Energy Consumption and Efficiency of Appalachian Hardwood Sawmills

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Abstract

A study of energy consumption and efficiency for Appalachian hardwood sawmills was conducted in the Appalachian region. Primary data were collected through a mail survey on sawmills in the region in 2010, while secondary data were obtained from site audits at 17 sawmills over the last 10 years in West Virginia. The results from the mail survey showed that hardwood lumber production volume ranged from 700 to 600,000 board feet (BF) per wk, and monthly electricity consumption per mill averaged 220 kWh per thousand board feet (MBF) with an average electric bill of $17.78/MBF/mo. The energy audit results indicated that hardwood lumber production volume ranged from 4,250 to 400,000 MBF/y, and the energy use and total cost per thousand board feet of lumber production averaged 160.89 kWh/MBF and $10.04/MBF, respectively. The average marginal cost for all energy audits was $17.87/MMBtu (¢6.10/kWh). The annual carbon dioxide emission conserved was 587,045 pounds per mill. On average, engineers on site visits proposed changes that could save approximately 14.89 percent of the annual energy used. The results presented in this article provide energy profiles for Appalachian hardwood sawmills and reveal some potential techniques for reducing energy consumption.

The US hardwood sawmills at one time produced over 13 billion board feet (BF) of lumber per year valued at $8 billion (Bowe et al. 2001). Owing in part to the globalization of forest products market and the slowing domestic housing market, sawmills are experiencing low demand and falling profits. Hardwood lumber production in the United States has fallen 25 percent since 2000 (Parhizkar et al. 2009). In the Appalachian region, hardwood production has declined by more than 40 percent (Luppold 2009, Wang et al. 2010). This is especially true during the US financial and economic crisis of 2008 and 2009, which caused devastating effects on the hardwood industry in the region.

To survive under the current difficult economic and market conditions, hardwood sawmills must improve their sawmilling efficiency, search for new markets, and reduce manufacturing costs. Lumber production efficiency has always been a major concern to Appalachian hardwood sawmills. Recently, cost-saving consideration through energy conservation has gained much attention (Gopalakrishnan et al. 2003, Mardikar 2007).

Hardwood production is very energy intensive. Energy use by the lumber manufacturing industry accounts for 5 percent of the total energy input in the US manufacturing industry (Bond 2008). In 2001, the lumber manufacturing industry spent $368 million for electricity and $128 million for fuels (Bond 2008). A typical hardwood sawmill usually consists of five main operations including log debarking, log sawing, flitch edging and trimming, side-cuts chipping, and lumber drying. If a sawmill produces only rough green lumber and has no kiln-drying facility, electricity will be the primary energy consumed; otherwise steam or combustion heat will be the most important component of energy use. Kiln drying is the most energy intensive process in the production of surfaced dry lumber, which uses six to nine times more energy than the sawmilling operation itself (Wengert and Meyer 1992).

Energy costs can be a significant component of operating costs in a lumber manufacturing industry (Gopalakrishnan et al. 2003). Energy costs in a typical sawmill facility can vary between 1 and 10 percent of the total operating costs (Mardikar 2007). In the past, energy cost did not represent a large portion of total costs. However, today more attention is being given to energy consumption as energy prices rise (Mate 2002). Increasing energy costs have a significant

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impact on the profit margin of lumber production, which is typically about 3 to 4 percent of the total cost (Bond 2008). Both natural gas and electricity energy sources occupied about 25 percent of total energy consumption by the sawmill industry (Bond 2008). Energy waste in sawmills is becoming more and more expensive, which is likely to increase operation costs.

The Appalachian region is one of the most important hardwood lumber producing regions, supplying 68 percent of the eastern hardwood sawtimber (Luppold 1995). Besides the challenge from globalization, hardwood sawmills in the region have to deal with issues such as increasing energy and fuel costs, log and logger availability, low-grade timber, increased stumpage costs, and low demand from the domestic housing market (Buehlmann et al. 2007). A better understanding of the current energy consumption and efficiency will help the Appalachian hardwood sawmills find effective ways of reducing energy consumption and cost and thus increasing their competitiveness in the global forest products market.

The objective of this study was to examine the energy consumption and efficiency in Appalachian hardwood sawmills, particularly in the state of West Virginia. Specifically, this study (1) assesses the energy consumption of Appalachian hardwood sawmills, (2) provides recommendations to sawmills regarding effective ways of reducing both energy consumption and costs, and (3) determines energy conservation opportunities by analyzing energy assessments.

Methods

Current profile of Appalachian sawmills

A formal mail survey of Appalachian hardwood sawmills was conducted during the summer and fall of 2010 to gather general energy consumption and efficiency information. The survey design was based on Dillman's tailored design method (Dillman 2000). The mailing lists of the Appalachian hardwood sawmills were obtained from the National Hardwood Lumber Association (NHLA 2008), the Appalachian Regional Commission (ARC 2009), and other state agencies. The 776 firms identified as hardwood sawmills in the Appalachian region were selected as the sample population. A total of 238 responses were received, of which 58 surveys were usable. The responses included 21 from Pennsylvania, 16 from West Virginia, 8 from Ohio, 6 from New York, and 7 from other states including Connecticut, Maryland, Missouri, and South Carolina. The questions were designed to determine the monthly cost of electric and gas bills, the efficiency of electric motors used along with the percentage of total motors that were highly efficient, number and type of air compressors, number of dry kilns, kiln capacity, type of fuel used, and monthly electricity and natural gas consumption. The survey also asked if any energy-efficient upgrades were going to be made in the near future. Returned surveys were examined for completeness and usability and were then entered into Excel spreadsheets and analyzed using SAS.

Mill specific energy audits

In addition to the formal mail survey of sawmills in the central Appalachian region, data were collected during intensive energy audits at 17 hardwood sawmills in West Virginia by the Industrial Assessment Center at West Virginia University. The intensive assessments included a complete audit of all energy use at the participating mills. Information such as electrical consumption, hours of operation, and load factor were measured on major energy-consuming equipment at each mill. Recording devices, including power analyzers, digital stroboscopes, and temperature guns, were used in the data collection process. Motor Master Software was used to analyze the energy data, especially for electrical motors (Mate 2002, Gopalakrishnan et al. 2005). The audits helped to define energy conservation practices that could be implemented over a 10-year period and the estimated cost savings that would occur given these changes. Based on the audit data, energy conservation opportunities and recommendations defined by these assessments were summarized so that the results could be used to help sawmills better understand their energy use.

Results and Discussion

Profile of Appalachian sawmills

Among the respondents, 74.1 percent reported being a single facility, 25.9 percent had multiple facilities, and 89 percent used one shift per week. The number of employees per mill averaged 30, with an average weekly lumber production of 145,610 BF. In small sawmills (<40,000 BF/wk), each employee produced an average of 4,199 BF/wk, while in medium mills (40,000 to 200,000 BF/wk) this number increased to 4,554 BF/wk. Large sawmills (>200,000 BF/wk) were by far the most efficient, with a per employee production of 5,145 BF/wk, which may be attributed to the application of advanced automation technology and better management at large sawmills. On average, the operation hours per mill were 2,132 hours in 2010. Average residue production among the respondents was 139.2 tons/wk for chips and 81.1 tons/wk for sawdust (Table 1). When asked whether they have plans to upgrade their mills in 2011 to make them more energy efficient, 18.8 percent of the respondents answered ''Yes.''

Most respondents used electricity as the main energy resource; very few used natural gas. Electricity consumption per month per mill averaged 107,007 kWh, and the average electric bill was $9,278/mo; therefore, the average electric cost rate was $0.0867/kWh. Based on lumber production volume, the monthly electricity consumption per mill ranged from 31 kWh per thousand board feet (MBF) to 588 kWh/MBF and averaged 220 kWh/MBF. The monthly electric bill ranged from $2 to $41.67 per MBF with an average of $17.78/MBF.

Major energy systems

Motor systems.—Electric motors are frequently used by hardwood sawmills in the Appalachian region and are the

Table 1.—Operation statistics of surveyed sawmills in 2010.

Variable	Mean (SD)	Minimum	Maximum
Operating hours (per y)	2,132 (515)	768	4,032
No. of employees	30 (38.91)	0	200
Production (BF/wk)[a]	145,610 (150,489)	700	600,000
Log inventory (wk)	6.13 (7.57)	0	50
Chips/wk (tons)	139.19 (166.39)	0.2	1,000
Sawdust/wk (tons)	81.08 (100.57)	0	500

[a] BF = board feet.

major electricity-consuming units. The federal government, in conjunction with energy utilities, has focused on increasing the use of highly efficient motors (Dunning and Ward 1998). About 38, 45, and 17 percent of the respondents ran electric motors at 80 to 90 percent, 91 to 94 percent, and 95 percent or more efficiency, respectively. As evidenced by the survey data, more attention needs to be paid to electric motor efficiency. By increasing efficiency, the cost of the motor system is reduced, leading to an overall increase in energy efficiency at sawmills. Several methods can be used by hardwood sawmills to reduce the cost of motor systems, such as switching motors off when they are idle, keeping balance between maintenance and production, and selecting suitable motor size. In addition, a motor management system can be used to aid in improvement of energy consumption and efficiency by documenting motor inventory and analyzing various energy conservation opportunities.

Lighting systems.—Lighting systems are often overlooked as a way to save energy. Different lighting systems may have different efficiencies. As indicated by Wengert and Meyer (1992), the efficiency of incandescent, fluorescent, mercury vapor, and sodium was 10, 20, 24, 33 percent, respectively. In these surveys, about 54 and 13 percent of the respondents used the relatively less-efficient fluorescent lighting and incandescent bulbs, respectively. Thirty-three percent of the respondents used both lighting systems. Electric energy savings could be achieved in sawmills through the use of more energy-efficient lighting system, such as mercury vapor lamps or high-pressure sodium lamps.

Air compressor systems.—Compressed air plays important roles in many automated processes in a typical hardwood sawmill. Wengert and Meyer (1992) pointed out that the most inefficient use of electrical energy is in compressing air at sawmills. About 40 and 50 percent of the responding sawmills used conventional air compressors and high-efficiency screw drive air compressors, respectively. An additional 10 percent of the respondents used both types of air compressors. Screw drive air compressors can create a much larger volume of air while using far less energy, thus making them substantially more energy efficient (Elliot 2006). Respondents' concern over effects of energy cost indicates that air leakage was also a major problem. Identifying and preventing air leaks can help reduce electricity consumption.

Kiln-drying systems.—Rough green lumber sawn from hardwood logs is usually dried in conventional dry kilns using wood and fossil fuels as heat sources (Denig et al. 2000). Kiln drying lumber is an energy intensive process that can consume up to 60 to 70 percent of the total energy needed to manufacture lumber (Breiner et al. 1987, Simpson 1991). Respondents who used kilns owned five dry kilns on average. The average capacity of all dry kilns was 4,521 MBF/y per mill. The electricity used in kilns averaged 29,775 kWh/mo per mill, with an average monthly electricity bill of $3,417. Based on the volume of lumber dried, electricity consumption in kilns averaged 114 kWh/MBF/mo per mill, with an average monthly electricity bill of $16.08/MBF. It is noted that sawmills produce a large amount of wood residues during the production of lumber and other wood products from saw logs. Some large mills are already burning their wood residues in boilers to produce heat for their kiln dryers. For those responding sawmills that need to dry lumber, the average monthly residue consumption was approximately 467 tons. Many energy saving opportunities exist in kiln drying, such as predrying and regular maintenance.

Energy conservation opportunities defined in energy audits

Mill manufacturers can implement a variety of energy management activities to improve energy efficiency, especially by making an energy audit. Energy audits can help a mill assess their energy use and evaluate what measures could be used to improve energy efficiency without negatively affecting production. Of the mills audited in this study, the majority produced lumber, and the main energy source was electricity. On average, mills that were audited operated for 2,951 h/y and had 56 employees per mill. Annual lumber production averaged 55,444 MBF. Average energy use for each of the audited mills was 2,782,659 kWh. Audit teams recommended procedures to conserve approximately 275,110 kWh/y per mill. Likewise, the conservation procedures recommended could save the audited mills an average of 587,045 lb/y of carbon dioxide emissions (Table 2). Results indicated that implementing the assessment recommendations could significantly reduce the audited sawmill's energy consumption. The basic information, specific energy cost, and conservation information for all the energy audits are shown in Tables 3 and 4.

Assessment recommendations.—Overall, 6 to 11 assessment recommendations were made for each sawmill, with an average of 8 (Table 3). The most frequent recommendation was to implement a motor management system, followed by replacing belts and working with air compressors (Fig. 1). A motor management system such as MotorMaster+ software can identify and analyze motor driven systems for various energy conservation opportunities. Likewise, replacing belts can improve motor efficiency. Standard V-belts have been shown to have an efficiency of about 92 percent, while Cog Belts flex more easily and have the potential to increase the efficiency of the drive system by 2 to 8 percent (Oregon Department of Energy 2007). Reducing compressor settings and using outside air can also increase efficiency. The energy required to compress and deliver air increases by 1 percent with every 2-lb/in^2 increase in pressure. Likewise, because it is generally cooler outside a sawmill than inside, using outside air can also reduce compressor energy requirements. Finally, repairing compressor air leaks can increase the energy savings by reducing the amount of time the compressor has to be

Table 2.—Statistics of energy audits of sawmills between 2001 and 2010.

Variable	Mean (SD)	Minimum	Maximum
Operating hours (per y)	2,951 (1,196)	1,728	5,508
No. of employees	56 (52)	17	185
Production (MBF/y)[a]	55,444 (129,954)	4,250	400,000
Audit implementation cost ($)	18,633 (27,099)	1,437	105,483
Energy usage (kWh/y)	2,782,659 (3,633,416)	316,916	11,561,562
Energy conserved (kWh/y)	275,110 (267,745)	21,954	1,100,514
CO_2 emission saved (lb/y)	587,045 (566,622)	48,079	2,410,091

[a] MBF = thousand board feet.

Table 3.—Basic information for energy audits of sawmills between 2001 and 2010.

Mill ID	No. of employees	Total operating hours (h/y)	Production (MBF/y)[a]	Assessment recommendations	Recommendations implementation cost ($)
1	60	4,680	4,680	6	6,433
2	60	4,680	4,810	6	6,451
3	75	2,340	9,100	8	11,601
4	55	4,000	13,000	9	105,483
5	53	5,508	11,500	9	8,398
6	185	2,550	400,000	8	7,781
7	24	2,210	7,280	6	16,856
8	20	2,000	5,500	8	3,100
9	25	2,000	6,000	10	30,647
10	185	2,550	400,000	11	64,943
11	24	2,184	7,000	6	1,437
12	61	4,080	40,000	11	17,734
13	20	1,960	5,720	8	4,568
14	17	2,168	4,250	6	2,825
15	47	3,536	12,500	9	17,103
16	18	2,000	6,000	9	9,066
17	19	1,728	5,200	6	2,329

[a] MBF = thousand board feet.

Table 4.—Energy cost and conservations of sawmills between 2001 and 2010.

Mill ID	Marginal cost/MMBtu ($)	Marginal cost/kWh ($)[a]	Average energy used (kWh/y)	Total cost ($/y)	Energy conserved (MMBTu)	Energy conserved (kWh)[b]	CO_2 emission saved (lb)[c]	Recommended energy savings ($/y)
1	16.23	0.06	1,832,663	101,516	1,063	311,456	682,294	27,598
2	16.45	0.06	1,885,541	105,861	1,094	320,542	701,981	28,263
3	21.95	0.07	725,606	54,359	421	123,368	270,173	21,737
4	15.95	0.05	2,185,920	118,980	1,010	296,023	640,381	84,804
5	5.59	0.02	5,918,400	228,000	1,427	418,096	913,050	29,741
6	7.84	0.03	11,469,248	541,199	1,850	657,206	1,187,720	14,861
7	21.66	0.07	927,168	68,534	470	137,682	301,582	22,165
8	19.32	0.07	900,000	59,340	1,189	348,501	762,939	22,721
9	21.24	0.07	522,538	41,314	737	215,871	472,265	20,244
10	7.88	0.03	11,561,562	323,839	3,756	1,100,514	2,410,091	135,253
11	22.45	0.07	653,568	46,188	184	54,048	118,365	3,502
12	16.44	0.06	4,844,700	449,872	959	280,969	615,322	16,593
13	23.90	0.08	365,952	29,847	178	52,202	114,322	4,257
14	11.22	0.04	601,329	47,538	393	115,141	252,159	9,055
15	11.25	0.04	1,845,015	121,239	512	149,900	328,281	15,396
16	24.93	0.09	749,079	63,725	251	73,400	160,753	6,011
17	39.44	0.13	316,916	42,649	75	21,954	48,079	2,794

[a] 293 kWh/MMBtu.
[b] 1 kWh = 3,413 Btu.
[c] CO_2 emission rate = 2.19 lb/kWh.

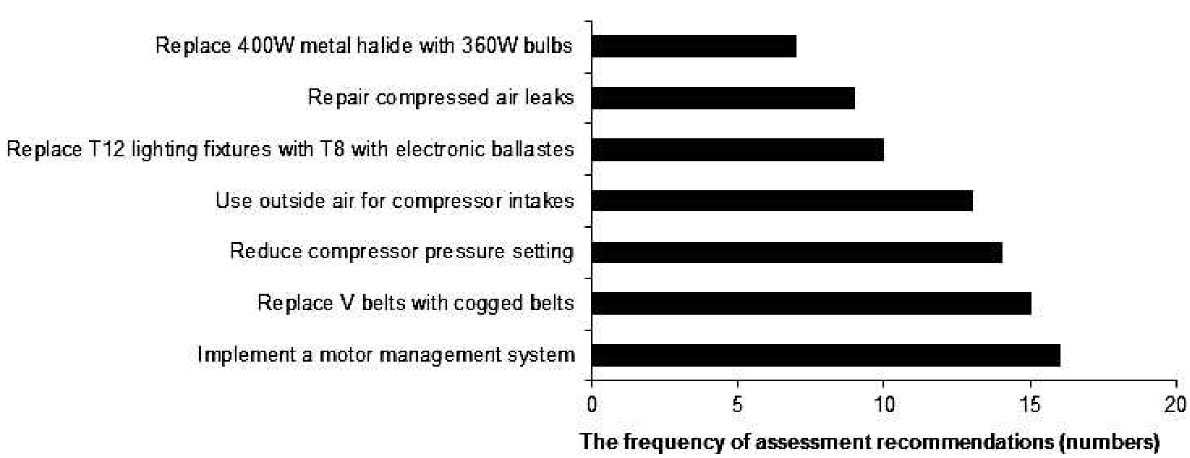

Figure 1.—Most common recommendations issued to sawmills.

operated to produce the air that is lost to leakage. In lighting, recommendations included replacing existing T12 lighting ballasts and bulbs with T8 bulbs with electronic ballasts and reflectors. This changeover can save up to 50 percent of the original energy use. Also, replacing 400-W metal halide with 360-W metal halide bulbs can reduce the amount of energy used for lighting (Oregon Department of Energy 2007).

Implementation cost for assessment recommendations at sawmills ranged from $0 to $100,000, with an average of $18,633 (Table 3). Some assessment recommendations could be easily done at a low cost. Several of the recommendations had no costs associated with them, for example, turning off lighting when not in use. Others were costly, including changing an existing natural gas fueled boiler to a sawdust fueled boiler, with an investment approaching $100,000. Similarly, since the implementation cost varied for each recommendation, the payback period was also different. The payback period varied from immediately to 2.6 years. For example, the payback period for switching off equipment when not in use was immediate, while it took 2.6 years to pay back an installation of capacitor banks to reduce electrical spikes. Overall, the average payback period was 8 months based on the average energy savings and associated implementation costs.

Marginal cost per million British thermal units.—The marginal cost of electricity per million British thermal units is calculated by dividing the total cost of electricity for all months by the total amount of electricity consumed in those months (Mate 2002). The average marginal cost of a million British thermal units based on all energy audits was $17.87/MMBtu (¢6.1/kWh) ranging from $5.59/MMBtu (¢2.0/kWh) to $39.44/MMBtu (¢13.0/kWh; Table 4). It was noted that the marginal cost per million British thermal units was quite different among the visited mills. For example, the marginal cost per million British thermal units was $5.59, $7.84, and $7.88 for Mills 5, 6, and 10, while the marginal cost increased to $39.44 for Mill 17. From this we can see that Mills 5, 6, and 10 were more efficient than Mill 17. When we closely observed these mills, Mills 5, 6, and 10 had a large demand cost, and energy consumed per year was much more than the other mills. Mill 5 also produced rough lumber and other wood products such as pallet, while Mills 6 and 10 conducted lumber drying along with rough lumber production. Mill 17 was a small-scale plant that only produced lumber; therefore, less energy was consumed, and its marginal cost was higher compared with other sawmills.

Energy use.—Energy use was analyzed by using energy use per thousand board feet of production and energy use per employee (Fig. 2). The energy use per thousand board feet of production is calculated by dividing the total annual energy consumed in kilowatt hours by the annual lumber production in thousand board feet. During all of the energy audits, the energy use per thousand board feet of production varied from 28.67 to 514.64 kWh/MBF, with an average of 160.89 kWh/MBF (Fig. 2a). The energy use per thousand board feet of production was very high for Mill 5 because of large energy demand in this mill as compared with other mills, and the total operating hours per year was the greatest in Mill 5. In addition, less volume of lumber was produced in this mill. For Mills 6 and 10, energy use per thousand board feet of production was low because of the large volume of lumber produced in these two mills as compared with other mills. Energy use per employee varied from 9,675 to 111,668 kWh per employee, with an average of 41,762 (Fig. 2b). Figure 2b also shows that energy use per employee in Mill 5 was very high compared with other mills. It was also found that energy use was significantly different among all production levels (Fig. 3). This can be explained by the wide variation in electricity rates and the difference in demand rates. The energy use per thousand board feet of production was very high for small production levels (<5,000 MBF) because of the small volume of lumber production, while the 8,000 to 12,999 production level indicated more energy use because of the large energy demand cost that occurred in this level as compared with other levels. In addition, a pallet manufacturing mill, which requires more energy consumption, is located at this level.

Total cost.—Total cost was analyzed by using total cost per thousand board feet of production and total cost per employee, respectively (Fig. 4). The total cost per thousand board feet of production is obtained by dividing the total cost of the facility by the annual thousand board feet of lumber production. The total cost per thousand board feet production showed almost the same pattern as the energy use per thousand board feet of production for all the mills (Fig. 4a). The total cost includes energy use cost and energy demand cost. The demand charge is used to compensate the utility company for the capital investment required to serve peak loads. The demand cost can be calculated by multiplying demand rate in dollars per kilowatt hour by demand used in kilowatt month per year. In all the audit sawmills, the average total cost per thousand board feet of production was $10.04/MBF, ranging from $1.35 to $22.01 per MBF. When looking at mills individually, the total cost can be obtained by multiplying the energy use values of

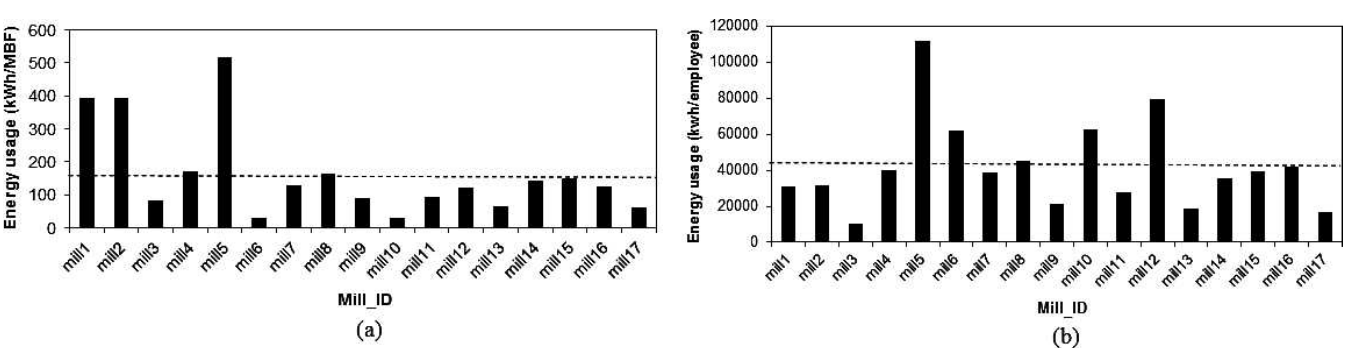

Figure 2.—Energy use for all mills (dashed line represents the mean over all mills). (a) Energy use per thousand board feet (MBF) of lumber production. (b) Energy use per employee.

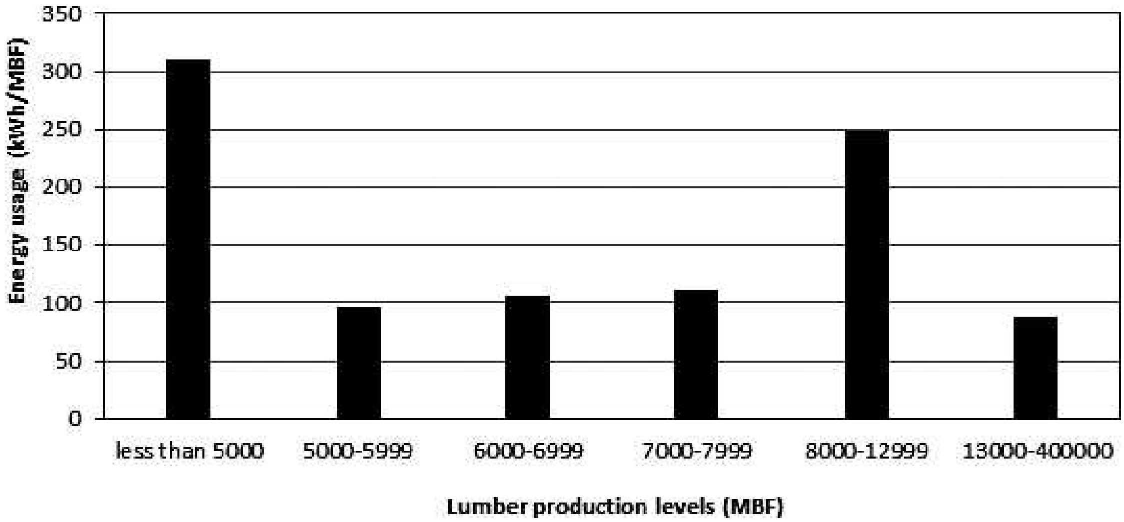

Figure 3.—Energy use per thousand board feet (MBF) of lumber production by production levels.

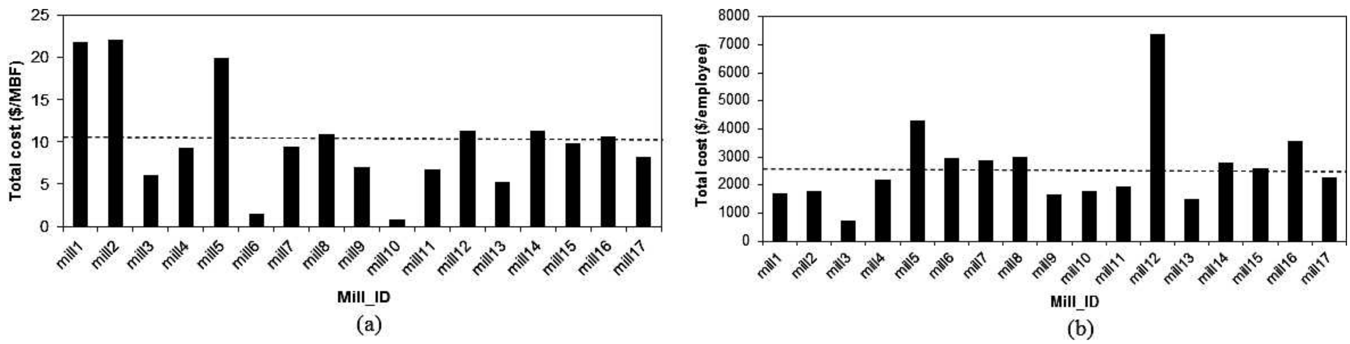

Figure 4.—Total cost for all mills (dashed line represents the mean over all mills). (a) Total cost per thousand board feet (MBF) of lumber production. (b) Total cost per employee.

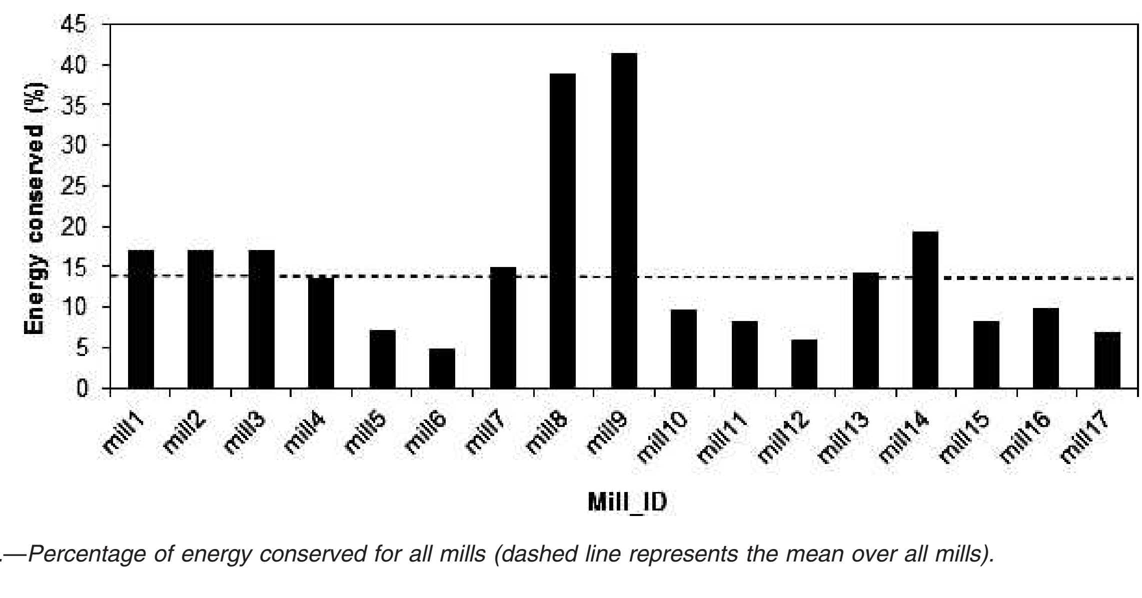

Figure 5.—Percentage of energy conserved for all mills (dashed line represents the mean over all mills).

kilowatt hour by the rate of dollars per kilowatt hour. Otherwise, demand cost will be added to the total cost. In some cases, demand costs can be a significant portion of the total electricity charges. In one of the audits, demand costs amounted to as much as 52 percent of the total electricity costs. Therefore, it is necessary to focus on demand costs to reduce the total electricity costs in some mills. Many techniques can be used to reduce demand charge. One good way is to downsize motors or use high-efficiency motors, since motors are the largest contributing factor on demand during startup. If the total cost of the facility was divided by the number of employees, an average total cost per employee was $2,632 based on all of the energy audits, ranging from $725 to $7,375 (Fig. 4b). Figure 4b also shows that total cost per employee in Mill 12 was very high compared with other mills. Mill 12 produced large amounts of lumber, and the annual demand cost was $259,627/y, while annual energy use cost was only $190,245.

Energy conservation potential.—The percentage of energy conserved is calculated by dividing energy that could be conserved in kilowatt hours by the energy used per year. The average energy savings achieved was 14.89 percent of the annual energy used, with a range from 4.73 to 41.31 percent (Fig. 5). It is noted that Mills 8 and 9 have large energy conservation as compared with other mills. When we closely observed these two mills, we found that large energy savings would result from following the recommendations, such as implementing a motor management system, replacing drive belts on large motors with energy-efficient cog belts, and repairing compressed air leaks. Mill managers need to address these items in order to reduce energy consumption. The average energy conserved per thousand board feet, derived by dividing the annual energy conserved in kilowatt hours by the annual lumber production in thousand board feet, was 24 based on all of the energy audits, ranging from 1.64 to 66.64 kWh/MBF. Similarly, if the annual energy conservation (kilowatt hours) was divided by the number of employees, an average energy conservation was 5,341 kWh per employee based on all of the energy audits, ranging from 1,155 to 17,425 kWh per employee.

Conclusions

Assessing energy consumption and efficiency should be a critical component of the day-to-day management of hardwood sawmills. Consumption and efficiency will only become more important in the future as a result of economic conditions, energy prices, energy supply, and environmental concerns. Survey responses from 58 Appalachian hardwood sawmills revealed that the electricity consumed per month per mill averaged 220 kWh/MBF, and the average electric bill was $17.78/MBF/mo. Many opportunities exist for sawmills to reduce energy costs and waste in their lumber production. The energy assessment in 17 sawmills indicated that greater energy savings are possible through process changes and implementing new and more energy-efficient technologies. Some assessment recommendations could be easily implemented for saving energy in mills, with very little investment and good payback periods.

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