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Motor Systems Efficiency Supply Curves: Assessing the Energy Efficiency Potential of Industrial Motor Systems

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Abstract

Motor-driven equipment accounts for approximately 60% of manufacturing final electricity use worldwide. In this paper, using a combination of expert opinion and available data from the United States, Canada, the European Union, Thailand, Vietnam, and Brazil, bottom-up electricity 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 electricity 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. Overall, Thailand, Vietnam and Brazil have a higher percentage for cost-effective potential as compared to total motor systems electricity use. This results from the lower efficiency base case and lower labor costs for the three developing countries than for the EU, the US, and Canada. 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.

1. Introduction

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.

This paper was informed by several previous studies. One of the most comprehensive assessments of industrial motor systems to date was conducted by the U.S. Department of Energy (US DOE) and has been used extensively as a foundation for further analysis [1]. Also useful was the US DOE publication of energy footprints describing the electricity use of different industrial sub-sectors[2]. In the European Union, de Almeida et al.[3] conducted an extensive assessment of electricity efficiency potential in industrial motor systems in EU. International Energy Agency (IEA) also roughly presented the potential for energy efficiency in industrial motor systems in[4]. The potential for electricity saving in the industrial motor systems have also been presented as a part of broader energy efficiency opportunity studies such as the studied by McKinsey & Company [5] and Fraunhofer ISI[6].

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 Conservation Supply Curve (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.

2. Methodology

For these Phase 1 analyses, six countries/region were selected that represent varying sizes and levels of industrial development, and for which industrial electricity 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. These countries/region were chosen based on several considerations including the availability of data for electricity use by industry sub-sector, the information related to industrial motor systems, and the contact persons in these countries that provided the required information and data. Other countries such as China, India, Japan, etc. are planned to be included in Phase 2 of this study.

The first step was a literature review to develop a baseline of information. Next, a data collection framework was developed to obtain expert input to supplement the existing data. Input was sought from a total of seventeen motor system experts known to the authors through prior research and responses were received from thirteen of them. At least four experts responded for each of the three systems analyzed (compressed air, fans, and pumping), with one expert providing input on two systems. A Delphi-type approach was used in which several iterations of expert opinion were used to refine the final inputs to the analyses.

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 the main report of this study published by UNIDO [7].

2.1. Experts Input

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 electrical system efficiency practices representative of each of three efficiency base case scenarios for each system type. Each list was tested with the experts, who were asked whether they were representative of the scenarios. Table 1 provides the list of practices defined for each base-case efficiency level for the pumping system. Similar tables for the compressed air and fan systems were developed and published in [7].

The experts were then asked to provide a low to high estimated range of the electrical system 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.

2.2. Data Preparation and Assumptions

The experts were asked to assign electrical system efficiency, expressed as a range, for LOW-MED-HIGH efficiency base cases. Table 2 below is the consolidated results of these expert inputs, 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 electrical system 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 the pump system, 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 3 shows the base case efficiencies assigned to each country for each motor system type.

Table 1. Characteristics of LOW-MEDIUM-HIGH Efficiency Base Case Scenarios for Pumping Systems

No.	LOW Efficiency Base Case Scenario
1	Few pumping systems have ever been assessed for electrical system energy efficiency
2	Maintenance is limited to what is required to support operations
3	Flow is typically controlled by throttling or bypass
4	Flow in excess of actual system needs is common
5	Variable speed drives are not commonly used
6	Motors of all sizes are routinely rewound multiple times instead of replaced
7	5% or less of the installed motors are high efficiency--either EPAct or EFF1 equivalent
No.	**MEDIUM Efficiency Base Case Scenario**
1	~15% of pumping systems have been assessed for electrical system energy efficiency
2	Maintenance is a routine part of operations and includes some preventative actions
3	System operators take steps to avoid controlling flow via throttling or bypass
4	Efforts are taken to efficiently match supply with demand
5	Variable speed drives are proposed as a solution for flow control
6	Motors ≥ 37 kW are typically rewound multiple times, while smaller motors may be replaced
7	~25% of the installed motors are high efficiency--either EPAct or EFF1 equivalent
No.	**HIGH Efficiency Base Case Scenario**
1	~30% pumping systems have been assessed for electrical system energy efficiency
2	Both routine and predictive maintenance are commonly practiced
3	Flow is not controlled by throttling or bypass except in emergencies
4	Fluid is only pumped where and when needed to meet demand
5	Variable speed drives are one of several flow control strategies commonly applied to increase system efficiency
6	Most facilities have a written rewind/replace policy that prohibits rewinding smaller motors (type <37 kW)
7	50% or more of the installed motors are high efficiency--either EPAct or EFF1 equivalent

Table 2. Consolidated system efficiency for LOW-MED-HIGH efficiency base case

Motor System type	**System efficiency**			
	low end (%)	**high end (%)**	**Average (%)**	**Used in our analysis**
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%**

Determining the impact of energy efficiency measures: A list of potential measures to improve electrical system efficiency was developed for each system type and sent to the experts for review. Ten energy-efficiency technologies and measures for pumping systems [8], ten measures for the fan systems [9], and sixteen measures for compressed air systems [10] were analyzed. For each group of measures, we asked experts to provide their opinion on electricity 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.

Table 3. Base case efficiencies assigned to each country for each motor system type

Country	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

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 [1]. 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 (between 1000 hrs 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 very large systems (large than 1000 hp or 745 kW). For these systems, costs estimates varied widely- possibly due to the customized requirements of larger systems. Because these wide variations imposed additional uncertainty on the final results, we decided to exclude systems larger than 1000 hp (745kW) from the final analysis. This reduced the total electricity 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. A more extensive dialogue with experts on the cost drivers of larger systems might result in sufficient disaggregation to permit their inclusion in future analyses.

Because the goal of the analysis is to assess the total potential for energy efficiency in industrial motor systems in the base year , the estimated full cost of the measures analyzed was used rather than the incremental cost for energy efficient measures. Therefore, the electricity savings is based on the assumption that all the measures are installed in the base year.

Experts input for motor system characteristics described above were reduced to a single value for each characteristic based on an analysis of average and median values. These consolidated values were further validated through one more round of expert review before being included in the analyses. Table

4 depicts the final values for 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 [7]. 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 electricity use data availability. Country-specific data was collected from various sources.

Data from three sources: [1 – 3] were used to construct a preliminary table of motor system use by industrial sector. The experts were then asked to estimate a) the system electricity use as % of overall electricity use in the sector, OR b) System electricity use as % of motor system electricity use in the sector. The results from the experts were compared with the three studies and final estimates were developed for 1) the motor systems electricity use as a % of total electricity use in each industrial sector and 2) for each system (pump, compressed air, and fan), the electricity use as % of overall motor system electricity use in the sector. These values were then applied to the electricity use data for each 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 electricity lost through heat of compression (typically 80% of input electrical 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.

2.3. 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 [11]. The Cost of Conserved Electricity (CCE) can be calculated from Equation 1.

$$CCE = \frac{(Annualized\ capital\ cost + Change\ in\ annual\ O\&M\ costs)}{Annual\ electricity\ saving} \quad \textbf{(1)}$$

The annualized capital cost can be calculated from Equation 2. The change in operation and maintenance (O&M) costs is the amount of change in the annual O&M costs after the implementation of the efficiency measure.

Annualized capital cost = $\mathrm{Capital\ Cost} * \left(\frac{\mathrm{d}}{(1-(1+\mathrm{d})^{-\mathrm{n}}}\right)$ **(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 Electricity for all energy efficiency measures, the measures are ranked in ascending order of Cost of Conserved Energy. In CSCs an electricity 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 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 electricity saving and cost are not presented in this paper because of lack of space and can be found at [7]

Table 4. 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	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	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	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

Labor Adjustment Factor for the cost of measures: Typical capital costs (materials and labor) of installing the selected measures were provided by several experts for each motor system type. Since most of these experts are in the U.S., Canada, and European countries, these cost estimates were more representative of those locations. A significant proportion of the installed cost of many system improvement measures is the labor. To address the disparity in labor costs among the six countries/regions studied, 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 and applied to 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 (see [7] for further details).

3. Results and Discussion

As previously mentioned, the electricity saving potentials represent the total existing potentials for the energy efficiency improvement in the studied motor systems in the base year. The authors are aware that a complete penetration of efficiency measures is not likely reachable and, in any event, values approaching a high penetration rate would only be possible over a period of time. While conducting the scenario analysis by assuming different penetration rates for the energy efficiency measures was beyond the scope of this study, it is worthy of further study.

3.1. 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 [7]. The name of the measures related to each number on the supply curve is given in the tables 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 5-6). In Table 6, 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 electricity 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 7 shows that in all countries studied except Vietnam, the total technical energy saving potential, which is the total amount of electricity saving can be achieved by the implementation of all measures under the described methodology, is around 45% of the total pumping system electricity 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 3). Because Vietnam falls into LOW base case efficiency, the share of total technical energy efficiency potential compared to the total pumping system electricity 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 electricity 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.

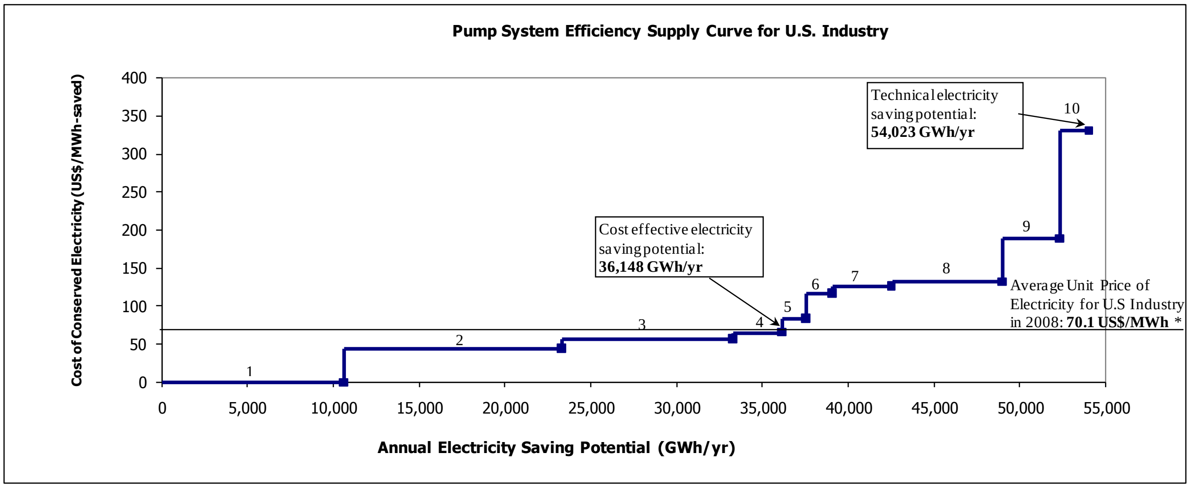

Figure 1. US Pumping System Efficiency Supply Curve

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 5. Total annual cost-effective and technical energy saving and CO2 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 electricity 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 electricity 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 electricity savings, equipment 1000 hp or greater are excluded

Table 6. Cumulative annual electricity saving and CO2 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 for flow control	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 type	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 type	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 electricity savings, equipment 1000 hp or greater are excluded

Table 7. Total annual cost-effective and technical energy saving potential in pumping systems in studied countries

Country	Annual Electricity Saving Potential in Industrial Pumping System (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

3.2. 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 [7] 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 8 shows the cost effective as well as technical potential for electricity saving in compressed air system. For Thailand, Vietnam, and Brazil with LOW base case efficiency (see Table 3), the share of total technical energy efficiency potential for industrial compressed air systems relative to total compressed air electricity 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 proportion of large compressed air systems (omitted from this study) in the US and Brazil due to the mix of industries.

The three developed countries have the cost-effective potential of 21% - 28% of the total compressed air system electricity 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 electricity price line).

Table 8. 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 (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

3.3. 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 [7] 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 9 shows that U.S., Canada and EU with MEDIUM base case efficiency have a total technical electricity saving potential of 27% - 30% as compared with total fan system electricity use in the base year for the industries analyzed. Thailand, Vietnam, and Brazil, with LOW base case efficiency (see Table 3), have a higher percentage of total electricity saving technical potential (40% - 46%) as compared with total fan system electricity 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 electricity 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 9. Total annual cost-effective and technical electricity saving potential in fan systems in studied countries

Country	Annual Electricity Saving Potential in Industrial Fan System (GWh/yr)		Share of saving from the total Fan system electricity 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 electricity savings, equipment 1000 hp or greater are excluded.

4. 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 the base year. Table 10 provides a summary of these results. Many cost-effective opportunities for energy efficiency improvement in the motor systems in the six countries have been identified but frequently not adopted, leading to what is called an “efficiency gap”[12]. This is explained by the existence of various obstacles especially non-monetary barriers to energy-efficiency improvement.

In some cases, the ranking and cost-effectiveness of the efficiency measures on the CSCs do not align withreal-world practices, see [7]. For instance, the replacement of motors with more efficient type which is commonly advised and implemented in industry and supported by various policies in different countries may not always be as cost-effective as some other low-cost measures. This can be helpful information for policy makers in developing program strategies to promote energy efficiency..

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.

Table 10 Total Annual Electricity Saving and CO2 Emission Reduction Potential in Industrial Pump, Compressed Air, and Fan Systems

Country	**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 electricity savings, equipment 1000 hp or greater are excluded

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