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FINAL REPORT
TURNING RESEARCH INTO RESULTS

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MASTER

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I BACKGROUND

In September, 1989, the ACEC Research and Management Foundation (ACEC/RMF) submitted a proposal to the U.S. Department of Energy (DOE) in response to the Existing Buildings Efficiency Program's Solicitation Number DE-PS01-89CE21034. On May 15, 1990, DOE informed ACEC/RMF that it had been selected for a grant award; the final agreement was signed on July 23, 1990.

The purpose of the effort was to develop an information package showing engineering firms that energy services can be sold to owners and developers successfully and profitably, that not every design that goes beyond code results in a lawsuit, that owners can be shown the value of paying for the additional design analysis that energy efficient design requires.

The package was envisioned to include examples of buildings that succeed in terms of energy, cost, and design team benefits. It was further conceptualized as both a technical and marketing resource to provide helpful facts, references to relevant documents, graphic materials to be used during client presentations, and guidance on the latest in useful research results.

The impetus behind this was that few engineers were being asked by their clients to produce more energy efficient designs. Because clients did not ask for such designs, many engineers had not had the resources to explore, learn, and implement energy efficient design techniques. Lacking this expertise, and therefore lacking an awareness of the significant financial benefits available to clients from energy efficient designs, consulting engineers were not presenting their clients with the right information in the right terms needed for the client to see the value of energy efficient design. Thus the clients were not asking for energy efficient designs and the engineers were not receiving the resources needed to learn about and promote energy efficient designs.

ACEC/RMF requested DOE funding for this effort because the work would not have been undertaken otherwise. ACEC/RMF had no funds of its own for the effort and the obvious source of funds – the consulting engineering profession – was not aware of the value to the profession of the effort. DOE agreed to provide \$73,500 to support the effort.

Work on the project commenced in August, 1990. Through discussions with all parties involved in the effort, the final package concept was refined to result in a booklet aimed at both consulting engineers and owners of existing buildings. The final distribution strategy was for ACEC/RMF to supply copies of the package to consulting engineering firms, which would in turn pass them on to clients.

II SUMMARY OF ACTIVITIES

Summarized below are the major milestones and activities related to the effort. These have been drawn from the progress reports submitted to the DOE Project Officer.

July 1990

- Grant agreement signed on July 23, 1990.

August - October 1990

- Delivered Management Plan to DOE.
- Identified contacts at DOE, national laboratories, utilities, and trade associations for technical information.
- Met with DOE program managers to discuss promising near-term technologies.
- Selected ACEC member firms involved in energy retrofit projects for discussions to determine the type and format of information to be included in the information package.
- Developed telephone protocol for discussions with individuals identified in steps above.
- Initiated telephone discussions with individuals identified in steps above.
- Began reviewing current technical literature.
- Began collecting information on demonstrations of energy retrofit technologies.

November - December 1990

- Presented project overview at DOE Briefing on November 6, 1990.
- Mailed copies of the Management Plan to other grant recipients at the request of the DOE program manager.

- Completed telephone discussions with ACEC members to determine the type and format of information to be included in the information package.
- Completed telephone discussions with ACEC Energy Committee members to determine the type and format of information to be included in the information package.
- Developed letter requesting information on results of demonstrations of energy efficient technologies; letter was mailed to more than 400 organizations (utilities, engineering firms, etc.).

January - March 1991

- Synthesized information received from request for information.
- Continued review of literature to collect current technical information.

April - May 1991

- No work on the effort was performed during this period due to the departure of the ACEC/RMF Executive Director and the transition activities associated with the arrival of the new Executive Director.

June - December 1991

- Materials from interviews, requests for information, and the literature review were collated and reviewed.
- A rough draft outline of the final product was prepared.
- At the end of December Sherri Snell, Project Manager, left ACEC/RMF.

January 1992

- Carl Hanson joined ACEC/RMF as Project Manager at the beginning of January, 1992.
- Finalized definition of the information package's content and format.

- Reviewed information on results of demonstrations of energy efficient technologies (i.e., case studies) received from utilities, associations, and engineering firms in response to mailed request.
- Jon Stone, DOE Project Officer, informed ACEC/RMF that Ernest Freeman had taken over his responsibilities.

February - September 1992

- Worked with DOE to modify the contract to extend the period of performance until January 22, 1994 (intended to be 1993, but the document granting the extension specified 1994).
- Prepared draft document, including case studies.
- Submitted draft document to DOE for review. Also mailed the draft to representatives of seven ACEC member firms for review.
- Received comments from DOE and from four out of the seven ACEC member firms.
- Began revising the document as per comments received.

October 1992

- Continued revising the document as per comments received from DOE and consulting engineers.
- Determined final format for the document: a 5.5 x 8.5" saddle stitched booklet.

November 1992

- Prepared final version of the booklet *An Introduction to Energy Efficient Technologies for Existing Buildings for Building Owners and Managers*.
- Delivered booklet to printer for printing and binding.
- Prepared mailing labels for ACEC firms to receive copies of the booklet.

December 1992

- Received four hundred copies of the printed and bound booklet from printer.
- Mailed copies of the booklet to three hundred and seventy targeted ACEC member firms.

January 1993

- Received and processed requests for additional copies of the booklet. When the small stock of reserves was exhausted, engineering firms were authorized to make their own photocopies of the booklet.

III RESULTS

The final product of the effort, a booklet titled *An Introduction to Energy Efficient Technologies for Existing Buildings*, was completed and distributed in December, 1992. The format – a 5.5 x 8.5" booklet – was intended to make the contents less formidable and to make it easier to read.

The final product of the effort did not deviate sharply from the original conception, although there were some modifications. The greatest change was that the booklet was aimed at both consulting engineers and their clients (both actual and potential), rather than primarily at the consulting engineers. The expectation is that the consulting engineers will distribute the booklets as part of their marketing efforts to encourage their clients to consider using more energy efficient technologies. Meanwhile, the engineers will themselves have received encouragement to learn more about energy efficient technologies and to seek out opportunities to apply them.

Although there is no way to quantify directly the effect of the booklet (resulting from both the final product and the process of developing it), ACEC/RMF believes that this effect, whatever its extent, is important. The booklet has certainly contributed to the recipients' everyday awareness of the applicability and practicability of energy efficient technologies, which will lead to more retrofits using these technologies. This and similar efforts to promote the use of energy efficient technologies, particularly in existing structures, contribute to the ever increasing acceptance of energy efficient technologies by both consulting engineers and their clients. This is a "win - win" situation for the engineers, the clients, and the greater public; everybody benefits from the use of energy efficient technologies.

An Introduction to

**Energy Efficient
Technologies for
Existing Buildings**

for

Building Owners and Managers

Prepared under a grant from
The U.S. Department of Energy

November 1992

About this Booklet

The preparation of this booklet was funded by a grant from the U.S. Department of Energy's (DOE) Office of Building Technologies to the American Consulting Engineers Council Research and Management Foundation (ACEC/RMF).

The information contained in this booklet was collected from utility companies, national laboratories, trade associations, individual consulting engineers, universities, and manufacturers. The contents and format were determined by ACEC/RMF in consultation with DOE and ACEC member firm representatives serving on various ACEC Committees. The technologies featured in this booklet were selected by the DOE Office of Building Technologies in consultation with members of the consulting, academic, and manufacturing engineering community.

ACEC/RMF makes no warranty or representation, express or implied, with respect to the information contained in this booklet, nor does ACEC/RMF assume any liabilities with respect to the use of this information.

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INTRODUCTION

Purpose of this Booklet

The purpose of this booklet is to provide you — the owner or manager of an existing building — with basic information about selected energy efficient technologies that can be installed in existing commercial buildings to increase energy efficiency and reduce operating costs. We hope that the information provided here will encourage you to work with a top of the line consulting engineer to investigate using these and other energy efficient technologies in your building. The end goal is of course to reduce the amount of energy used by your building and so to reduce your energy costs.

The first six sections of this booklet are devoted to introducing a variety of energy efficient technologies. Not all technologies available to you are presented, nor is each technology described in great detail. The intention here is only to introduce you to a range of options, even if some of these options are inapplicable to your situation. Note that although costs for some technologies are given, these costs may vary across the country and are likely to change over time; they are intended only as rough indicators. The case studies presented in the next to last section of this booklet are intended to indicate how the technologies have been used and what the results have been.

Information about these and other energy efficient technologies abounds and is freely available. In the last section of this booklet is a list of organizations that can provide you with a great deal of information, both theoretical and practical. If you are interested in using energy efficient technologies, refer your questions to a professional consulting

engineer who will be aware of the latest technological developments and will also be able to evaluate the appropriateness of applying the various technologies in your building. You should not attempt to implement any measures directly without professional consultation.

General Considerations

The consulting engineers who contributed to this effort indicated that first cost is the single most important barrier to installing energy efficient technologies in existing buildings. Compounding this is the uncertainty with which benefits (i.e., energy savings) can be predicted and measured. In this vein, the engineers pointed out that:

- It is difficult to attribute energy savings to a single measure within the context of an entire building. Numerous factors, including weather, occupancy, intensity of use, stability of load, and human error must be evaluated.
- To the extent that savings can be identified, first cost should be compared to current annual savings in cost (energy and maintenance) to determine payback. BTU per square foot per year should be used as the measure for each technology considered.
- Life-cycle costing is not used often because the assumptions (e.g., energy prices) that life-cycle models are based on cannot be accurately predicted.

In practice, all before-the-fact savings estimates for particular installations are educated forecasts; only after the building has been operated with the new equipment for a few years does it become possible to identify the actual cost savings realized.

An important caution in considering the use of some energy efficient technologies is the operation and maintenance of the technologies once they are installed. New systems and new equipment may require training for operation and management staff. If appropriate training and maintenance are not provided, innovative systems may not operate properly and end up being labeled as failures. It is therefore extremely important to be aware of and provide the training required for operation and maintenance of each technology.

A related issue is that staff may interpret the installation of new technologies as criticism of their operation of the building. The confidence and cooperation of the staff must be secured early in the process to ensure that the new technologies will be properly operated and maintained.

Operation and maintenance can be eased further through the use of parallel equipment (e.g., boilers, air conditioners, chillers, pumps, fans, etc.). Equipment redundancy adds stability and dependability, reduces the problem of spare parts, and makes individual equipment breakdowns less disruptive, as repairs can be undertaken in a more leisurely fashion. For example, with two pieces of equipment installed in parallel, if one breaks down, the other (designed for one half of the full load) is able to assume two-thirds to three-quarters of the full load while the broken unit is repaired.

In addition to the savings that can be generated directly from the use of energy efficient technologies, you should be aware that many power utilities provide rebates and other incentives to customers who install energy efficient technologies. Refer to the case study section at the end of this booklet for examples of how utility rebates have added to building owners' and operators' savings. You should check with your power supplier to determine whether any such incentive programs could benefit you.

Although there are many advantages to installing and using energy efficient technologies, there *are* barriers or cautions to using specific technologies that you should be aware of. These are noted in the appropriate sections. Most of these barriers are surmountable and appear to have more to do with careful selection and calculation of the costs and benefits involved than with any inherent drawbacks of the technologies.

Despite the general and specific barriers mentioned here, more and more existing buildings are being refitted with energy efficient technologies. Through continuous design innovation and increasing use of the technologies, first cost is being reduced to the point that in many cases it is no longer a major consideration. It is likely that you can benefit by installing energy efficient technologies in your existing commercial buildings; we encourage you to work with a qualified consulting engineer to explore the possibilities.

LAMPS

Commercial buildings typically apply from 25% to 50% of their electrical usage for lighting. As the energy efficiencies of the lamps available on the market vary substantially, lamp selection can have a major impact on both energy usage and demand. Furthermore, the heat given off by indoor lamps can also affect the amount of energy needed for space cooling.

While the principal benefit deriving from more efficient lamps is lower operating cost, improved lighting can also result in increased worker productivity; fewer errors/rejects and enhanced quality control; more retail sales; more effective safety and security; and less exposure to legal liability, among many other benefits. These benefits can result in installation cost paybacks of six months or less. Note, though, that reduced productivity, more errors and rejects, and so on may result from poorly designed relamping programs.

For most commercial lighting applications, you will be able to choose from among several energy-efficient lamps. Six types of lamps are commonly used for indoor and outdoor lighting: incandescent, fluorescent, mercury vapor, metal halide, high-pressure sodium, and low-pressure sodium. The last four are all so-called High Intensity Discharge (HID) lamps. Each of these lamp types is presented in greater detail following this introductory section.

The most common concern in selecting lamps is color. Low-pressure sodium lighting, for example, cannot be used as the only source of illumination for any application which depends on color recognition because it makes all objects appear to be grey, yellow, or black. The color rendering index (CRI) of a lamp is a measure of the degree of color shift objects undergo when illuminated by the lamp as compared with the objects'

colors when illuminated by a reference source of comparable color temperature. On a range from 0 to 100, the closer to 100 the CRI of a lamp, the easier it is to tell one color from another when they are illuminated by the lamp. Standard incandescent lamps have the highest CRIs — close to 100 — of the lamps discussed here.

When selecting lamps, you should compare light output (lumens), power (watts), and lamp life (hours), all of which are printed in lamp catalogs and on lamp packages. From this information you can easily determine a lamp's efficiency, which is the lumens per watt. A good rule of thumb in determining the relative efficiencies for most light sources is that efficiency increases as wattage increases. For example, one 100-watt incandescent bulb provides 1,750 lumens of light at 17 lumens per watt, while a 60-watt bulb provides 890 lumens of light at 15 lumens per watt. Substituting one 100-watt bulb (1,750 lumens) for two 60-watt bulbs (1,780 lumens) would produce about the same amount of light while consuming less electricity.

Most high-efficiency lamps last as long as — or longer — than their standard counterparts. However, problems can arise due to improper application, particularly lack of compatibility between the replacement lamp and the existing ballast. Manufacturers' recommendations should be followed to ensure that the rated life and other performance objectives are achieved.

The more efficient and longer-lived a lamp, the more expensive it tends to be. For example, a standard 40 W fluorescent lamp typically lists for 33% less than the cost of a high-efficiency, reduced-wattage 34 W fluorescent lamp.

Incandescent Lamps

The incandescent lamp is the most common lighting source in U.S. homes, mainly because its CRI is from between 95 to 100. Unfortunately, they also waste the most energy: ninety percent of the energy consumed by an incandescent lamp is given off as heat rather than as visible light. This is because incandescent lamps do not directly convert electricity to light, but rather use electricity to heat a coiled tungsten filament in a vacuum or inert gas-filled bulb until the filament glows.

Not only do incandescent lamps have the shortest life span of all available lamps, but, near the end of the bulb lifetime, the light output decreases by up to 20 percent of its original level. This is because the filament evaporates with use, releasing molecules that coat the surface of the bulb and slowly cause the bulb to darken. As it darkens, the bulb consumes almost the same amount of energy as it did when new, yet emits less light. In addition, because the filament becomes thinner with use, it also has increasingly higher electrical resistance, which further reduces the lamp's efficiency. The bulb eventually burns out when the filament ruptures.

Long life bulbs (which last from 1,500 to 3,500 hours) are less efficient than standard incandescent lamps because the filament is operated at a lower temperature to extend its life. Incandescent bulb life can also be extended with a penny-sized wafer that fits into a standard light socket. One version of the wafer is the diode, which reduces the bulb's light output by 75 percent and its efficiency by 50 percent, while extending its life 50 times. Another type of wafer, a thermistor, reduces the light output and efficiency by 10 percent while tripling the life of the bulb. Because these devices lower both efficiency and light output they are recommended only for use where it is very difficult or expensive to replace the lamp. You should

use long life incandescent bulbs only where replacement is difficult, but even then you should consider replacing or converting incandescent lamps to fluorescent lamps (which have lives of over 10,000 hours).

Fluorescent Lamps

Fluorescent lamps convert electric power to visible light by using an electric charge to "excite" gaseous atoms. These atoms emit ultraviolet radiation which is absorbed by the phosphor coating on the tube walls; the phosphor coating produces the visible light. These lamps require a ballast (a small transformer) that provides the high voltage necessary to initiate the charge and also regulates the current that flows through the tube.

Fluorescent lamps are four to five times more efficient, and have rated lives 20 or more times longer, than incandescent lamps.

Summarized in the table below are the significant differences between an incandescent and a fluorescent lamp providing approximately the same light output.

	Standard Incandescent	Compact Fluorescent
Life (hours)	750	10,000
Energy Consumption (watts)	75	18
Light Output (lumens)	1,190	1,100
Efficiency (lumens per watt)	15.9	61.1
Retail purchase price	\$0.77	\$18.20

Most fluorescent lamps require a special fixture. The fixture for the standard, straight fluorescent tube consists of a metal channel that contains the ballast. Ballast selection is a vital

concern in fluorescent lighting, given the many choices available. Energy-saving fluorescent ballasts can reduce lighting system energy usage by 9% and electronic ballasts can save up to 25%. In addition to the ballast, most fluorescent lamps with a 40-watt rating or less require a small starter, which results in a brief start-up delay; the lamp will flicker for a few moments when first turned on before achieving full illumination. "Rapid start" fluorescent lamps go on immediately without flickering. Lightweight, straight fixtures without the traditional magnetic core-coil ballast are available. These fixtures use a resistor to limit the current flow. Although this type of fixture is smaller, the resistor ballast is much more efficient than the standard magnetic fixtures.

U-shaped and circular fluorescent tubes are also available. With adapters, which both contains the ballast and holds the fluorescent tube, circular lamps can be used in conventional incandescent sockets for both ceiling and table lamps. Initial costs for both the adapter and a circular fluorescent tube range from \$10-45, but this expense is recovered through reduced operating and bulb replacement costs. Compact fluorescent lamps look similar to incandescent lamps and can be installed directly in incandescent fixtures.

Four kinds of fluorescent bulb temperatures are widely available: cool white, deluxe cool white, warm white and deluxe warm white. The deluxe warm white bulbs are more red than their cool white counterparts and tend to be more "flattering" to people. However, the warmer colored phosphor lamp is 30 percent less efficient than the cool white lamps. Advances with rare earth phosphors are allowing much more variation in color temperatures, ranging from warm white (2800° K) to the very cool daylight colors (5000° K). In addition, they operate with increased efficiency and have very good color rendition. The fluorescent lamps made with these rare earth phosphors are called tri-color phosphors and

manufacturers have given them names such as "regal white," "ultralume," etc.

Lamps with the same color temperature may have different CRIs. Most package labels provide the color temperature, but a lamp's CRI is rarely listed; the manufacturer can provide you with this figure. Fluorescent lamp CRIs range from 50 to 90.

Old fluorescent lamps sometimes flicker; this is usually a sign of a defect and the lamp should be replaced promptly. Even when the lamp is dead, the ballast will still draw power when turned on. Note that flicker may also result when fluorescent lamps are applied in a cold environment, generally below 40° F.

Switching fluorescent lamps on and off shortens the operating life of the lamp, but unless the switching frequency is greater than once every few minutes, it is generally cost effective to turn the lamps off as needed.

Mercury Vapor Lamps

Mercury vapor lighting historically has been applied for outdoor purposes, but can be used indoors as well. Compared with incandescent lamps, mercury vapor's long rated life (24,000 hours or more) reduces the cost of lamp replacement labor.

Mercury lamps are the least expensive of the four types of high efficiency lights. Their color temperature is white or blue-white and their CRIs range from 15 to 35. Mercury lamps are available in sizes ranging from 40 to 1,000 watts. The 175-watt size provides 5,800 lumens of light and is comparable to a 300-watt incandescent, which provides 6,000 lumens. The very cool color temperature (5900° K) and lack

of reds limit the mercury lamp's applications. Mercury lamps used to be the most common high intensity discharge (HID) lamp, but advances in metal halide and the high-pressure sodium lamps now make them preferable to mercury lamps.

Metal Halide Lamps

These lamps can last almost as long, and can be twice as efficient, as mercury vapor lamps while giving the same light output, making them a more popular selection for outdoor lighting, particularly when good color rendition is a factor. Some metal halide lamps can provide color rendition similar to incandescent lamps, making them suitable for indoor use.

Metal halide have the best CRI (generally around 60), of the HID lamps. They are sometimes used for commercial interior lighting because of their excellent color and are the preferred light source for stadiums where there are television broadcasts. Until recently, 175 watts had been the lowest wattage metal halide lamp, but now a 50-watt metal halide lamp is available that generates 60 lumens per watt. Metal halide lamps should last 14,000 hours, compared to 750 hours for the incandescent.

High-pressure Sodium Lamps

These lamps provide both high efficiency (only low-pressure sodium lamps are more efficient) and long life, but are one of the more expensive light sources. Their "golden white" output produces some color shifts (for example, some reds take on a brownish cast), but all colors remain recognizable.

Because of their low CRI (20 to 25), these lamps are rarely used for interior commercial lighting; they are used more frequently for interior industrial applications, such as in

warehouses and manufacturing. Their small size and high efficiency make them a popular choice for street and area lighting. The smallest size available is 35 watts, providing 2,250 lumens, 500 more than a 100-watt incandescent (1750 lumens) and somewhat less than a 150-watt incandescent (2750 lumens). High pressure sodium lamps are a good investment for extensive area lighting and are used extensively for outdoor lighting.

Low-pressure Sodium Lamps

These lamps are the most efficient of all, converting nearly 35 percent of energy consumed to light. Unfortunately, low-pressure sodium lamps are also the largest and most expensive. Because of their size, it is difficult to control the light distribution from low-pressure sodium lamps and because their color output is monochromatic (yellow), all colors appear as shades of grey, yellow, and black, resulting in a very low CRI.

A low-pressure sodium bulb should last at least 10,000 hours and deliver as much light at the end of its life as when new. These lamps are used occasionally for lighting streets and parking lots. They are used more frequently in Europe than in the United States.

LIGHTING FIXTURES

A basic lighting fixture is composed of a lamp holder, wiring connections, and a lamp, along with (in most cases) components that accommodate the needs of the lamp(s) employed and the application involved. A housing with a mirror-like reflectorized internal finish commonly is used with point light sources (incandescent and fluorescent) to control its distribution. In fluorescent fixtures, highly reflective matted finishes are common, providing diffuse lights.

Lenses or louvers are used to control light distribution and to shield lamps from direct view. Except for those which use incandescent lamps, fixtures also house ballasts, devices which transform power to condition its current and voltage characteristics suitable for the specific type and wattage of the gas-discharge lamp employed.

One classification of fixtures is based on the relative upward and downward components of light distribution. This method identifies six kinds of fixtures: direct; semi-direct; general diffuse; direct indirect; semi-indirect; and indirect.

Fixtures are also classified by how they are mounted:

Surface	installed directly on the ceiling
Pendant	suspended from the ceiling
Regressed	mounted in the ceiling with the opening for the fixture above the ceiling line
Recessed	mounted above the ceiling or behind a wall or other flat surface, with the opening of the fixture level with the surface

Other fixture classification methods relate to the number and types of lamps used, specific applications involved, and type of lenses, shielding, and diffusing media employed, among other factors. One important criterion for fixtures is how heat is dissipated. An enclosed 4-lamp fixture, for example, tends to operate lamps "hot", reducing light output and efficiency. On the other hand, some of the new lamp types require a steady state, relatively high ambient temperature within the fixture enclosure.

Fixture considerations are critically important in building design. While efficiency is a concern, other equally significant factors include:

- **Coefficient of utilization (CU)** is the ratio of light that reaches the work plane to the light emitted by the lamps alone. Manufacturers determine fixture CU values based on standardized tests and provide these data in their catalogs. CU ratings depend on conditions unique to the applications, such as mounting heights, room proportions, and reflectances of the walls, ceiling, and floor. As a result, a fixture does not have a unique CU; each value is based on a different application. Manufacturers provide the range of a given fixture's CU for the particular space in which it is being used.
- **Visual comfort probability (VCP)** is a measure of direct or discomfort glare from a lamp. It indicates how comfortable people will find the light provided by a given type of fixture. A rating of 70 indicates that 70% of the people seated in a space would not be bothered by glare from the fixture. The higher the VCP rating, the more comfortable a given fixture's light output should be. As with CU ratings, VCP ratings of a given fixture are based on standardized tests and vary depending on conditions

unique to the installation, their arrangement in space, and the lighting distribution from the fixture.

- **Light loss factor (LLF)** is the ratio of illuminance on an area after a certain time to the initial illuminance on the area; it is a measure of how a fixture will be affected by use over time. Factors such as lamp age and cleanliness play a role in a fixture's LLF.

Fixtures which provide high quality, energy efficient lighting will improve the quality of lighting provided by a system. In the case of fixtures, high efficiency — in the form of high CUs — can mean immediate payback, in that fewer fixtures will be needed to satisfy a quantity demand. On the other hand, a high CU refers only to the raw light entering the work space; attention should also be paid to the quality of the light (e.g., VCP). High quality lighting can have a significant impact on worker productivity, retail sales, and other lighting-dependent activities, resulting in additional dollar benefits.

Fixtures are essential to lighting and several kinds are usually employed in any given building to provide precisely the type of lighting desired. For example, showrooms and other areas subject to extensive modifications benefit from fixtures that can be relocated easily. Fixtures that drop into a suspended ceiling, or that operate from an electrified grid or track, are often used for this purpose. Their appearance is an important concern, as well as function. In storage areas, however, appearance is seldom an issue, and functional considerations predominate. In this regard, some fixtures are designed to distribute light on a horizontal surface, while others are designed for vertical surfaces, i.e. wall washing. For different types of hazardous area lighting, there is a variety of enclosed fixtures available. Their use is governed by the National Electrical Code or local codes.

An energy-efficient fixture may cost up to 20% more than its standard counterparts. As with lamps, the fixture with the lowest purchase price tends to be the most expensive to operate.

Fixtures are inherently reliable and can last up to 20 years, or half the life of a typical building, provided that recommended care is taken. Standard ballasts last from 12 to 15 years and are easily replaced. In the case of fluorescent fixtures, energy-saving ballasts can last twice as long as their standard counterparts.

LIGHTING CONTROLS

Lighting controls are used minimize energy and demand costs by eliminating unnecessary lighting system use. The lighting controls used in commercial buildings range from manual wall switches and dimmers to centralized programmable controllers that operate all indoor and outdoor lighting automatically. Between these two extremes are many options, permitting a close match between specific lighting needs and the controls installed to meet them. Many lighting controls are automatic, helping to ensure efficient and effective operation without reliance on human initiative. Some controls are time-programmable, others are event-initiated, and some have elements of both.

Reduced usage also helps reduce cooling loads and can extend lamp life. Commercial lighting controls can be used individually to control a specific lighting subsystem or may be part of an overall energy management system which controls other building energy systems, e.g. HVAC. The principal controls used with lighting include:

Time-based controls activate and deactivate their load at predetermined times — for example, on at dusk and off at dawn. Many varieties of electro-mechanical and electronic devices are available. Timers are available from most hardware or department stores for \$10 - \$20.

Dimmers are available for control of incandescent, fluorescent, and HID lighting. The capacity ratings of these devices range from 100 to 6,000 W. Dimmer controls allow light levels to be manually adjusted in response to needs of different activities and can save energy if they

are used regularly. Most light sources can be dimmed by controlling the amount of power applied to them, but only fluorescent lamps can be dimmed over their entire range without affecting light color.

Solid-state dimmer controls are generally used for residential incandescent lamps. These dimmers save energy by reducing the amount of power delivered to the light while consuming very little themselves. In addition, because bulbs are operating on reduced voltage, the life of the bulb is extended. Dimmer fixtures replace standard light switches and are inexpensive and easy to install. Dimmers for fluorescent lamps that can be used with standard ballasts are now available, but have not been used widely. With the introduction of solid-state ballasts that simplify the dimming of fluorescent lamps, wider use is anticipated.

Caution should be exercised in replacing standard light switches with dimmers, particularly when replacing incandescent lamps with high intensity discharge fixtures, as the fixtures may not work properly with a conventional dimmer.

Rheostats are an older type of dimming mechanism that are still sold occasionally. Because they work by transforming the portion of energy not used for light into heat, rheostats do not save energy.

"Hi-lo" switches provide two settings for overhead lamps. While they do not have the flexibility

of full range dimmers, they do save energy and are comparable to the three-way bulbs used in table lamps. Three-way light bulbs, however, are not very efficient. A better alternative is a high wattage lamp with a solid-state dimmer.

Photocells are used mostly for on/off operation of outdoor fixtures. When ambient light falls below a predetermined level, lighting is activated; it is deactivated when the level is exceeded. A typical photocell control system can operate several control lighting circuits. Photocell controls can also be combined with time controls. Photocells do not switch the lights, but only measure the amount of light. They generate an electrical current when exposed to sunlight; the current strengthens as the sunlight increases. Ancillary circuits operate a relay to turn the light off or to lower levels of illumination.

Occupancy sensors are optical, ultrasonic, or infrared sensors that react to interruption of a beam of light, sound, or heat, respectively. Occupancy sensors cost more than on-off timers and are best suited to situations where space occupancy is unpredictable. Ultrasonic controls react to sounds; most units have user-adjustable sensitivity and time delay. In most instances ultrasonic controls are mounted on the ceiling and local switches are often employed as overrides. Passive infrared controls react to the infrared energy given off by mammals. Those now on the market provide effective control for spaces as large as 2,000 square feet.

Computer (microprocessor) based centralized systems can be used to control lighting and other loads (e.g., HVAC). The central controllers of these systems permit program entry via a keyboard and can also display the OFF/ON status of the relays they control. Some systems accept manual override through the keyboard or push button telephones.

Lighting controls are effectively used in both new and old lighting installations, and options are available for all commercial applications. Time controls and photocells are typically used to control outdoor lighting. Dimmer photocells are applied for indoor perimeter area lighting, and dimmers are applied where task lighting needs are subject to frequent change. Ultrasonic, passive infrared, and similar sensors are often installed in interior areas subject to less than full-time use. These sensors can also be integrated into an overall building security system. Centralized lighting control systems can be used in buildings of all sizes, and in many cases are integrated with systems that perform other functions as well.

Occupancy and daylighting sensors have not been used extensively in the past because they required rewiring and re-circuiting, but present technology allows occupancy sensors to be directly interchanged with wall switches in certain enclosed environments, thereby minimizing any rewiring involved.

The more sophisticated the control, the more expensive it is likely to be, with modular systems being more expensive. The more sophisticated centralized lighting control systems can cost \$2,500 or more, including relays and contactors.

When used as prescribed by the manufacturer and for the purposes for which they have been designed, even the most sophisticated lighting control systems are reliable.

HEATING, VENTILATION, AND AIR CONDITIONING

For heating and cooling purposes, commercial buildings use an applied or built-up system consisting of a chiller (and boiler) to supply chilled (and heated) water to either fancoil units or to air handlers. There are many options for improving the effectiveness and efficiency of applied systems. The benefits of installing energy efficient HVAC equipment are not only that current operating costs are reduced, but that the resale value of the property is enhanced. Heat pumps, unitary air conditioning equipment, cool storage, and double bundle chillers are discussed in the following sections.

A heat pump is a device which extracts heat energy from a source at a low temperature and makes it available as useful heat energy at a higher temperature. Heat pumps may be classified according to their heat source: air; water; geothermal energy; soil; and waste heat recovery. Discussed here are air source heat pumps and closed water loop heat pumps.

Air conditioning systems are either unitary or built-up. In a unitary system, the entire system is housed in a single package. Built-up, or field-erected, systems, on the other hand, are composed of factory built subassemblies interconnected by piping, wiring, and ducting during final assembly on the building site.

Cool storage, also known as thermal energy storage or off-peak cooling, is a technology for storing cooling energy in a thermal storage mass which in turn is used to provide cooling as needed. An inexpensive storage medium such as water, ice, or eutectic salts stores cooling produced during off-peak hours for use during peak hours. Conventional refrigeration

equipment — enhanced with additional components to produce the operating temperatures required — is operated to make ice or chilled water which is stored in insulated tanks and used as needed to meet building cooling requirements.

Double bundle chillers recover heat from interior spaces and then use the recovered heat to heat exterior spaces, thereby potentially eliminating an oil or gas fired boiler.

Each of this technologies can help to increase the energy efficiency of your building, but not all may be applicable to your situation. Refer any questions you may have to a qualified consulting engineer.

Air Source Heat Pumps

In warm weather, air-source heat pumps transfer heat from interior air to air outside the conditioned space. In cold weather, they extract heat from outdoor air and deliver it inside. Air-source heat pumps are equipped with an auxiliary or supplemental heating sources which are activated during particularly cold weather (less than 25°F).

Air-source heat pumps can be used in any type of commercial building, new or existing. When used in buildings of three stories or less, they generally serve as the sole source of heating and cooling. In expansive low-rise buildings, such as shopping malls, multiple heat pump units can provide both economy and flexibility. In tall buildings, heat pumps are often used to supplement large central systems. Heat pumps can be particularly cost-effective in buildings where considerable waste heat is generated (e.g., laundries) because the waste heat can be used to heating other areas.

Air-source heat pumps provide all the benefits associated with other electric heating equipment such as comfort, reliability, and cleanliness. In addition, their operating cost is low and they can make good use of any available waste heat. They are available in many sizes and configurations, making them practical for modernization projects as well as for new commercial construction. Their maintenance needs are about the same as conventional electric cooling equipment.

Most air-source heat pumps installed in commercial buildings are unitary (i.e., pre-engineered and factory assembled in one or two modules). The three most common configurations are:

- **Packaged terminal heat pumps** are designed to serve a room or zone. Available from 0.5 to 1.25 tons

cooling capacity, they are intended for through-the-wall installation.

- **Single packaged heat pumps** include all components and controls in one factory-made assembly. They range from 2 to 35 tons in cooling capacity. Roof-mounted units are more popular than floor-mounted units in commercial buildings with flat roofs.
- **Split system heat pumps** are popular for small commercial building applications. They range in capacity from 1 to 30 tons and have an indoor and outdoor section connected by refrigerant tubing and a thermostat. The indoor section consists of a fan, indoor coil, and filter; the outdoor section usually houses the compressor fan, outdoor coil, reversing valve, and controls.

Some manufacturers now offer "triple split" or three-piece systems with a separate compressor package for indoors. These systems can be used to advantage in cold climates.

Industry performance standards require manufacturers to express both heating and cooling capacity at standard rating conditions developed by the Air-Conditioning and Refrigeration Institute (ARI). The standards employ several terms to rate heat pump efficiency:

COP The Coefficient of Performance is the ratio of useful heating or cooling provided to the energy consumed. COP is an indication of a heat pump's steady-state performance in heating mode and is measured at 47°F and 17°F outdoor air. It is calculated by dividing the system's total heating output (including circulating fan heat, but not supplementary resistance heat) by the electrical input (watts). A high COP means high

efficiency. High efficiency pumps typically have heating COPs of 2.8 - 3.4 at 47°F and 2.0 - 2.5 at 17°F.

HSPF The Heating Season Performance Factor is the ratio of total heat delivered to the total electrical power input, including supplementary resistance heat. It is a measure of dynamic rather than steady state performance; unlike COP, it considers annual or seasonal variations in weather and their effect on performance. HSPFs are calculated using test procedures developed by the Department of Energy and since adopted by ARI for pumps with capacities of less than 65,000 Btu/hr. HSPF values for unitary air source heat pumps currently range up to 8.85

EER The Energy Efficiency Ratio is similar to COP, but is expressed in Btu/hr watt, and expresses efficiency in the cooling mode. EER value for high efficiency pumps currently range up to 12.

SEER Similar to HSPF, SEER considers a heat pump's dynamic performance. It is the total cooling delivered by a heat pump during the cooling season (in Btu) divided by the total electrical energy input (in watt-hours) during the same period. SEERs of high efficiency air source heat pumps range up to 10.

The installed cost of an air-source split system heat pump ranges from \$850/ton for a 20-ton unit to \$1,300/ton for a 2-ton unit; the cost for a single packaged unit is about \$50-\$100/ton lower. Most manufacturers provide warranties, and contract maintenance is readily available. The American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) estimates a heat pump's life expectancy at 15 years, the same as for a conventional electric air conditioner.

Closed Water Loop Heat Pumps

A closed water loop heat pump system is a simple, flexible, and reliable semi-decentralized approach to meeting the year-round space conditioning needs of small multi-room buildings. Through "balanced heat recovery" this system collects and redistributes internal heat gains from lighting, office machinery appliances, solar radiation, and people. The collected internal heat is used either to meet the immediate heating requirements of the building or stored for future use. When internal heat gains are particularly high, storage can be used as a sink for the excess heat. Cool water can also be stored to help reduce cooling demand during peak periods.

The closed water loop heat pump system concept is adaptable to both new buildings and renovation projects. Small buildings that are good candidates for this system include radio and television complexes, computer centers, apartments, some hospital spaces, nursing homes, schools, dormitories, hotels, and combination structures containing office and commercial spaces along with apartments. A variety of water to air heat pumps (horizontal, vertical, and console units) are available. A system can be configured for almost any installation. If the building has a typical amount of internal heat gain, needs simultaneous heating and cooling, and requires about 50 to 70 tons of cooling capacity or greater, then that building could be considered for the closed water loop heat pump system.

In a closed water loop heat pump system, a two-pipe closed water loop supply and return circuit continuously circulates water throughout the building. Loop water temperature usually is maintained at between 60°F and 90°F throughout the year. During cold weather, most perimeter water source closed loop heat pumps (typically averaging about 2 tons capacity) operate in the heating mode, transferring heat from

the water loop to conditioned spaces. In most such instances core area units will still be operating in cooling mode, adding enough heat to the loop water to meet perimeter area requirements. When loop water falls below 60°F, heat is added to the loop either from thermal storage or from a supplemental source (such as an electric or fossil fuel fired boiler) to maintain minimum loop temperature. During warm weather, most or all of the units in the building operate in the cooling mode, removing heat from the conditioned space and transferring it to the water loop. Typically, heat is rejected to the outdoor air through a closed-circuit cooling tower or by other means. Heat rejection equipment is activated only when the loop temperature exceeds 90°F.

Many applications of this system lend themselves well to thermal storage. Installations which cool the loop during the day and heat the loop at night (such as a school) are excellent for heat storage. This may be accomplished by installing a large storage tank in the closed loop circuit ahead of the boiler and allowing the loop temperature to build up to 90°F during the day. The stored water at 90°F can be used during unoccupied hours to maintain heat in the building or a water-to-heater heat pump can be used to heat the stored water to the higher temperature (160°F) and thus reduce the storage tank size while increasing the amount of stored heat. The boiler would not be used until the water loop had dropped below 60°F. The storage tank operates as a flywheel to prolong the period of operation where neither heat makeup nor heat rejection is required.

Industry performance standards require water-source heat pump manufacturers to express both heating and cooling capacity at standard rating conditions developed by the Air-Conditioning and Refrigeration Institute (ARI).

The installed cost of water-to-air heat pumps typically used with closed loop systems generally ranges from \$1,200 per ton for a 1-ton unit to \$500 per ton for a 20-ton unit. Additional cost elements include the cost of piping heat rejection equipment, the boiler, pumps, and controls. Even when these costs are added, the total cost of closed water loop system can be lower than other competitive systems. In nearly all cases of applications in qualified candidate buildings, it is the preferred choice due to its lower life-cycle costs. Operating costs can be economical provided that there is opportunity to shut down or cut back the usage of individual units.

The closed water loop system is efficient, cost-effective, and very reliable. The life of major components is typically 15 to 20 years.

The primary benefits associated with these systems are lower initial costs and fast track or design-build compatibility. These systems can easily be applied in concert with a conventional control systems for zones that might be used or brought up during off hours. Individual units can be operated at greatly reduced load on nights, weekends, or other periods of low occupancy when the entire building does not have to be conditioned. The system can also be used in concert with large energy recovery and storage systems.

Disadvantages of these systems include that the system requires more electrical energy on a ton for ton air conditioning basis and also requires considerable electrical power for heating. Noise levels, floor space condensate, wiring, and access for maintenance are poor. Preventive maintenance is limited. Proper ventilation for correct indoor air quality should be tempered and supplied carefully by a separate system.

Unitary Air Conditioning Equipment

Unitary air-conditioning equipment consists of matched cooling components in one or more factory-fabricated assemblies. Often, heating equipment compatible with the cooling system is incorporated as well. Built-up, or field-erected, systems, on the other hand, are composed of factory built subassemblies interconnected by piping, wiring, and ducting during final assembly on the building site. Three types of unitary air-conditioning equipment are commonly used in commercial buildings:

- **Single-packaged units** have all their components and controls packaged in one factory-made assembly. Roof-mounted horizontal units are more popular than floor-mounted: they distribute air to conditioned space through ductwork.
- **Split system units** are independent subsystems tied together by a single control system; these are the most popular for small commercial buildings.
- **Packaged terminal air conditioners** are designed to serve a room or zone. Packaged terminal units are more frequently used in condominiums, office buildings, hotels, motels, nursing homes, and individually metered, multistory buildings, as well as building spaces which require individual zone control.

Unitary equipment of all types can be used in both new and existing buildings and for renovation and expansion projects as well. Existing installations are usually more expensive than new installations because electrical, architectural, and structural modifications may be required to accommodate the units.

As a rule, a system's cost-per-ton decreases as its capacity increases. The installed cost of packaged rooftop air conditioning equipment ranges from \$800/ton for a 50-ton unit to \$1,250/ton for a 2-ton unit. The split systems typically cost about \$50-\$100/ton more. The installed cost for packaged terminal units ranges from \$650/ton for a four-ton unit to \$1,600/ton for a half-ton unit. Generally, as capacity increases, the cost per ton decreases.

Energy efficient unitary air conditioning units are as reliable as their time-tested standard counterparts, with a life expectancy of 15 to 20 years. Most manufacturers offer one year warranties and extended service contracts.

The main benefit of using unitary air conditioning equipment is that the high-efficiency equipment provides equal comfort, but with less energy consumption and lower operating costs. The dollar savings in some cases can be substantial.

Cool Storage

Cool storage, also known as thermal energy storage or off-peak cooling, is a technology for storing cooling energy in a thermal storage mass which in turn is used to provide cooling as needed. An inexpensive storage medium such as water, ice, or eutectic salts stores cooling produced during off-peak hours for use during peak hours. Conventional refrigeration equipment — enhanced with additional components to produce the operating temperatures required — is operated to make ice or chilled water, which is stored in insulated tanks and used as needed to meet building cooling requirements.

There are two types of cool storage systems:

- **Chilled water storage systems** use a conventional chilled water cooling system augmented by a chilled water storage tank. During off-peak periods, the chiller cools water to approximately 40°F and then the chilled water is pumped to a storage tank. When chilled water is needed, it is pumped out of the storage tank to cooling coils and then returned to the tank. Chilled water storage systems are essentially chilled water air conditioning systems with a storage tank. Storage tanks are usually made of concrete, plastic, or steel, with concrete tanks the most common. They may be set in the basement of a building, buried, or located on-grade, and they generally operate at atmospheric pressure. There are three common tank system designs, characterized by the means utilized to separate chilled supply water from warm return water: thermal stratification, diaphragms, and empty tank.
- **Ice storage systems** are commonly sold as packaged units. There are two basic types, characterized by the means of ice production — ice building and ice harvesting. Although

less efficient — by about 20% — than conventional chilled water air conditioning (due to the lower evaporator temperatures necessary for ice production) offsetting gains can be made in the efficiency of the distribution system through the use of low temperature water/air systems. Ice storage tanks are much smaller than chilled water tanks of the same cooling capacity since ice stores 144 Btu/lb, while chilled water stores about 20 Btu/lb.

Both ice and chilled water systems can be sized for full storage or partial storage. Full storage systems meet the entire cooling requirement during on-peak hours from storage, without operation of the refrigeration system. Partial storage systems require less storage capacity and smaller-capacity refrigeration equipment because peak cooling requirements are met partly by the compressor and partly by storage.

Both ice and chilled water systems are applicable to new and existing construction and renovation projects, although retrofit applications may be limited by space requirements, storage system weight, and architectural considerations. Cool storage is most cost-effective in buildings that have a high, narrow cooling load profile during a utility's "on-peak" period, including office, retail, health facilities, schools, colleges, restaurants, and lodging facilities. Cool storage is not, generally speaking, cost effective in buildings with small cooling loads, uniform daily load profiles, or where peak cooling load occurs during off-peak hours.

The similarity of the equipment used in chilled water storage to that used in central chilled water air conditioning makes it generally better suited than ice storage for buildings where the existing water chillers can be incorporated into the system. On the other hand, the packaged, modular nature of ice storage normally makes it better suited for space-constrained sites.

Cost varies widely depending on the medium and mode of operation, system design, installation configuration, location and size of the storage tank, and site-specific constraints. Storage systems generally, but not always, have a first cost greater than conventional air conditioning and their cost-effectiveness is sensitive to utility rate structures.

Because conventional air conditioning consumes power primarily during peak hours, it contributes a major share of electricity costs. By using cool storage to take advantage of lower off-peak rates and reduce peak demand, you can reduce your utility bills significantly, although this is dependent on electric power pricing. Note that there is no time of day metering charge for electricity in the Northwest and that storage may therefore not provide significant cost savings.

Cool storage can be simple and reliable since the thermal storage mass has no moving parts and can last for 30 years with minor maintenance. Other benefits from cool storage are more site-specific and include:

- Efficiency gains from operation of cooling towers or condensing units at closer to design conditions and lower (night time) temperatures;
- Improved comfort levels resulting from lower humidities made possible by ice storage and low-temperature air distribution;
- Smaller freon systems, less noise, smaller pipes and pumps; and
- Reduced electrical service entrance requirements resulting from the system's ability to meet design-day loads with smaller chillers.

ENERGY MANAGEMENT SYSTEMS

Energy Management Systems (EMSs) reduce energy waste through automatic control of a building's energy using systems. Typically, an EMS controls heating, cooling, and ventilation (the most energy intensive building system). Lighting and service hot water, which are also significant energy using systems, can also be controlled by an EMS. The basic function of an EMS is to reduce operating costs by allowing the building operator to control the energy-using systems more effectively without impairing their normal functions or occupant comfort and productivity.

An EMS provides the user with reduced energy costs and sometimes better control of the operation and maintenance of the building's energy-using systems. An EMS can provide from 10 to 20% reduction in a building's energy use, providing the system is well designed and is operated and maintained properly.

EMS can be broadly classified in terms of the control and monitoring functions performed, and also in terms of the hardware configuration required to perform the functions. EMSs range from systems dedicated to performing only one control function to multi-function systems. Functions include:

- Turning off equipment when the building is unoccupied, according to a set schedule.
- Restarting equipment at the latest possible time before occupancy.

- Changing thermostat temperature set points when the building is unoccupied.
- Using free cooling from outdoors when temperature is suitable.
- Providing more sophisticated economizer-based temperature and humidity.
- Reducing excessive heating and cooling in HVAC systems.
- Balancing boiler operation to loads and controlling combustion air.
- Reducing peak electrical demands.
- Turning off equipment a percentage of the time according to an established schedule.
- Logging conditions, equipment run time, energy use, etc.

An EMS can be applied to almost all new or existing commercial buildings for automating functions which otherwise would be performed manually. One caution here is that extensive training may be required for the operations and maintenance staff.

EMSs are available from many manufacturers, with most offering maintenance and service agreements. The maintenance cost is typically between 10 - 12% of initial equipment cost.

EMSs vary widely in cost. Initial costs for installing EMSs in existing buildings are generally higher than new installations

because of the restrictions imposed by existing controls, cabling, structural members, etc. However, significant cost benefits may still be realized, particularly when control modernization — which often accompanies the installation of an EMS — will make an older building more compatible with today's needs.

Single-function time clocks range in price from \$300 to \$1,800, depending on the control function. Stand alone, multi-function system costs range from \$12,000 to \$15,000. Central station systems performing limited control functions range in cost from \$3,000 to more than \$100,000 depending on the type of data transmission media and the number of transmitters and field points. Central station, multi-functional systems range in cost from \$10,000 to over \$850,000 depending on the number of points. Fully distributed systems range in cost from \$50,000 to over \$1,000,000 depending on the number of points and the number of microprocessors installed.

EMSs are generally reliable, although to function properly and perform the duties for which they were installed, a thorough system check-out, adequate operator training, and regular maintenance are necessary. An EMS's reliability will also depend on the age of the equipment and the number of its components. More extensive maintenance will be required for a sophisticated EMS consisting of a number of microprocessors and field panels than for a simple time clock controller.

ENERGY EFFICIENT MOTORS

Electric motors convert electrical energy into mechanical energy. They are generally classified by their horsepower, which is the product of the motor's torque and speed. Motors with a horsepower rating of less than 1 hp are fractional horsepower motors; those of 1 hp or more are classed as integral horsepower motors. The efficiency of a motor is the ratio of useful power output to its total power input. Industry standards for testing and labeling of motor efficiencies are described in NEMA Standard MG1-1983. Most motor manufacturers now offer energy efficient models which consume 3 to 8% less energy depending on size and load.

Energy efficient motors can be applied anywhere a standard motor would otherwise be used for fans, pumps used with HVAC systems, and refrigeration compressors and fans. New installations allow for a wider range of efficient motor applications; in most cases, replacing standard motors with energy efficient motors poses no problems. Nonetheless, energy efficient motors must be used with care for loads which are sensitive to speed because these motors have lower slip values than standard units and thus run closer to synchronous speed (i.e., faster).

The cost of energy-efficient motors ranges from roughly \$300 for a one horsepower motor to \$500 for a five horsepower motor. The cost per horsepower continues to decline up to \$40/hp for a 50 hp motor and remains about the same for larger sizes. The energy-efficient motors are 20 to 25% more expensive than standard motors of the same size.

To calculate annual operating savings with energy-efficient motors, use the following equation:

$$S = .746 * HP * C * N (100/Eb - 100/Ea)$$

Where:

- S = Savings in dollars per year
- HP = Horsepower rating of the motor load
- C = Energy cost in cents per kilowatts per hour
- N = Running time in hours per year.
- Ea = Efficiency rating of energy-efficient motor
- Eb = Efficiency rating of standard motor

Because energy efficient motors produce less waste heat, they has a longer operating lives than standard motors.

Reduced electricity costs for energy and demand are the principal benefits of using energy efficient motors. Depending on motor location, reductions in waste-heat dissipation may lower cooling loads and thus cooling costs. Additionally, because energy-efficient motors have longer operating lives, replacement costs are avoided for a longer time. The softer start of many of the variable speed drive options reduce mechanical degradation on the driver device, resulting in less maintenance and longer life.

CASE STUDIES

Each of the following case studies highlights the use of one or more of the technologies discussed in this booklet. The case studies are drawn from a variety of sources (the source for each is noted) and so they do not all report the same information or use the same format. The main purpose of including these case studies is to give you a sense of how the technologies discussed in the foregoing sections have been applied and what the results have been.

Seafirst Building, Bellevue, Washington
Heat Recovery Chiller

The Seafirst Building is a 390,000 square foot, 21 story office building served by Puget Sound Power and Light Company. A 200-ton reciprocating heat recovery chiller and a 320 ton high efficiency centrifugal chiller supply cooling directly and charge an ice storage bank. During the winter, the heat recovery chiller operates as a the lead chiller and applies its heat output to meet primary and pre-heat space heating loads. During nightly ice making, the recovered heat output maintains the interior temperature at 70 F, reducing electrical resistance demand for morning warm-up. While making ice and heating water, the heat recovery chiller operates with a heating COP of 3.5. In the cooling-only mode, the two chillers in combination achieve a COP of 4.65.

The facility consumes 31% less energy than a conventional facility that meets the Washington State Energy Code. The ice storage and heat recovery features account for more than half of the total energy savings and will save an estimated \$56,400 annually in utility costs. The design received and Energy Edge Award from Bonneville Power Administration and the Washington State Energy Office.

(Source: Electric Power Research Institute)

Carter Presidential Center, Atlanta, Georgia Heat Recovery Chiller

The 150,000 square foot facility includes a museum, library, offices, and conference center with a restaurant. The facility is served by Georgia Power Company. One 200 ton centrifugal heat recovery chiller and one 200 ton cooling-only chiller meet the 400 ton peak cooling load. Heat is supplied by the heat recovery chiller or a 450 kW electric boiler. Because strict control of temperature and humidity is required in document storage areas, reheat is a necessity.

The heat recovery chiller operates as the lead chiller during the heating season, supplying 46 F chilled water to meet the cooling load and 105 F water for space heating and terminal reheat. In summer, when cooling is the greater concern, the heat recovery chiller is the lag chiller. It operates when cooling loads rise and the need for humidity control increases.

Reheat energy requirements are supplied by the heat recovery chiller and excess heat is rejected to two cooling towers.

According to design engineers and a General Services Administration analysis, HVAC energy consumption is 35% lower than for a similar conventionally designed facility. The project received the Georgia AIA/Georgia Power energy design award in 1988.

(Source: Electric Power Research Institute)

Meier & Frank Department Store, Portland, Oregon Computerized Energy Management System, Relamping

The Meier and Frank system of department stores is a locally operated subsidiary of the May Company, a St. Louis based department store chain. Meier and Frank operates seven stores throughout Oregon. From 1977 to 1985 Meier and Frank slashed energy consumption by 35% while expanding store hours by 15% and adding four stores.

In each building, energy functions are controlled by an on-site Climatron computer, which monitors and controls building mechanical systems (e.g., by adjusting start-up and shut-off times of lights and equipment). Individual on-site systems are linked to the Portland, Oregon office of the Equipment Superintendent, who can monitor each building's behavior. He periodically samples the information gathered, pulls 'bottom line' numbers from utility bills, and enters all the figures into a computerized data base which provides a long term record of overall building performance.

In addition to the computerized energy management system, the stores were made more energy efficient by delamping and relamping with high efficiency or lower wattage lights. The energy operating cost for one store averages \$1 million per year; the 35% savings across the seven stores amounted to \$2.5 million per year.

(Source: So Show Me - New Energy Efficient Commercial Buildings, BPA, 1985)

**Unipart Group Limited Warehouse, Cowley, England
Occupancy Sensing Light Switching**

Unipart's warehouse uses pallet racking in 116 narrow aisles, each aisle lit by a row fluorescent tubes. Because of the random nature of occupancy, aisles were continuously lit throughout the working day. An occupancy sensing lighting system using microwave sensors was installed in September, 1986.

The system uses microwave Doppler shift sensors to detect motion within a selected area. Sensors at either end of each aisle give full coverage of each aisle area and are positioned so that movement of trucks passing outside the aisles is not detected. Once movement is detected, the lights are switched on and remain on for an adjustable time (from 30 seconds to 30 minutes) after movement has ceased. Key access to the controls allows the automatic system to be over-ridden if necessary.

Lighting energy consumption prior to the installation of the automatic control system estimated at 5,660 GJ (1,571,000 kWh). The average percentage lighting 'on time' after installation of the sensors was reduced by 70%, leading both to reduced energy usage and to longer life spans for the fluorescent tubes. The payback period for the energy efficient technology was 1.8 years.

(Source: CADDET)

**Plaid Pantry Convenience Stores, Northwest
Heat Recovery and High Efficiency Lamps and Ballasts**

Plaid Pantry had 133 stores operating and 57 new stores under way when it looked to increase its margin through energy conservation. Plaid Pantry's major energy saver is heat recovery from the refrigeration units. Compressor waste heat transfers by fluid to a heat exchanger, providing heat for the entire store. There is no back-up heat system. The heat recovery system is efficient to the point where the energy savings translate directly into lower construction costs for new stores. With the heat recovery units, wall insulation and double paned windows are no longer needed.

The stores already used fluorescent lighting, but they were replaced by super saver high efficiency fluorescent lamps and efficient ballasts.

(Source: So Show Me - New Energy Efficient Commercial Buildings, BPA, 1985)

**Radisson Plaza Hotel, Orlando, Florida
Building Automation System**

A \$75,000 investment in a building automation system has netted the Hotel a 28% return; the system has saved \$54,000, an 8.5 annual electricity savings, in its first 18 months and is expected to yield a standard 2 year payback.

The project included replacing the existing system with a 320 point system. Installing the new system was more cost-effective than upgrading the original system because it included 13 new stand-alone field panels, software programming, chiller optimization, control for three of the hotel's variable air volume air handlers and temperature control for the hotel's main ballroom. Existing relays and pneumatic/electric switches were re-used.

The new system has cut 128 kilowatts from what was once a 1,088 kilowatt peak demand at the 300,000 square foot facility. The system is used to control two 300 ton centrifugal chillers; the hotel has an average cooling load of 400 tons. The new system reduced electricity consumption by 500,000 kWh and annual emissions by 670,000 lbs of CO₂.

(Source: Energy User News, August 1990)

Piantedosi Bakery Company, Malden, Massachusetts
Energy Efficient Motors

The Piantedosi Bakery saw a return of 7.4 % from the installation of 100 energy efficient fractional horsepower that replaced an equal number of standard motors on the company's conveyor belt system. In addition to the motors, the company also installed three speed drives, each of which controls around 30 of the motors. The result is that the bakery's conveyor system — which carries rolls from baking to packaging — can move at a slower pace, thereby removing more moisture from the rolls.

Total cost to the bakery was \$36,968 for both measures, including a \$16,854 rebate from Massachusetts Electric's Design 2000 program for the speed drives and \$3,384 for the motors. The total cost without the rebates would have been \$57,206. Payback is expected to be around 3.2 years. The retrofit is on track to save \$10,800 in demand charges and around \$720 in energy charges. AT a rate of about 7 cents per kWh, this comes to about 10,286 kWh yearly. CO2 emissions will be reduced by about 13,783 lbs annually. The bakery's return on equity is 12%.

(Source: Energy User News, August 1990)

**University of California at Berkeley
Switch from Incandescent to High Pressure Sodium Lamps**

Based on first year savings, the University of California at Berkeley expects to realize a 60% return on investment for a high pressure sodium lamp conversion in a reception area and hallway in Tollman Hall. The University spent \$4,060 to retrofit 58 150 watt incandescents with 50 HPS lamps. The conversion will show a simple payback of 14 months.

The project's life cycle will be determined by the life of the ballast, which the manufacturer claims to be 60,000 hours. Because the lamps are operated 24 hours per day, the project's useful life is 6.85 years. The lamps will be replaced after 10,000 hours, even though it shifts in color as it ages. While new lamps deliver white light, older lights deliver a yellower light. Because the lamps are in non-critical areas, the University has no objections to the color change.

In 6.85 years the bulbs will be changed five times at \$26.90 per lamp, for a total of \$7,801. During the same period, incandescent lamps would have to be changed 30 times at \$4 per lamp, for a total of \$6,960. The University will pay an extra \$841 in equipment costs for the new lamps. Annual energy savings are \$3,506: each 50 watt HPS lamp uses an 8 watt ballast and saves 92 watts over the incandescent lamps. With 24 hour operation, the University is saving 46,148 kWh at a cost of 7.5 cents per kWh. CO₂ emissions will be reduced by 62,642 lbs annually.

(Source: Energy User News, August 1990)

New England Medical Center, Boston, Massachusetts Ballast Retrofit

New England Medical Center will realize a 12% return on investment from a ballast and lamp retrofit at six of its major buildings in Boston. The project resulted in a 371,250 kWh electricity reduction with an emissions reduction of 497,475 lbs of CO₂ annually.

The retrofit included the conversion of 3,570 standard magnetic ballasts with the same number of energy efficient one and two lamp magnetic ballasts. While the old ballasts consumed 16 watts each, the new ballasts consume only 4 watts each. The Center also retrofitted 6,594 35 and 40 watt 4 foot fluorescent lamps with 28 watt lamps.

In total, the hospital received \$17,800 in rebates from General Electric and its utility, Boston Edison. The \$7,100 GE rebate recouped almost a tenth of the hospital's \$71,500 lamp purchase. In addition, Boston Edison paid the hospital \$10,700: \$1 for every 40 watt tube replaced and \$3 for every standard ballast replaced. Total cost for the job was \$132,500. In addition to the equipment cost, the hospital spent \$48,500 on in-house installation and \$12,500 on engineering fees, administrative expense, and overtime labor. After subtracting the rebates, the center's actual investment was \$114,700. The retrofit should net the hospital \$29,700 in annual energy savings. The project's useful life will be determined by the life of the ballasts, which the manufacturer claims is 20 years.

(Source: Energy User News, August 1990)

RESOURCES

The following organizations can provide further information on the technologies discussed in this report. This list is not comprehensive; there are hundreds of organizations performing research into energy efficiency and many organizations produce a variety of publications ranging from newsletters to journals to books. The organizations listed here are those we found to be helpful in preparing this report. The public power utilities were also of great help; you should inquire with the utility in your area about the programs it offers, both in terms of providing information and any incentives for installing and using energy efficient technologies.

American Public Power Association
2301 M Street, NW
Washington, DC 20037
(202) 775-8300

American Society of Heating Refrigeration and Air-
Conditioning Engineers (ASHRAE)
1791 Tullie Circle, NE
Atlanta, GA 30329-2305
(404) 636-8400

Centre for the Analysis and Dissemination
of Demonstrated Energy Technologies (CADET)
Swentiboldstraat 21
6137 AE Sittard
P.O. Box 17, 6130 AA SITTARD
The Netherlands
31-(0)46-595-224

Conservation and Renewable Energy Inquiry and Referral
Service

P.O. Box 8900
Silver Spring, MD 20907
(800) 523-2929

Edison Electric Institute
1111 19th Street, NW
Washington, DC 20036
(202) 778-6552

Electric Power Research Institute (EPRI)
3415 Hillview Avenue
Palo Alto, CA 94303
(415) 855-2000

Energy Resource Center
7895 SW Mohawk Street
Tualatin, Oregon 97062
(503) 692-4800

Gas Research Institute
800 West Bryn Mawr Avenue
Chicago, Illinois 60631
(312) 399-8238

Industrial Heating Equipment Association
1901 N. Moore Street
Arlington, VA 22209

International Institute for Energy Conservation
420 C Street, NE
Washington, DC 20002

International Thermal Storage Advisory Council (ITSAC)
5252 Balboa Avenue, Suite 401
San Diego, CA 92117
(619) 560-1878

Lighting Design Lab
400 E. Pine Street, Suite 100
Seattle, WA 98122

Lighting Research Center
Rensselaer Polytechnic Institute
Troy, New York 12180-3590
(518) 276-8716

Lighting Controls Council
National Electrical Manufacturers Association
2101 L Street, NW
Washington, DC 20037
(202) 458-8400

New York State Energy Research and Development Authority
Two Rockefeller Plaza
Albany, NY 12223
(518) 465-6251

Office of Technology Assessment (OTA)
Congress of the United States
Washington, DC 20510-8025
Publications information: (202) 224-8996

Rocky Mountain Institute
1739 Snowmass Creek Road
Snowmass, CO 81654-9199
(303) 927-3128