energy**design**resources

design brief

DRIVEPOWER

To truly minimize the energy use of a drivepower system—which includes the motor, its controls, and the connection between the motor and the equipment it drives—designers need to consider how these components operate as a system rather than looking at them individually.

Summary

In a typical building, motors are used in a variety of applications to provide (among other things) ventilation, cooling, and vertical transportation. An average building may contain literally hundreds of motors, and their collective energy use can account for as much as one-quarter of a building's energy costs. Even so, all too often designers give the selection and sizing of motors short shrift—as can be seen by the prevalence of oversized, inefficient induction motors.

The establishment of national standards for motor efficiency and the adoption of a premium-efficiency specification by the motor industry have improved this situation considerably, but many designers still mistakenly believe that simply specifying an energy-efficient motor is enough to ensure efficient operation. To truly minimize the energy use of a drivepower system—which includes the motor, its controls, and the connection between the motor and the equipment it drives—designers need to consider how these components operate as a system rather than looking at them individually.

Undertaking a critical evaluation of the entire drivepower system and combining good engineering with efficient components such as premium-efficiency motors and variable-speed drives can reduce the energy use of motor-driven systems by 50 percent or more. When you consider that in a single year, a motor often consumes energy worth about 10 times the unit's initial cost, system improvements can easily pay for themselves within the first few months of operation.

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Introduction

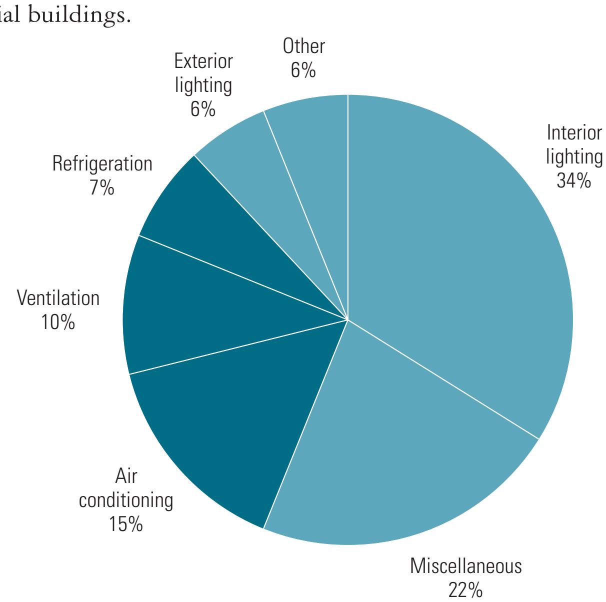
Electric motors account for an estimated 32 percent of all electricity consumed in California's commercial buildings.[1] Most of these motors are used in heating, ventilating, and air-conditioning (HVAC) applications as drivers for fans, pumps, and air-conditioning compressors (see **Figure 1**). The operating cost for these motors can be as much as 50 to 75 cents per square foot per year.

Although there are certainly benefits to improving motor efficiency, that is only one facet of reducing the cost of an entire system.

In the past, some attention was given to improving the efficiency of motor-driven systems through utility demand-side management (DSM) programs, but more often than not those programs addressed only the most obvious target—the efficiency of the motor itself. Although there are certainly benefits to improving motor efficiency, that is only one facet of reducing the cost of an entire system. An evaluation that considers how the motor, controls, and driven system work together—and how they influence other building systems—can make it possible to significantly reduce the cost of purchasing, operating, and maintaining the equipment. For example, focusing solely on motor efficiency

Figure 1: Electrical use by end use for commercial buildings in California

Typically, motors used to drive fans, compressors, and pumps in commercial buildings account for about 32 percent of all electricity consumed in California's commercial buildings.



Courtesy: Platts; data from California Energy Commission may yield a 1 to 5 percent reduction in operating cost, but improvements that take into account the entire drivepower system may provide savings of 50 percent or more.

In virtually all applications—and especially in pumps, blowers, and fans, for which energy use in many applications varies as the cube of flow—the best system optimization will result from starting all the way downstream, with the intended end use, and then working back upstream. The farther downstream a saving is made, the more dramatic are its benefits upstream, because so many avoided losses along the way will successively multiply its effect. This not only compounds the savings, but it may also allow the upstream components to be smaller and therefore cheaper. Capturing that compounding can dramatically cut costs.

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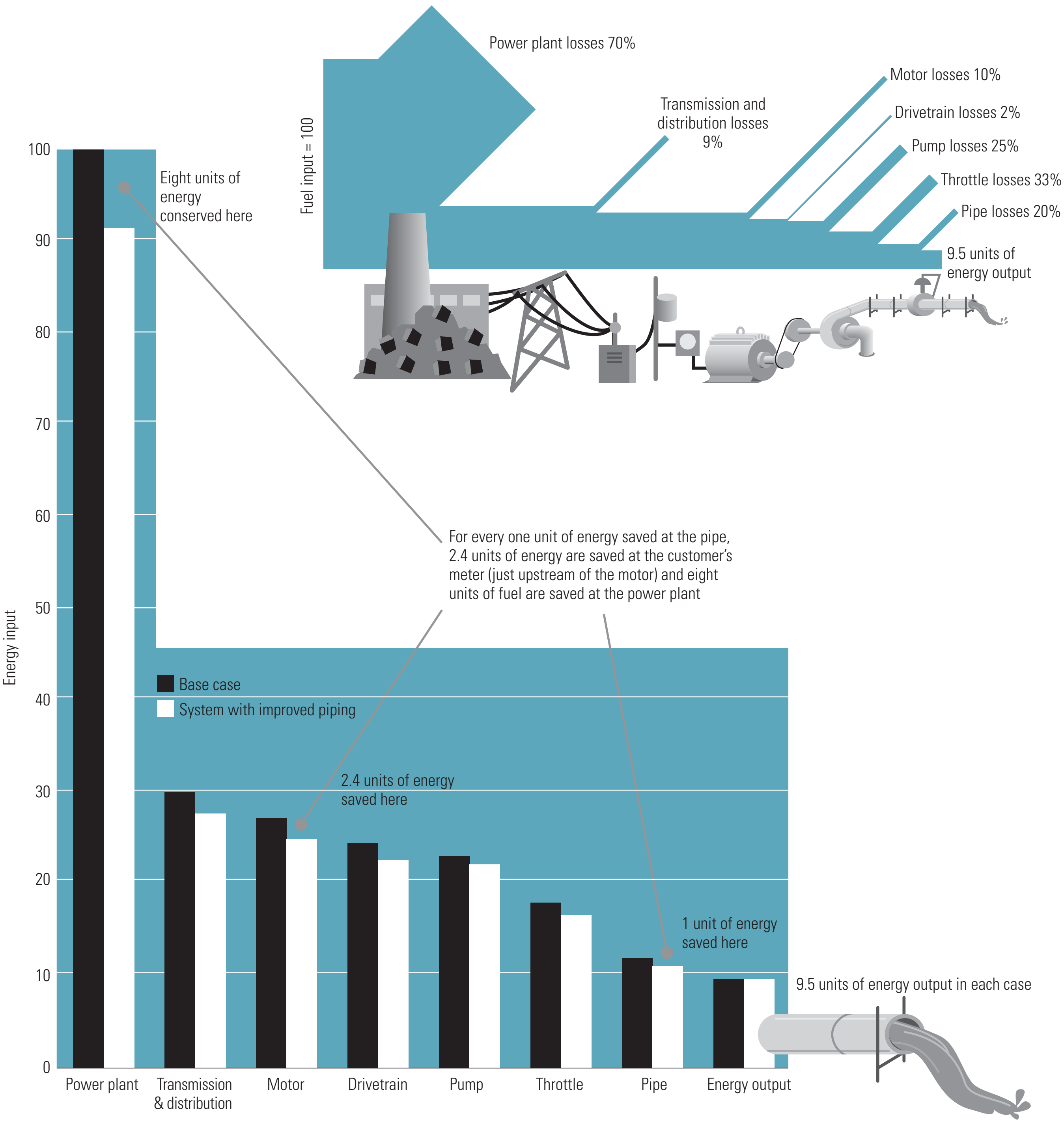
The friction encountered by a flowing fluid is roughly proportional to the fifth power of pipe diameter. Pipe sizing thus offers powerful leverage over energy use. A 15 percent increase in pipe diameter—say, from 3.5 inches to 4 inches—can cut pressure drop in half. This halving of pressure drop can in turn allow the pump, coupling, motor, controls, and electrical service to be much smaller, yielding significant capital cost savings.

This leverage is illustrated in **Figure 2** (page 4) which shows how the energy losses compound upon each other working upstream from the task being served to the utility generating station. Figure 2 assumes a typical pumping application involving a throttling valve, pump, mechanical drivetrain, and electric motor. Given the losses incurred in each step of the process, one unit of energy saved at the entrance to the piping through reduced friction yields 2.4 units of savings at the utility meter and over 8 units of reduced fuel input to the power plant. In contrast, a unit of savings achieved farther upstream—at the motor, for example—would save only one unit of energy at the customer meter and three units of fuel energy at the power plant, because the motor's losses are not compounded by as many components between it and the power plant.

Figure 2: The leverage of downstream efficiency

The diagram below shows the percentage of energy lost at each step in the base case system, which requires 100 units of fuel input at the power plant to deliver 9.5 units of energy output in the form of fluid flow exiting the pipe. The bar chart compares the base case with an otherwise identical system that has a one-unit reduction in pipe friction—by making the pipe slightly larger, smoother, straighter, or by using better valves. This one-unit savings at the downstream end of the system is compounded by efficiencies of the upstream components to yield 2.4 units of savings at the utility meter just upstream of the motor and over 8 units of fuel savings at the power plant.



Courtesy: Platts

Although this document focuses on efficiencies that can be gained through the drivepower system itself, the designer should ask, and answer with care, the following questions about the driven system:

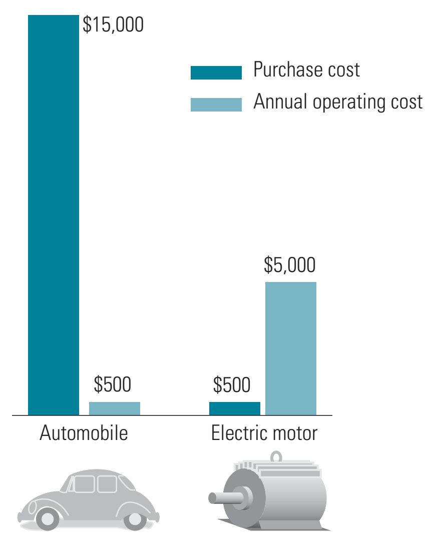
- How much flow, with what time-varying patterns, is really required to achieve the goals of a well-controlled, optimized process?
- How big should the pipes or ducts be, and how short, smooth, and "sweet" can they be made with optimal system layout, to deliver that flow? For more information on piping and ducting losses, refer to Design Briefs on "Chiller Plant Efficiency," "Integrated Design for Small Commercial HVAC," and "Advanced Variable-Air-Volume Systems."
- How big and with what performance curve should the pump or fan be specified to deliver that flow pattern, and how efficient can the pump or fan be made over that operating range?
- What will be the optimal size and efficiency of the mechanical drivetrain that transmits torque to the pump or fan? of the motor? of its controls? and of their electrical supplies?
- What control sequences and staging of equipment (such as pumps and compressors) will give optimal performance?

The systems approach often provides opportunities to reduce the cost of other building systems as well. For example, reducing the necessary size of motors and transformers reduces cooling loads in electrical rooms, which in turn makes it possible to install smaller, less-expensive cooling systems for those spaces.

Many electric devices cost much more to buy than to operate for a single year, but electric motors are a notable exception to that rule of thumb. Under typical operating conditions, an electric motor that drives a pump or fan will consume on the order of 10 times its capital cost in electricity every year. (See **Figure 3**.) For

Figure 3: Relationship of purchase price to operating costs for electric motors and automobiles

A car costs much more to purchase than to operate, but the cost of a motor is small relative to its annual operating costs. Because the operating costs far exceed a motor's purchase price, it is usually a financially sound decision to pay more up front to get a more efficient model.



Courtesy: Platts

this reason, the extra cost of a more efficient motor system can often be recovered quickly, and given the long life span of most motors, system efficiency improvements can rack up huge savings over the 10 to 15 years that they may be in service.

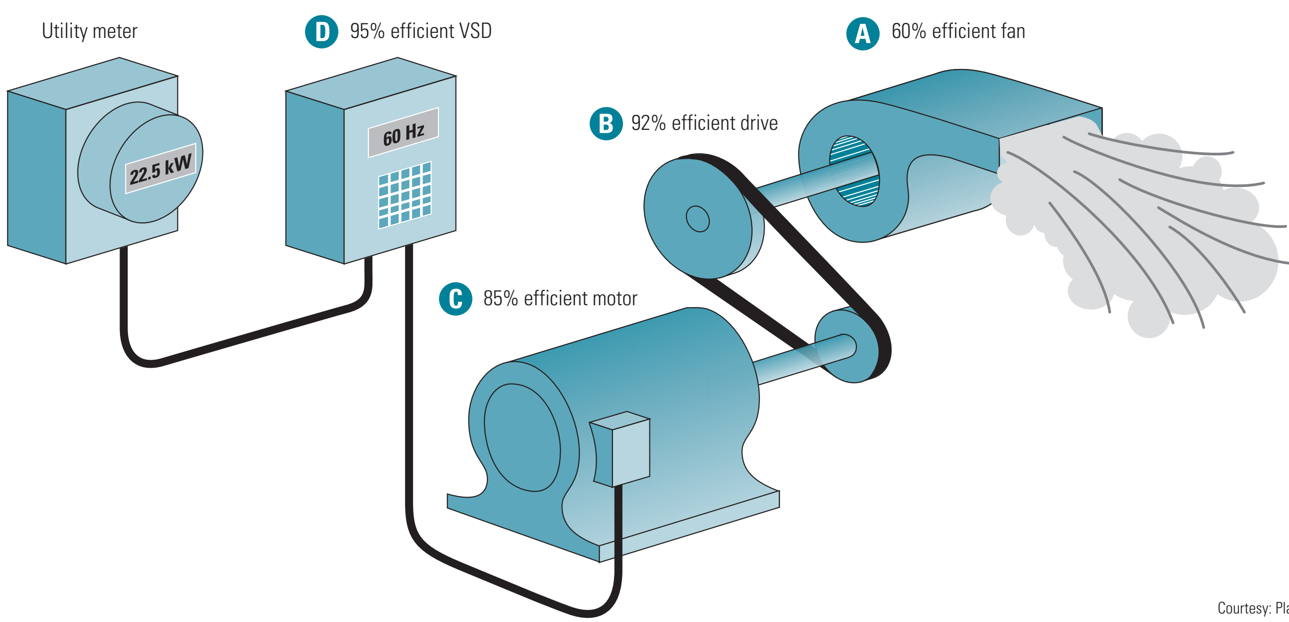
Designing an Efficient Drivepower System

The gains in efficiency that can be realized by installing a premium-efficiency motor can easily be offset by the negative impact of oversizing the motor, improperly connecting it to the driven load, or choosing the wrong type of controls for it. (See **Figure 4**.) To minimize the overall energy impact of drivepower systems, the designer must "start at the load"—the reason for installing the drivepower in the first place—and work back through the entire system, paying attention to:

- *The range of requirements for which the driven equipment is to be sized.* This should be evaluated before sizing the fan or pump. Efficiencies in the delivery of chilled or hot water or

Figure 4: Typical drivepower system

If this fan system were perfectly efficient, only 10 kilowatts (kW) of power would be needed to achieve the desired airflow. Unfortunately, in the real world, the inefficiency of each component in the system (including the fan, fan belt, motor, and variable-speed drive) will increase the power measured at the electricity meter. This example shows how those inefficiencies add up, ultimately making it necessary to draw 22.5 kW to deliver the desired amount of air to the conditioned space. Thoughtful design and efficient equipment selection could reduce the power requirement for this system to about 15 kW—an improvement of about 33 percent.



Courtesy: Platts

air can be obtained by properly designing the distribution system (for example, pipe size and size of ductwork) for the fluid delivered.

- *The efficiency of the driven equipment (A).* Don't underestimate the value of selecting an efficient pump or fan, for there can be vast differences in efficiency between seemingly similar equipment. For example, an airfoil centrifugal fan can be as much as 30 percent more efficient than the typical forward-curved fan, although the two provide about the same performance.

- *The connection between the driven equipment and the motor (B).* The efficiency of a drivepower system will also be affected by the way the motor is connected to the driven equipment. For example, the standard v-belts used to connect fans to motors typically cause a 3 to 5 percent reduction in motor horsepower due to simple frictional losses. Instead of driving the equipment, this lost motor power is dissipated as waste heat. The use of efficient belts or direct-drive connections can cut such frictional losses in half.

- *The size and efficiency of the motor driving the load (C).* When it comes to efficiency, all motors are not created equal. The difference between two seemingly identical motors can be vast, especially in the case of small, single-phase motors. Efficiency varies according to how heavily the motor is loaded, so an oversized premium-efficiency motor may actually operate less efficiently than a properly sized motor that just meets the minimum federal efficiency standard.

- *The controls regulating motor operation (D).* For motors driving centrifugal loads, such as pumps and fans, the controls used to regulate the flow of air or water can also have a profound impact on energy consumption. Choosing the right means of control can make the difference between an average system and an efficient one.

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- *The power quality implications of the drivepower system.* If not carefully selected for the job, motors and their controls (including options such as variable-speed drives) can have a negative impact on power quality. Selecting appropriate, compatible components—and installing them correctly—can go a long way toward minimizing potential power quality problems.

To get the best possible energy and cost savings, use the system approach: "right-size" the motor for the task, select a premium-efficiency motor, pick the most efficient motor controls, and properly install the drivepower components to minimize power quality problems.

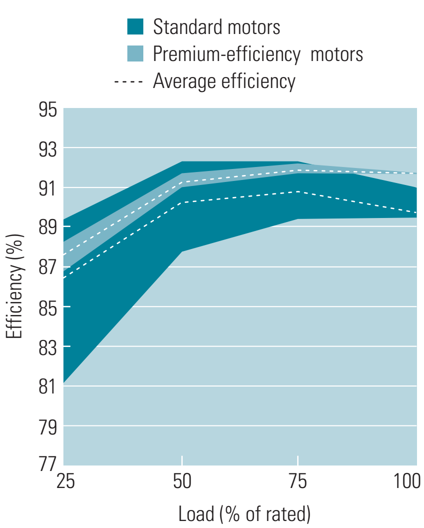
Size the Motor for the Task

Traditionally, mechanical engineers have calculated the actual horsepower required for a task and then selected a larger motor than is absolutely required to avoid problems associated with overloaded motors and to allow for variations in the assumed operating environment. A certain amount of conservatism is certainly warranted when sizing motors, but designers should be aware that an oversized electric motor also has distinct disadvantages when compared with one that has been right-sized. An oversized motor can make for:

- *Poor efficiency.* Electric motors are generally most efficient when operating from 75 to 100 percent of full-load capability. An oversized motor is often needlessly inefficient because of light-load operation—particularly if it is operating at less than 50 percent of full load. The extent to which efficiency changes on the basis of the load usually varies according to motor size, mostly because of different construction practices for small, medium, and large motors. **Figure 5** shows typical partial-load efficiency curves for a 10-horsepower (hp) induction motor.

Figure 5: Efficiency vs. load for 10-hp standard and NEMA premium motors

Many larger motors achieve peak efficiency at close to 75 percent load. This graph assumes a 460-volt, 1,800-rpm, TEFC motor.



Notes: EPACT = U.S. Energy Policy Act of 2005; hp = horsepower; TEFC = totally enclosed fan-cooled; V = volt. Courtesy: Platts

- *Reduced power factor.* A lightly loaded motor operates at lower power factor than a fully loaded motor, and low power factor will increase energy costs in regions where utilities charge for it. The major electric utilities in southern California, for example, may charge at least some of their customers for low power factor.

- *Higher first cost.* Oversized motors cost more than smaller, properly sized motors. An oversized motor also requires a more robust electrical system, including the cost for wiring to the motor, the starter, and the disconnect switch.

- *Drain on building electrical systems.* Oversized electric motors needlessly tax a building's electrical system. The energy required to energize the magnetic fields for inductive loads (such as motors and fluorescent ballasts) reduces the amount of energy available to serve other loads in the building. In new construction, the capacity of the entire electrical system—including conductors and transformers—must often be increased to accommodate the power requirements of oversized motors. Properly sizing motors, and, where necessary, installing power factor correction capacitors, can sometimes allow the designer to reduce the capacity of a facility's electrical distribution system without compromising performance.

An oversized motor is often needlessly inefficient because of light-load operation—particularly if it is operating at less than 50 percent of full load.

"Service factor" is one reason that oversizing is usually unnecessary. It is the percentage by which a motor can safely exceed its nameplate horsepower rating—and it can range from 0 to 25 percent of full-load output. Given that 88 percent of the motors on the market today have a service factor of 1.15 (meaning that the motor can safely operate at 115 percent of full-load output) or greater, most motors already have a reasonable tolerance built in for changes in operating conditions that increase motor load. The service factor for a motor is almost always stamped on the nameplate. Note that, although it is safe to run a motor up to its service factor, running it close to the service factor for an extended

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period of time will degrade the motor insulation faster, shortening its useful life.

To maximize overall efficiency, carefully and realistically calculate the horsepower requirements for a given application. Avoid applying excessive factors of safety at every step of the calculation. The final motor selection should include a modest margin of safety[2] on the horsepower, and that should make additional safety factors redundant.[3]

Select a Premium-Efficiency Motor

The Energy Policy Act of 1992 (EPAct 1992) mandated that nearly all three-phase, general-purpose motors up to 200 hp manufactured for sale in the U.S. after October 24, 1997, meet minimum efficiency levels. Although this standard set the floor for energy efficiency, following its enactment, some manufacturers used terms like “high-efficiency” and “premium-efficiency” to describe motors that barely exceeded the standard, whereas other manufacturers reserved such terms for models that exceeded the standards by a wide margin. In 2001, the National Electrical Manufacturers Association (NEMA) brought uniformity and credibility to these terms by establishing its NEMA Premium specification (**Table 1**, page 11). In thc document, the term “premium efficiency” refers to motors that meet or exceed the NEMA Premium specification.

In new construction applications, it is often economically attractive to purchase premium-efficiency motors over standard-efficiency models. For example, consider an 1,800-rpm, 20-hp motor that will drive a constant-speed pump. One manufacturer’s standard motor for this application has a full-load efficiency of 91.0 percent, with a purchase price of $935. A premium-efficiency motor that meets these same requirements has a full-load efficiency of 93.0 percent, with a purchase price of $989. Under typical operating conditions,[4] the energy-efficient motor will save about $75 per year as compared with the standard-efficiency motor. Considering the incremental cost for the

Table 1: The NEMA premium-efficiency specification

The National Electrical Manufacturers Association (NEMA) adopted its NEMA Premium specification in 2001, bringing credibility to the term "premium efficiency." The minimum efficiency of the NEMA specification is shown here for each motor class, along with the amount by which each exceeds the Energy Policy Act of 1992 (EPAct) standard in parentheses. Note that, although EPAct covers motors only up to 200 horsepower (hp), the NEMA Premium specification covers low-voltage motors up to 500 hp as well as medium-voltage motors from 250 to 500 hp (not shown).

	Open motors			Closed motors		
Hp	2-pole	4-pole	6-pole	2-pole	4-pole	6-pole
1.0	77.0 (NA)	85.5 (3.0)	82.5 (2.5)	77.0 (1.5)	85.5 (3.0)	82.5 (2.5)
1.5	84.0 (1.5)	86.5 (2.5)	86.5 (2.5)	84.0 (1.5)	86.5 (2.5)	87.5 (2.0)
2.0	85.5 (1.5)	86.5 (2.5)	87.5 (2.0)	85.5 (1.5)	86.5 (2.5)	88.5 (2.0)
3.0	85.5 (1.5)	89.5 (3.0)	88.5 (2.0)	86.5 (1.0)	89.5 (2.0)	89.5 (2.0)
5.0	86.5 (1.0)	89.5 (2.0)	89.5 (2.0)	88.5 (1.0)	89.5 (2.0)	89.5 (2.0)
7.5	88.5 (1.0)	91.0 (2.5)	90.2 (1.7)	89.5 (1.0)	91.7 (2.2)	91.0 (1.5)
10	89.5 (1.0)	91.7 (2.2)	91.7 (1.5)	90.2 (0.7)	91.7 (2.2)	91.0 (1.5)
15	90.2 (0.7)	93.0 (2.0)	91.7 (1.5)	91.0 (0.8)	92.4 (1.4)	91.7 (1.5)
20	91.0 (0.8)	93.0 (2.0)	92.4 (1.4)	91.0 (0.8)	93.0 (2.0)	91.7 (1.5)
25	91.7 (0.7)	93.6 (1.9)	93.0 (1.3)	91.7 (0.7)	93.6 (1.2)	93.0 (1.3)
30	91.7 (0.7)	94.1 (1.7)	93.6 (1.2)	91.7 (0.7)	93.6 (1.2)	93.0 (1.3)
40	92.4 (0.7)	94.1 (1.1)	94.1 (1.1)	92.4 (0.7)	94.1 (1.1)	94.1 (1.1)
50	93.0 (0.6)	94.5 (1.5)	94.1 (1.1)	93.0 (0.6)	94.5 (1.5)	94.1 (1.1)
60	93.6 (0.6)	95.0 (1.4)	94.5 (0.9)	93.6 (0.6)	95.0 (1.4)	94.5 (0.9)
75	93.6 (0.6)	95.0 (0.9)	94.5 (0.9)	93.6 (0.6)	95.4 (1.3)	94.5 (0.9)
100	93.6 (0.6)	95.4 (1.3)	95.0 (0.9)	94.1 (0.5)	95.4 (0.9)	95.0 (0.9)
125	94.1 (0.5)	95.4 (0.9)	95.0 (0.9)	95.0 (0.5)	95.4 (0.9)	95.0 (0.9)
150	94.1 (0.5)	95.8 (0.8)	95.4 (0.9)	95.0 (0.5)	95.8 (0.8)	95.8 (0.8)
200	95.0 (0.5)	95.8 (0.8)	95.4 (0.9)	95.4 (0.4)	96.2 (1.2)	95.8 (0.8)
250	95.0 (NA)	95.8 (NA)	95.4 (NA)	95.8 (NA)	96.2 (NA)	95.8 (NA)
300	95.4 (NA)	95.8 (NA)	95.4 (NA)	95.8 (NA)	96.2 (NA)	95.8 (NA)
350	95.4 (NA)	95.8 (NA)	95.4 (NA)	95.8 (NA)	96.2 (NA)	95.8 (NA)
400	95.8 (NA)	95.8 (NA)	95.8 (NA)	95.8 (NA)	96.2 (NA)	95.8 (NA)
450	95.8 (NA)	96.2 (NA)	96.2 (NA)	95.8 (NA)	96.2 (NA)	95.8 (NA)
500	95.8 (NA)	96.2 (NA)	96.2 (NA)	95.8 (NA)	96.2 (NA)	95.8 (NA)

Note: NA = not applicable.

Courtesy: Platts; data from NEMA

energy-efficient motor of $54, this investment will pay for itself in under nine months—a payback that is likely to meet any organization's rate-of-return requirement for an investment. More significantly, over the course of the motor's life span of about 15 years, savings from the premium-efficiency motor will in many cases repay the entire motor's cost several times over.

Although the economics of premium-efficiency motors will vary according to the specific application, in most cases there is a sound financial argument for investing in premium-efficiency

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How to Calculate Efficient Motor Savings

For applications in which a motor will operate at constant speed according to a well-defined schedule, calculating the savings for motor efficiency upgrades is a fairly straightforward exercise. Here's how it is done:

$$S = 0.746 \times C \times LF \times N \times [(100 / E_S) - (100 / E_H)] \times P_{AVG}$$

Where:

- S = Annual cost savings
- 0.746 = conversion from horsepower to kilowatts
- C = nameplate horsepower of the motor
- LF = load factor for application
- N = number of operating hours per year
- E_S = efficiency of existing motor at a given load factor
- E_H = efficiency of proposed motor at load factor of new motor
- P_{AVG} = average cost per kilowatt-hour for electricity

For evaluations of more-complicated applications, consider using a computer program called MotorMaster+. It contains an extensive database of motors, including efficiency and price for each, which allows the user to easily compare the economics of different motor selections. MotorMaster+ may be downloaded free of charge from www.oit.doe.gov/bestpractices/software_tools.shtml#mm.

motors. Many utilities around the country offer rebates to reduce or eliminate the incremental cost of a premium-efficiency motor. In California, a statewide program provides rebates to motor distributors to encourage them to keep premium-efficiency motors stocked on their shelves. Some distributors will pass all or a portion of the rebate on to their customers, further improving the economics of premium-efficiency motors. The three large investor-owned utilities also offer their customers an incentive or rebate to purchase energy-efficient motors for new construction and retrofit projects. The sidebar on this page presents a simple calculation to estimate the annual energy savings that a motor efficiency upgrade would yield.

To obtain maximum energy savings, buyers should choose motors that meet the NEMA Premium specification. Buyers should explicitly state the required minimum efficiency levels according to motor size in their specifications and carefully review contractor bids to be sure that the required efficiency level has been met.

Although the nationwide motor efficiency standard and the NEMA Premium specification are steps in the right direction, they do not ensure that all motors sold will be efficient. For example, the EPAct standards do not apply to single-phase, fractional-horsepower motors. That's unfortunate, because many pieces of equipment in a building—including exhaust fans, refrigerated drinking fountains, and certain types of HVAC equipment such as fan coil units or fan-powered, variable-air-volume (VAV) zone terminals—are driven by such small, single-phase motors. If those motors are not carefully specified, their efficiency can vary by as much as 50 percent for two seemingly identical units.

The impact of inefficient fractional-horsepower motors can be severe in buildings with a lot of them, as would be the case when fan-powered VAV terminals are used to distribute air. In such an installation, there may be one small, inefficient motor for every 500 to 1,000 square feet of conditioned space, and that can add up to hundreds of little energy-wasters hidden away above the ceiling.

Two higher-efficiency alternatives for fractional horsepower motors are the electrically commutated motor (ECM) and the switched-reluctance motor (SRM). Although neither of these technologies has the widespread application of the conventional induction motor typically selected for fractional, single-phase applications, both are substantially more efficient than induction motors, particularly at partial load. This efficiency improvement comes at increased cost, but proponents of the SRM claim that in large volumes it should be cheaper to produce than the induction motor. And one manufacturer of HVAC equipment is reportedly gearing up to produce ECM motors for VAV terminal fans with an incremental cost of only about $30.

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Another thing to watch for is the availability and use of "special purpose" motors. EPAct standards only apply to general purpose motors; special purpose motors are not governed by any standards for efficiency. In some cases, what a manufacturer refers to as a "special purpose" motor is really just a relabeled version of their standard-efficiency product line. Because the difference between a special purpose and a general purpose motor is not rigidly defined, some original equipment manufacturers (OEMs) have decreed that their equipment requires special purpose (read inexpensive and inefficient) motors. Specifying minimum efficiency requirements for all single- and polyphase motors provided as part of OEM equipment will ensure that inefficient motors are not hidden deep within the units.[5]

The savings that can be achieved by installing premium-efficiency motors varies with motor size and load factor (that is, the percentage of nameplate horsepower that the motor delivers under typical operating conditions). **Table 2** shows the energy cost savings for premium-efficiency motors versus EPAct standard motors in new applications.

Table 2: Comparison between EPACT minimum standard and premium-efficiency motors

Horsepower	Annual energy cost savings[a]	Incremental motor cost[a]	Simple payback (years)
1	$13	$61	4.5
20	$152	$114	0.7
75	$340	$420	1.2
100	$330	$618	1.9

Notes: a. Based on average price and performance data for a number of 1,800-rpm, TEFC motors operating at 100 percent load for 4,000 hours per year. Savings values assume an electricity price of $0.105/kWh. Price and performance data taken from MotorMaster+ software.

Courtesy: Platts

Case Study: Getting It Right

On a new construction project, the mechanical engineer was reviewing the manufacturer's submittal for a condenser water pump.[6] The submittal indicated that a 30-hp energy-efficient motor would be provided to drive the pump, despite the fact that the engineer had specified a 25-hp premium-efficiency motor. The engineer took a look at the pump performance curve and confirmed that the horsepower requirement for this application was 23.1 hp. When he called the pump manufacturer, he learned that the application engineer who made the pump/motor selection felt that a 25-hp motor was "too small"—even though the performance requirements for this pump were well understood and the calculations had already been reasonably conservative. The application engineer had substituted the 30-hp motor and selected an energy-efficient model, rather than the specified premium-efficiency motor.

The mechanical engineer knew that the motor would have a service factor of 1.15 and that a 25-hp motor would provide about 10 percent oversizing for the 23-hp load, so he rejected the submittal. In the revised submittal, the manufacturer specified the pump with the requested 25-hp premium-efficiency motor. The new motor was two full percentage points higher in efficiency than the motor that was previously submitted, and it only cost $200 more.

Table 3: Comparison between oversized EPAct minimum-efficiency and right-sized premium-effiency motors

Motor load (hp)	Motor sizes: EPAct vs. premium-efficiency (hp)	Efficiency of oversized EPAct motor (%)	Efficiency of right-sized premium-efficiency motor (%)	Annual energy cost savings[a] ($)	Average incremental motor cost[a] ($)	Payback of incremental cost (years)
0.75	1.5 vs. 1.0	81.5	86.1	16	39	2.5
15	25 vs. 20	92.6	93.5	49	26	0.5
50	100 vs. 75	94.4	95.3	153	–189	Immediate
75	125 vs. 100	94.2	95.7	389	–547	Immediate

Notes: EPAct = Energy Policy Act of 1992.
a. Based on average price and performance data for a number of 1,800-rpm, TEFC motors operating 4,000 hours/year at $0.105/kWh.

Courtesy: Platts; price and performance data from MotorMaster+ software

As noted earlier, right-sizing a motor can often more than offset the incremental cost of purchasing premium-efficiency motors. **Table 3** shows that, in many cases, the payback on installing a smaller premium-efficiency motor instead of an oversized EPAct standard-efficiency motor is instantaneous.

One of the most user-friendly tools available for assessing the economics of installing premium-efficiency motors is a computer program called MotorMaster+. Developed by the Washington State University Energy Program and the U.S. Department of Energy, MotorMaster+ allows the user to identify a range of efficient motors from different manufacturers to meet specific design criteria. MotorMaster+ may be downloaded free of charge at www.oit.doe.gov/bestpractices/software_tools.shtml#mm.

Use Efficient Motor Controls

When applied to HVAC systems where heating and cooling loads vary significantly over time, a motor controlled by a variable-frequency drive (VFD) provides an efficient means for regulating fan or pump operation. Induction motors are designed to run at a fixed speed that is proportional to their input power frequency—normally 60 hertz (Hz) in the United States. A VFD is an electronic device that provides power at varying frequencies, making it possible for induction motors to operate at anywhere from 10 to 300 percent of their nominal, fixed speed. For applications as small as 1 hp or as large as 5,000 hp, VFDs can cut energy use by 50 percent or more.

VFDs have been promoted for their ability to boost energy savings and improve motor performance. Because the power required to move a fluid varies in just about direct proportion to fluid flow multiplied to the third power, using a VFD rather than a throttling valve or damper to reduce flow can provide dramatic energy savings. For example, when an application requires only 50 percent of its design flow, the power required to create that flow will be approximately 0.50 x 0.50 x 0.50 = 0.125, or only 12.5 percent of the power requirement at rated flow. Note that the power requirement of the VFD-driven fan or pump that moves the fluid will be somewhat greater than this because the efficiency of both the VFD and the fan or pump decline with speed, but the overall system efficiency is greatly improved as a result of the cubic relationship between flow and power requirements.

For applications as small as 1 hp or as large as 5,000 hp, VFDs can cut energy use by 50 percent or more.

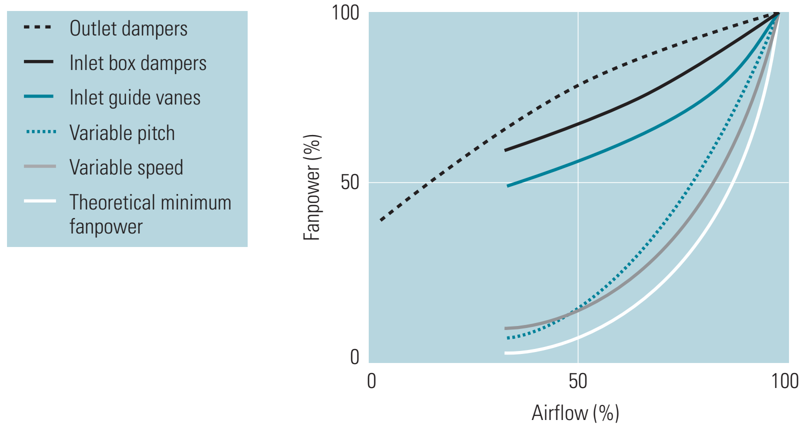
The application of VFDs for variable-air-volume air-handling systems has become increasingly common in new construction in southern California. This is due in part to the requirements of the California Energy Commission's Title 24 for fan capacity control on larger air-handling systems. Title 24 specifies that only certain types of fan capacity controls (those that consume 30 percent or less of design horsepower at 50 percent of design flow) can be used in new construction. From a practical standpoint, this requirement has limited the HVAC designer to using either a VFD to control airflow for a centrifugal fan, or to using variable-pitch fan blades in axial fan applications. **Figure 6** (page 16) depicts the energy input as a function of airflow for the most common means of fan capacity control. Basically, the more closely the curve for a specific fan control strategy matches that of the theoretical limit curve (the bottom curve), the more efficient this method will be.

Similar to Title 24 requirements for speed control for variable–air volume systems, the 2005 update to Title 24 contains a new section requiring speed control for all pumps greater than 5 hp in hydronic heating and cooling systems. Specifically, the code

Title 24 requires that fan and pump controls draw no more than 30 percent of full-load power when providing 50 percent of design flow.

Figure 6: The performance of different fan capacity control strategies

Title 24 standards require the use of fan capacity controls that consume 30 percent or less of design horsepower when providing 50 percent of design airflow.



Courtesy: Platts

requires that these systems be capable of operating at flow rates down to 50 percent of their design rate (as long as this is consistent with equipment manufacturer specifications), and that individual pumps "have controls and/or devices (such as variable speed control) that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow."[7]

During the design phase for a 300,000-square-foot commercial office building in Los Angeles, the cooling plant designer performed an economic analysis for installing a variable-flow chilled-water pumping system using variable-speed drives. He projected that the incremental cost for the VFDs, additional piping, controls, and pumps was about $28,000 when compared with a constant-flow system. A computer-based energy simulation revealed that the variable-flow system would save about $7,800 per year when compared with the constant-flow system, resulting in a payback of less than four years. On the basis of these favorable economics, the developer approved the variable-flow system. The building is now occupied and savings have exceeded the projections—largely because operating hours for the building have been a bit longer than anticipated.[8]

There are a few critical issues that need to be considered when selecting a VFD for a specific application:

- *Load profile.* VFDs are not 100 percent efficient—the drive's efficiency varies with load. If a VFD is misapplied to a constant-speed system, not only will there be no energy savings, but energy use may actually increase by 3 to 5 percent due to the inefficiency of the drive itself. In such cases, it is probably more efficient (and less expensive) to omit the VFD and use another strategy to regulate flow, such as a two-speed motor or riding the fan or pump curve. Note, however, that in high electric rate applications, VFD installations can be cost-effective even with an average loading up to 90 percent of full load.

- *Power quality features.* If harmonic distortion is a concern, consider specifying a VFD that includes integral power quality features such as line reactors and isolation transformers.

In addition to these issues, would-be buyers should know that when a TEFC (totally enclosed fan-cooled) motor with a VFD runs at reduced speed, the cooling fan mounted on the rotor spins at a slower speed, providing a reduced cooling effect on the motor windings, which can lead to overheating.

To provide reliable performance under variable-speed operation, many building operators and design engineers specify "inverter grade" electric motors. These motors usually feature better insulation, improved construction that results in cooler operation, and (sometimes) a separate constant-speed cooling fan to prevent motor windings from overheating when the motor is operating at low speeds. When possible, it is best to require that the motor and VFD (1) be provided by the same manufacturer and (2) be designed to operate synergistically. (See sidebar.)

In general, energy-efficient motors offer better compatibility with VFDs than standard-efficiency motors. Their increased efficiency means that less heat is generated within the motor, which results in lower operating temperatures at all operating speeds.

Integrated Motor/VFD Systems

In response to concerns about compatibility between motors and VFDs, a number of manufacturers now offer integrated systems (see **Figure 7**).[9] These systems combine a motor, a compatible VFD, and a keypad for programming the unit in one space-saving package. (Note that the buyer must provide any sensors or controls that are to direct the operation of the VFD.) In this integrated system, the motor is placed close to the VFD, minimizing long cable runs that can lead to power quality problems. In addition, compatibility between the motor and VFD is pre-engineered by the manufacturer, which may minimize the possibility of a motor failure due to a poor match between the two.

Figure 7: An integrated motor/ VSD system

Courtesy: MagneTek

Fractional-Horsepower VFDs

Although VFDs have traditionally been applied to polyphase motors larger than 5 hp, new fractional-horsepower VFDs—or microdrives—are becoming more commonly available. (See **Figure 8**.) These fractional-horsepower VFDs can be used with exhaust fans, small circulating pumps, and other fractional-horsepower loads to improve overall performance and efficiency. VFD control usually improves energy efficiency when compared with other methods of changing the operating speed of small motors.

Figure 8: Fractional-horsepower variable-speed drive

Courtesy: MagneTek

Install Drivepower Components to Maximize Power Quality

Power quality has become increasingly important in recent years because poor power quality can increase electric costs and may also cause malfunction or failure of sensitive electronic equipment. Most building operators are concerned with two elements of power quality: power factor and harmonics.

Power factor. Power factor is an indicator of how much of a power system's capacity is available for productive work. Utilities are concerned with low power factor because they must generate sufficient electricity to meet both the "real" power (the actual power consumed, which registers on the electric meter) as well as "reactive" power (the power used to energize magnetic fields, which doesn't register on the electric meter) loads in a building. Utilities generally do not charge most customers for "reactive" power, but low power factor makes it necessary to install larger wire and a larger transformer, which raises equipment costs, increases electrical losses, and makes the equipment require more space in what is usually an already cramped electrical room.

In most buildings, good ways to maintain high power factor include the following:

- *Right-size all electric motors.* Power factor is lower when a motor is lightly loaded.
- *Specify motors that have a high power factor.* If a facility contains a lot of motors, then power factor may be a significant issue. Some premium-efficiency motors have lower power factor than their less-efficient counterparts, but it is possible to find models in most motor classes that do not sacrifice power factor for efficiency. Your motor vendor or the MotorMaster software can help you identify the best units.

- *When low power factor cannot be avoided, apply power factor correction*. For example, in facilities that have a large number of fractional-horsepower motors, power factor correction devices such as capacitor banks should be installed.

Harmonics. Harmonics are voltage and current frequencies in the power system that are either above or below the normal 60-Hz sinusoidal power provided by utilities in the U.S. (see **Figure 9**). Harmonics are introduced into the power system by a variety of electronic devices, including VFDs and electronic lighting ballasts. Although harmonics are a necessary side effect of modern switching power supplies and electronics, they can harm other electrical equipment. For example, harmonics can affect the performance of motors and can interfere with the function of VFDs. However, these types of problems are not common.

Two main strategies can be employed to reduce the impact of harmonics:

- Locate motors within 50 feet of the variable-speed drive that controls them.

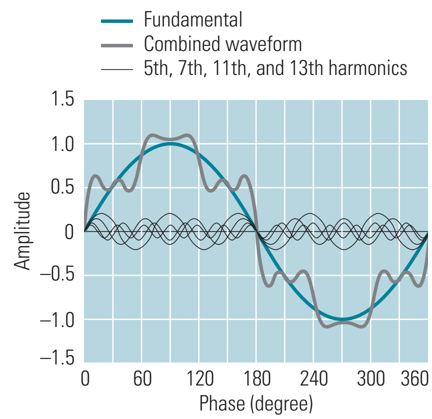
- In particularly sensitive environments (or when longer cable runs are necessary), install line reactors or isolation transformers to minimize the propagation of harmonics.

Drivepower and LEED

There are no LEED (Leadership in Energy and Environmental Design) points specifically associated with drivepower. However, LEED points are available for beating the ASHRAE 90.1 energy specification. In this regard, efficient drivepower system design, the selection of premium-efficiency motors, and the use of VFDs can contribute to LEED certification.

Figure 9: Waveform with VSD harmonics

This graph shows how harmonics distort the fundamental waveform.



Courtesy: Platts

For More Information

National Electrical Manufacturers Association (NEMA)

1300 North 17th Street, Suite 1847

Rosslyn, VA 22209

tel 703-841-3200

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web www.nema.org

NEMA is one of the leading standards-development organizations for electrical equipment. The EPAct 2005 motor efficiency standards are based on standards developed by NEMA. The NEMA Premium motor specification, which is the de facto definition of premium efficiency, is available at www.nema.org/gov/energy/efficiency/premium.

The Institute of Electrical and Electronics Engineers (IEEE)

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IEEE is the world's largest technical professional society. It seeks to advance the theory and practice of electrical engineering through sponsorship of seminars, symposia, and research. IEEE publishes about 25 percent of the world's technical papers on electrical engineering topics and is a valuable source of technical information on issues such as power quality and motor/VFD compatibility.

MotorMaster+

Those who are interested in analyzing the cost-effectiveness of energy-efficient motors will benefit from using the MotorMaster+ software. The program can be downloaded free of charge from www.oit.doe.gov/bestpractices/software_tools.shtml#mm. For further information, contact the Information Center of DOE's Industrial Technologies Program at 877-337-3463.

E SOURCE *Technology Atlas Series, Volume IV: Drivepower*

This highly acclaimed, regularly updated reference manual has earned a reputation as the most detailed "encyclopedia" available on end-use drivepower efficiency. (The Atlas series also includes volumes on *Lighting, Space Cooling and Air Handling,* and *Residential Appliances*.) To obtain a copy of the *Drivepower Atlas*, contact:

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Notes

1. California Energy Commission, "Energy Efficiency and Conservation: Trends and Policy Issues," prepared in support of the Public Interest Energy Strategies Report under the Integrated Energy Policy Report Proceeding, Docket # 02-IEP-01, Figure 5, from www.energy.ca.gov/reports/2003-05-29_100-03-008F.PDF (accessed August 17, 2005).

2. Margin of safety is an intentional oversizing factor applied to motor size to account for unforeseen variations in operation. For example, if a 10 percent margin of safety is applied to a motor application with a calculated requirement of 27.3 hp, the installed motor will have a nameplate horsepower of 27.3 hp + (10 percent x 27.3 hp) = 30 hp.

3. The appropriate margin of safety is application-specific and should be established by the Engineer of Record. Sometimes, motor-driven loads that are thought to be strictly constant actually do vary over time. For example, the load on a constant-volume fan motor will vary slightly over time due to the temperature and humidity (and therefore the density) of the air it moves.

4. Which would be 4,000 hours per year of operation at a load factor of 80 percent, with an average electric cost of $0.09 per kilowatt-hour. This example was developed with MotorMaster+.

5. The ability to control the efficiency of motors in OEM equipment will vary according to manufacturer and type of equipment. In general, if large quantities of equipment are involved, the manufacturer will be more willing to consider motor substitutions. For some types of equipment—such as refrigerated water coolers that contain small, hermetic compressors—it will often not be possible to make motor substitutions.

6. Craig Hofferber (August 18, 1998), Director of Commissioning Services, CFH Systems, Lake Forest, CA, 949-837-7641, chofferber@clubnet.net.

7. California Energy Commission, "2005 Building Energy Efficiency Standards for Residential and Nonresidential Buildings" (September 2004), pp. 98–99, from www.energy.ca.gov/title24/2005standards (accessed January 3, 2006).

8 Scot Duncan (August 25, 1998), Vice President of Energy Conservation, Retrofit Originality Inc., Irvine, CA, sduncan@dubnet.net.

9 MagneTek, Nashville, TN, 800-624-6383, productinfo@magnetek.com.

Energy Design Resources provides information and design tools to architects, engineers, lighting designers, and building owners and developers. Energy Design Resources is funded by California utility customers and administered by Pacific Gas and Electric Co., San Diego Gas and Electric, Southern California Edison, and Southern California Gas, under the auspices of the California Public Utilities Commission. To learn more about Energy Design Resources, please visit our web site at www.energydesignresources.com.

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