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Improved Energy Efficiency Technologies and Its Applications

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Abstract*: These sectors are substantial energy consumers, making their transition towards greener practices essential for reducing environmental impact and operational costs. Fortunately, a range of innovative solutions are available to pave the way for a more energy-efficient tomorrow. Successful energy efficiency programs often install and operate a range of energy-efficient technologies. The technologies can benefit multiple sectors by reducing energy demand and improving energy reliability.Energy efficiency is the use of less energy to perform the same task or produce the same result. Energy-efficient homes and buildings use less energy to heat, cool, and run appliances and electronics, and energy-efficient manufacturing facilities use less energy to produce goods.Energy efficiency is one of the easiest and most cost-effective ways to combat climate change, reduce energy costs for consumers, and improve the competitiveness of . businesses. Energy efficiency is also a vital component in achieving net-zero emissions of carbon dioxide through decarburization.*

Keywords: Building Envelope, Lighting, LEDs. CFLs. Appliances

I. INTRODUCTION

A variety of energy efficiency measures and technologies can be employed to reduce energy use. A sample list of common options appears below.

To determine the best suited technologies for any given program or application,. The best technology choice is determined by a combination of energy savings, availability, supporting policies, and other important factors.

II. ENERGY EFFICIENCY APPLICATIONS & TECHNOLOGIES

Residential
High-efficiency home heating, ventilation, and air conditioning (HVAC) systems
Insulation
Efficient appliances (e.g., clothes washers)
Commercial:
Efficient consumer electronics
Commercial refrigeration
LED lighting with sensors
Industrial:
Fuel-efficient motors
Enhancements to the building envelope (e.g., roof, siding, windows)
Agriculture:
Efficient pumps and motors
Transportation:
Fuel economy standards
Fuel-saving tire design
Building Envelope

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The building envelope is the outer shell of an enclosed building. The envelope separates the interior space of a building from the outside elements and is essential to maintaining a dry, heated, or cooled indoor environment. The building envelope consists of the roof, walls, and foundation of the building, as well as the window assemblies.

Roof and Wall Insulation

Roof and wall insulation can help reduce the amount of energy required to cool, heat, or alter humidity. Insulation decreases the rate of heat transfer with the outdoor environment. Insulation is typically rated with an "R-value" (higher numbers correlate with greater insulating properties).

Reduced Air Infiltration

Sealing gaps, cracks, or other leakage sites in the building envelope, including heating and cooling ducts, can reduce energy losses, improve overall building and system efficiency, and reduce energy bills.

Windows and Glazing

To enhance the energy efficiency of windows, manufacturers have introduced high-quality frame materials, multiple layers of glass, low-emissivity (infrared-insulating and ultraviolet light-reflecting) glass, and insulating gas fill between glass layers.

Lighting

Lighting is often the first stop for energy improvements due to its short investment payback period. Light-emitting diode (LED) bulbs are considered top-tier in terms of energy efficiency, and their prices have recently become more competitive with other efficient lighting technologies such as compact fluorescent lamps (CFLs). LED bulbs last more than three times as long as CFLs, and almost 25 times longer than incandescent bulbs. Due to lifetime cost savings, better quality light, and a number of improvements in performance, LEDs are the best choice for most lighting applications. Additionally, daylight and occupancy sensors can be paired with lighting systems to reduce energy use when natural light is adequate and when buildings and rooms are unoccupied.

LEDs

Light-emitting diodes are small light sources that are illuminated by electrons moving through a semiconductor material. LEDs generate very little heat and are exceptionally energy efficient when producing individual colors. Many use up to 90 percent less energy than an incandescent bulb to produce the same amount of light and last 25 times longer before needing to be replaced. They can be used in almost any application: street lighting is one particularly effective application for LEDs. The up-front cost of LEDs is typically higher than for CFLs or incandescent lamps but has been steadily dropping in many markets as demand and usage grow.

CFLs

Compact fluorescent lamps use one-fifth to one-third the electric power of incandescent light bulbs and last 8 to 15 times longer. CFLs have replaced incandescent light bulbs in many markets, although LEDs are rapidly becoming the preferred choice due to their efficiency and length of operation. Additionally, CFLs contain small quantities of mercury, which can complicate disposal.

High Performance T8s

High performance T8 (HPT8) systems have two components: a high-lumen, long-life T8 lamp, either fluorescent or LED; and a low-power electronic ballast (a device to control the electrical current). This combination results in energy savings over older systems that use T12 lamps with magnetic ballasts. It also improves light output by reducing flickering and noise. HPT8s are typically used for commercial lighting applications.

HID Lamps

High-intensity discharge (HID) lamps use electricity arcs between two electrodes to create an intensely bright light. Mercury, sodium, or metal halide gas acts as the conductor. HID lighting provides the second highest efficiency and longest service life of any lighting type. HID lamps are up to 90 percent more efficient than incandescent lighting and are used to light large indoor and outdoor areas such as gymnasiums, sports arenas, and car lots.

T5HOs

High-output T5 lamps (T5HOs) are 1.2-meter (4-foot) fluorescent lamps that are narrower in diameter than the comparable T8 fluorescent but produce roughly twice the light output. The light output of T5HOs makes them well-suited to commercial and industrial buildings with high ceilings.

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II. APPLIANCES

Most major-appliance manufacturers offer energy-efficient versions of their products, which are sometimes marked with a label to designate them as such. See the Standards, Rating and Labeling Technical Guide for more information on appliance labeling.

Clothes Dryers

Energy-efficient dryers use less energy than conventional models without sacrificing features or performance. They do this by deploying technologies such as moisture sensors that detect when clothes are dry and automatically shut the dryer off. Or they may incorporate low-heat settings, which use less energy in longer drying cycles.

Clothes Washers

Energy-efficient washers have greater tub capacities, which means fewer loads to clean the same amount of laundry. They can include technologies such as sensors to monitor incoming water levels and temperature; or repeated high-pressure spraying, instead of soaking clothes in a full tub of water. Front-loading clothes washers also use substantially less water than top-loading models. According to the U.S. Environmental Protection Agency (EPA), highly efficient clothes washers can use 25 percent less energy and 40 percent less water than regular washers.

Dehumidifiers

Energy-efficient dehumidifiers have more efficient refrigeration coils, compressors, and fans than conventional models, which means they remove the same amount of moisture but use 15 percent less energy.

Dishwashers

Efficient dishwasher technology includes a number of different features. Soil sensors, for instance, adjust the cycle to achieve minimum water and energy use by testing for dish dirtiness. Improved water filtration removes food soils from the wash water to allow efficient use of detergent and water. Finally, efficient jets use less energy to spray detergent and water over dishes when cleaning, and innovative dish rack designs maximize cleaning by strategically positioning dishes.

Refrigerators and Freezers

Efficient refrigerators and freezers used in residential, commercial, and industrial applications employ more effective insulation and higher efficiency compressors to save energy.

Vending Machines

Efficient vending machines incorporate more efficient fan motors, lighting systems, and compressors for refrigeration. Sometimes they include motion sensors which automatically switch to low-energy lighting and/or low-energy refrigeration mode during times of extended inactivity.

Electric and Electronic Equipment (Computers, Phones, TVs)

Owners can improve the efficiency of their electric and electronic appliances by using switch-mode power supplies (that convert electrical power efficiently), “smart” chargers (that communicate with batteries to ensure optimal charge), efficient backlighting settings, and low-power mode.

HVAC (Heating, Ventilation and Cooling Systems)

Heating and cooling (i.e., conditioning) the indoor environment ensures occupant comfort in many climates and can improve productivity. Ventilation systems can help improve indoor air quality and, when implemented correctly, can have positive health benefits for occupants. HVAC systems include a variety of technologies and can be used in residential, commercial, or industrial settings.

Air Conditioning

Air conditioning is the process of altering air temperature and humidity to distribute air and improve occupant comfort and indoor air quality. Air conditioners function in much the same way refrigerators do, by using energy to transfer heat from the interior of a building to the outside environment.

Types of air conditioners

Portable:: A unitary air conditioner, installed through a wall or window, cools a room by removing heat from the room and releasing it outdoors.

Central: A central cooling system uses ducts to distribute cooler and/or dehumidified airto a whole building.

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Ductless heating and cooling :Ductless heating and cooling systems are highly efficient products that deliver warm or cool air directly into different zones in a home, instead of routing it through ducts first. They are also referred to as mini-split, multi-split, or variable refrigerant flow (VRF) heat-pump systems..

Features of efficient boilers and furnaces

Mid Efficiency Heating System:

Exhaust fan controls the flow of combustion air and combustion gases more precisely
Electronic ignition (no pilot light)
Compact size and lighter weight improve mechanical efficiency
80–83 percent AFUE

High Efficiency Heating System at

Flue gases condense in a second heat exchanger for extra efficiency
Sealed combustion
90–98.5 percent AFUE

Boilers (gas or oil-fueled)

Boilers heat water or produce steam, which is circulated through a building to radiators or other terminal units in order to heat the building. A boiler's efficiency is measured by annual fuel utilization efficiency (AFUE), which is the ratio of useful energy output to energy input expressed in percentage terms. Higher AFUE percentages indicate higher efficiency.

Furnaces (gas or oil-fueled)

Furnaces heat air and deliver it directly to interior spaces. The efficiency of a furnace in converting gas or oil into heating energy is reflected in its annual fuel-utilization-efficiency (AFUE) rating, which is expressed as a percentage. The higher the number, the more heat the furnace can produce from each unit of gas or oil.

Heat Pumps: Air Source and Ground Source

Heat pumps transport heat from outside to inside (in heating mode), or from inside to outside (in cooling mode). There are two major types of heat pumps: air source and ground source. Air source heat pumps usually use a separate outdoor compressor unit to move heat in and out of a residence or building. Ground source heat pumps (also called geothermal heat pumps) provide heating, cooling, and water heating by taking advantage of the Earth's natural heat and stable temperatures. Ground source heat pumps use an underground piping system called a "loop" to move heat between deep wells in the ground and the inside of the building (in heating mode) or vice versa (in cooling mode).

Air Compression Systems

Energy efficiency opportunities for air compressors include comprehensive system evaluations, new compressors, refrigerated dryers, additional storage, enhanced controls, piping improvements, and leak repairs.
Chillers
There are two types of high-efficiency chillers for HVAC systems: air-cooled chillers and water-cooled chillers. A chiller's efficiency is measured by the coefficient of performance (COP), which is the ratio of heating or cooling provided to electrical energy consumed. Higher COPs indicate greater efficiency.

Features of high-efficiency chillers

Air-Cooled Chillers

Air Cooled Chillers:: Multiple reciprocating or scroll compressors in a single system to better match part-load conditions
Centrifugal compressors
Small air-cooled electric chillers have a radio of 1.6-1.1 kW/ton (COP of 2.2–3.2).

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arge and medium-sized air-cooled electric chillers have a radio of 0.95–0.85 kW/ton (COP of 3.7–4.1).

Water-Cooled Chillers

Water Cooled Chillers:: Double-effect absorption, where two generators are used sequentially to increase efficiency Absorption chiller/heater units, which use the heat produced by firing the chiller to provide space heating and hot water Water-cooled electric chillers have a radio of 0.8–0.7 kW/ton (COP of 4.4–5.0). Chillers with lower values, such as 0.6–0.5 kW/ton (COP of 5.9–7.0), may be energy efficient, but part-load performance should also be examined.
The COP of absorption units is in the range of 0.4–0.6 for single-effect chillers, and 0.8–1.05 for double-effect chillers. Manufacturers may improve chiller efficiency through enhanced controls, enlarged and improved condenser sections, and high-efficiency compressors with variable-speed motor drives. Evaporative or swamp coolers, which are packaged units that cool the air by humidifying it and then evaporating the moisture, use significantly less energy than all-electric chillers. Cumulatively, they can reduce peak electricity demand.

Heat Recovery

During inefficient manufacturing processes, 20 to 50 percent of energy consumed ultimately may be lost via waste heat. The waste is contained in streams of hot exhaust gases or liquids, or occurs through conduction, convection, or radiation from hot equipment surfaces and from heated product streams. Recovery technologies capture the waste heat for reuse in other processes. An example of one of these technologies is an economizer, which comes in condensing and air source models. Economizers can be paired with other equipment to improve its efficiency. For example, a condensing economizer can be paired with a boiler to recover heat from fluid that is hot, but not hot enough to be used in the boiler itself.

Ventilation Fans

The efficiency of ventilation fans, typically integrated into central HVAC systems, may be enhanced by features such as humidity sensors and motion ensors.

Ceiling Fans

Improved motors and blade designs deliver greater efficiency than in conventional models of ceiling fans.

Water Heating

Water heaters are often categorized by the type of fuel that powers them (electric, natural gas, or solar) and by whether they heat a storage tank or provide heated water on demand (also known as "tankless" systems).

Electric Storage Water Heaters

Also known as heat pump water heaters (HPWH), electric storage water heaters use a highly efficient heat pump to transfer heat from the surrounding air to an enclosed tank. During periods of high hot water demand, HPWHs automatically switch to standard electric resistance heat. These heaters also come with selectable operating modes, such as efficiency/economy, to maximize energy efficiency; and a vacation or timer option to place the unit in "sleep" mode.

Natural Gas Water Heater, Gas Storage

In high-efficiency gas storage water heaters, a glass-lined steel tank is heated by a burner located at the bottom of the tank. Efficient models simply have better insulation, heat traps, and more efficient burners. Very high efficiency models use a secondary heat exchanger that extracts more heat from the combustion gas, cooling it to the point where there is condensation—hence, these types of heaters are called "gas condensing."

Natural Gas Water Heater, Whole Home Gas Tankless

Whole-home gas tankless water heaters save energy by heating water only when needed and thereby eliminating energy lost during standby operation. When a hot water tap is turned on, cold water is drawn into the water heater. A flow sensor activates the gas burner, which warms the heat exchanger. Incoming cold water encircles the heat exchanger and

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leaves the heater at its set-point temperature. Combustion gases safely exit through a dedicated, sealed vent system. More efficient gas tankless water heaters use secondary heat exchangers to extract more heat from the combustion gas, cooling it to the point where there is condensation—hence these types of heaters are called "gas condensing."

Solar Water Heater

Solar water heaters come in a wide variety of designs, all of which include an energy collector and a storage tank. They use the sun's thermal energy to heat water and are typically described according to the type of collector and the circulation system.

Motors and Pumps (including industrial, agricultural and commercial examples)

Motors and pumps represent a substantial opportunity for energy efficiency improvements. The International Energy Agency estimates that electric motors (including those that drive pumps) account for 69 percent of electricity use in the industrial sector, 38 percent in the commercial sector, 22 percent in the residential sector, and 39 percent in the transportation and agriculture sectors combined.

Variable-Speed and High-Efficiency Motors

A variable-speed drive (VSD) is a type of adjustable-speed drive used in electro-mechanical drive systems. Its purpose is to control motor speed and torque by varying motor input frequency and voltage. VSDs are a relatively new technology that has not yet been widely implemented. Installing a VSD makes it feasible to closely correlate demand on the motor with the effort expended by the motor and, therefore, results in significant energy savings.

Examples of applications for vsds, by sector

Industrial: Air Compressors

Industrial Air Compressed: The benefits of using VSD technology in air compressors are reduced power cost, decreased power surges (from starting motors), and better overall performance (more constant pressure output). In addition, industrial settings can significantly improve efficiency by installing motors whose capacity matches the actual load requirements.

Agricultural: Pumps

Agriculture Pumps:;Most existing agricultural pump systems have bypass lines, throttling valves, or speed adjusters where flow is controlled. The most efficient way to improve performance, increase reliability, and reduce the life-cycle costs is through pump speed control. When a pump's speed is reduced, less energy is imparted to the fluid that is being moved, and less energy needs to be throttled or bypassed. Speed can be controlled in a number of ways, with the most popular being VSD technology..**uilding Ventilation Systems**

Commercial Building Ventilation System:: Building ventilation systems are designed to be able to operate at maximum load conditions. However, most operate at full load only for short periods of the day. The rest of the time, the system is over-powered for the need. The efficiency of such systems can be improved by varying the capacity to match actual load requirements. The most common method for doing so is to use VSDs to modulate the speed of pump motors, fans, and air conditioning systems.

Controls

Automated control technology enables building managers and owners to reduce the need for lighting, heating, or cooling during low-occupancy hours of operation.

System Monitoring, Controls, and Analytics

To increase energy efficiency, OEMs and MROs can turn to technologically advanced solutions that leverage data and technology.

Among these innovations, monitoring, controls, and analytics have emerged as crucial tools to optimize energy consumption.

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Monitoring

In both manufacturing and commercial buildings, the ability to monitor energy consumption in real-time helps optimize not only production and performance but also energy efficiency.

Sophisticated sensors and monitoring devices are installed throughout facilities to continuously track energy usage. This real-time data provides a clear picture of where, when, and how energy is being consumed.

For example, for manufacturers, monitoring systems can identify inefficiencies in production lines or equipment, allowing for immediate adjustments. In commercial buildings, these systems can track the usage of lighting, HVAC systems, and other electrical devices.

This level of awareness empowers facility managers to make informed decisions to reduce energy consumption.

Analytics

The real power of monitoring and control systems comes to light when paired with advanced data analytics. These analytics platforms crunch the vast amounts of data collected by monitoring systems to reveal insights and trends.

Analytics can predict when equipment is likely to fail, enabling timely maintenance that prevents costly breakdowns and energy waste.

By comparing energy usage data with industry benchmarks, organizations can identify areas where they can improve and set realistic energy reduction goals.

For MROs, data analytics can identify patterns of energy use that highlight opportunities for behavioral changes among occupants, encouraging them to use resources more efficiently.

Scheduled Preventative Maintenance

Machinery and equipment in OEM facilities and MRO sites are the workhorses that keep operations running. Over time, wear and tear can lead to decreased efficiency, resulting in higher energy consumption.

Preventative maintenance schedules ensure that these assets are regularly inspected, cleaned, and fine-tuned to operate at peak efficiency. This translates to less energy wastage and lower operational costs.

Replacing machinery and systems prematurely due to unexpected failures is both expensive and ecologically unsound.

Preventative maintenance extends the lifespan of equipment, reducing the need for replacements and lowering the environmental impact associated with manufacturing new machinery.

A longer lifespan means a more sustainable approach and a significant reduction in energy consumption over time.

Lighting: Occupancy Sensors and Timers

An occupancy sensor is a lighting control device that detects occupancy and turns the lights on or off automatically, using infrared, ultrasonic, or microwave technology. Timers are set to turn off lights or other equipment (such as fans) after a specified period of time.

Lighting: Dimming controls

Dimmers are devices used to lower the brightness of a light. Modern dimmers are built from semiconductors and are highly efficient since they dissipate far less power than the older, variable resistor-type dimmers.

HVAC: Programmable Thermostats

A programmable thermostat is designed to adjust the temperature according to a series of programmed settings that take effect at different times of the day. Heating and cooling losses from a building become greater as the difference in temperature between the interior and exterior increases. A programmable thermostat reduces these losses by allowing the temperature difference to narrow at times when it would not be objectionable to occupants or detrimental to processes.

HVAC System Upgrades

In addition to the integration of VFDs to enhance energy efficiency in HVAC systems, these systems can be optimized in other ways as they are significant energy consumers.

Upgrading to more efficient HVAC equipment and implementing advanced controls can lead to substantial energy savings without compromising comfort. Regular maintenance and optimizing temperature settings can further enhance efficiency.

This can be achieved with a robust system of programmable thermostats along with a technologically advanced sensor system with automation capabilities such as indoor and outdoor temperature and pressure sensors to increase the intelligence of HVAC systems.

This helps to reduce a building's energy waste and energy costs and maximize efficiency.

HVAC: Building Automation Systems

A building automation system can reduce energy consumption and operating costs by centralizing automated control of the heating, ventilation, air conditioning, lighting and other systems.

Process Equipment: Automatic Scheduling

Process controls determine how long equipment is required to operate, turning it on and off as needed.

Smart Meters

A smart meter is an electronic device that records the consumption of electric energy in intervals of an hour or less and communicates that information to the utility for monitoring and billing. Smart meters enable communication between the meter and the central system. These types of meters may also communicate with "smart" equipment, depending on device design as well as intermediary communication between the meter and other equipment, such as a Wi-Fi network or a power line carrier network. Smart meters permit greater control than traditional meters over the quantity of energy consumed and the times of use.

Since smart meters allow consumers to monitor their electricity consumption rates in real time, they can be paired with other behavioral incentives (i.e., price signals during peak-consumption hours) to positively reinforce energy conservation. The American Council for an Energy-Efficient Economy (ACEEE) reported in 2012 that across nine pilot studies involving real-time energy consumption feedback using smart meters, the average savings was 3.8 percent.

Smart Controls

Smart controls are at the heart of optimizing energy in manufacturing and commercial buildings.

These systems enable precise regulation of equipment and systems to match actual demand. In commercial buildings, smart HVAC controls adjust heating and cooling based on occupancy and weather conditions, reducing energy waste while ensuring comfort.

For OEMs, smart controls can fine-tune machinery to operate at the most energy-efficient speeds and settings. This not only reduces energy consumption but also improves production efficiency.

Sector-Specific Technologies

Transportation: Vehicles

Several jurisdictions around the world have put regulations into place to improve the average fuel economy of vehicles. One example is the Corporate Average Fuel Economy (CAFÉ) standards in the United States. Improvements in fuel economy are measured using miles per gallon (mpg) for this particular standard. Technological improvements that manufacturers have introduced include higher efficiency drivetrains and improved aerodynamics.

Transportation: Low-Rolling Tires

Fuel-efficient low-rolling tires use tread design and new materials to minimize the amount of gasoline required to move the vehicle.

Agricultural: Water Distribution Systems (Drip Irrigation)

Drip irrigation, also known as trickle irrigation, is a method that saves water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves,

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pipes, tubing, and emitters. Drip irrigation is more efficient than sprinklers or flood irrigation because a much higher proportion of the water delivered to the plants is absorbed by the soil. Drip irrigation saves energy by reducing the quantity of water that needs to be supplied and pumped.

III. CONCLUSION

The development and implementation of advanced energy saving and energy efficiency technologies in both the industrial and domestic spheres is, among other things, a crucial step towards solving environmental problems that have never been more pressing, including global climate change, excessive atmospheric pollution ...

In the world of manufacturing and maintenance, optimizing energy efficiency is especially paramount for the successful progression to smart factories and buildings.:

The problem of energy and energy resources has been and remains one of the most important global problems, in the solution of which all peoples, all countries of the world are interested. Saving energy resources is an issue that is especially important today and concerns all of us. In turn, the measures, recommendations, systematic approaches to improve energy efficiency, will save energy consumption in all industries several times. With the deployment and development of connected devices that allow for greater integration and automation of energy efficiency, new efficiency gains at higher levels of complexity are becoming increasingly possible; perhaps inevitable. But to take advantage of these evolving opportunities and align them to provide society with maximum benefit, and consider energy efficiency as the foundation of our path forward and leverage its massive scale and versatility to prepare for tomorrow's challenges.

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