for all countries studied (see UNIDO 2010 for details). Based on these analyses, “Correct damper problems”, “Fix Leaks and damaged seals” and “Isolate flow paths to nonessential or non-operating equipment” are the three most cost-effective measures for fan systems across the studied countries. “Replace motor with more energy efficient type” and “Replace oversized fans with more efficient type” are the least cost-effective.

Tables 8 shows that U.S., Canada and EU with MEDIUM base case efficiency have a total technical energy saving potential of 27% - 30% as compared with total fan system energy use in the base year for the industries analyzed. Thailand, Vietnam, and Brazil, with LOW base case efficiency (see Table 2), have a higher percentage of total energy saving technical potential (40% - 46%) as compared with total fan system energy use in the base year for the industries analyzed. This is because these three developing countries have the LOW efficiency base case,. The resulting percentage improvement over the base case efficiency for each measure is higher, resulting in higher technical saving potential. The three developed countries also have a lower cost-effective potential of 14% - 28% of total fan system energy use in the base year for the industries analyzed, as compared to the cost-effective potential of 40% - 46% for the developing countries. As with the other systems, the LOW efficiency base case and the application of a labor adjustment factor contribute to more measures falling below the electricity price line.

Table 8. Total Annual Cost-Effective and Technical Energy Saving Potential in Fan Systems in Studied Countries

	Annual Electricity Saving Potential in Industrial Fan System (100% penetration) (GWh/yr)		Share of saving from the total Fan system energy use in studied industries in 2008	
	Cost effective	Technical	Cost effective	Technical*
U.S	15,432	18,451	25%	30%
Canada	1,825	3,386	14%	27%
EU	12,590	13,015	28%	29%
Thailand	1,819	1,819	46%	46%
Vietnam	750	832	41%	45%
Brazil	3,327	3,327	40%	40%

* In calculation of energy savings, equipment 1000 hp or greater are excluded.

Conclusion

Energy Efficiency Supply Curves were constructed for this paper for pumping, fan, and compressed air systems in the U.S., Canada, EU, Thailand, Vietnam, and Brazil. Using the bottom-up energy efficiency supply curve model, the cost-effective electricity efficiency potentials for these motor systems were estimated for the six countries in the analyses. Total technical electricity-saving potentials were also estimated for 100% penetration of the measures in the base year. Table 9 provides a summary of these results.

Table 9. Total Annual Electricity Saving and CO_2 Emission Reduction Potential in Industrial Pump, Compressed Air, and Fan Systems

	Total Annual Electricity Saving Potential in Industrial Pump, Compressed air, and Fan System (GWh/yr)		Share of saving from electricity use in pump, compressed air, and fan systems in studied industries in 2008		Total Annual CO_2 Emission Reduction Potential in Industrial Pump, Compressed air, and Fan System (kton CO_2/yr)	
	Cost effective	Technical	Cost effective	Technical	Cost effective	Technical
U.S	71,914	100,877	25%	35%	43,342	60,798
Canada	16,461	27,002	25%	40%	8,185	13,426
EU	58,030	76,644	29%	39%	25,301	33,417
Thailand	8,343	9,659	43%	49%	4,330	5,013
Vietnam	4,026	4,787	46%	54%	1,973	2,346
Brazil	13,836	14,675	42%	44%	2,017	2,140
Total (sum of 6 countries)	**172,609**	**233,644**	**28%**	**38%**	**85,147**	**117,139**

* In calculation of energy savings, equipment 1000 hp or greater are excluded

This report and supporting analyses represent an initial effort to address a major barrier to effective policymaking, and to more global acceptance of the energy efficiency potential of motor systems. That barrier is the lack of a transparent methodology for quantifying the energy efficiency potential of these systems based on sufficient data to document the magnitude and cost-effectiveness of the resulting energy savings by country and by region. The research framework created to conduct the analyses supporting this Phase I report is meant to be a beginning, not an end unto itself.

The authors and sponsors of this research seek to initiate an international dialogue with others having an interest in the energy efficiency potential of motor systems. Through this dialogue, it is hoped that the initial framework for quantifying motor system energy efficiency potential created for this report with a combination of expert opinion and limited data will be refined and the availability of data increased.

The approach used in this study and the model developed should be viewed as a screening tool to present energy-efficiency measures and capture the energy-saving potential in order to help policy makers understand the potential of savings and design appropriate energy-efficiency policies. However, the energy-saving potentials and the cost of energy-efficiency measures and technologies will vary in accordance with country- and plant-specific conditions. Finally, effective energy-efficiency policies and programs are needed to realize the cost-effective potentials and to exceed those potentials in the future.

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