Tips for Energy Conservation for Industries

THERMAL UTILITIES

Boilers

- Preheat combustion air with waste heat
  (22 ^{0}C reduction in flue gas temperature increases boiler efficiency by 1%).
- Use variable speed drives on large boiler combustion air fans with variable flows.
- Burn wastes if permitted.
- Insulate exposed heated oil tanks.
- Clean burners, nozzles, strainers, etc.
- Inspect oil heaters for proper oil temperature.
- Close burner air and/or stack dampers when the burner is off to minimize heat loss up the stack.
- Improve oxygen trim control (e.g. -- limit excess air to less than 10% on clean fuels). *(5% reduction in excess air increases boiler efficiency by 1% or: 1% reduction of residual oxygen in stack gas increases boiler efficiency by 1%.)*
- Automate/optimize boiler blowdown. Recover boiler blowdown heat.
- Use boiler blowdown to help warm the back-up boiler.
- Optimize deaerator venting.
- Inspect door gaskets.
- Inspect for scale and sediment on the water side
  (A 1 mm thick scale (deposit) on the water side could increase fuel consumption by 5 to 8%).
- Inspect for soot, flyash, and slag on the fire side
  (A 3 mm thick soot deposition on the heat transfer surface can cause an increase in fuel consumption to the tune of 2.5%.)
- Optimize boiler water treatment.
- Add an economizer to preheat boiler feedwater using exhaust heat.
- Recycle steam condensate.
- Study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple boilers.
- Consider multiple or modular boiler units instead of one or two large boilers.
- Establish a boiler efficiency-maintenance program. Start with an energy audit and follow-up, then make a boiler efficiency-maintenance program a part of your continuous energy management program.

Steam System

- Fix steam leaks and condensate leaks
  (A 3 mm diameter hole on a pipe line carrying 7 kg/cm^2 steam would waste 33 kilo litres of fuel oil per year).
- Accumulate work orders for repair of steam leaks that can't be fixed during the heating season due to system shutdown requirements. Tag each such leak with a durable tag with a good description.
- Use back pressure steam turbines to produce lower steam pressures.
- Use more-efficient steam desuperheating methods.
- Ensure process temperatures are correctly controlled.
- Maintain lowest acceptable process steam pressures.
- Reduce hot water wastage to drain.

- Remove or blank off all redundant steam piping.
- Ensure condensate is returned or re-used in the process
  (6 ^{0}C raise in feed water temperature by economiser/condensate recovery corresponds to a 1% saving in fuel consumption, in boiler).
- Preheat boiler feed-water.
- Recover boiler blowdown.
- Check operation of steam traps.
- Remove air from indirect steam using equipment
  (0.25 mm thick air film offers the same resistance to heat transfer as a 330 mm thick copper wall.)
- Inspect steam traps regularly and repair malfunctioning traps promptly.
- Consider recovery of vent steam (e.g. -- on large flash tanks).
- Use waste steam for water heating.
- Use an absorption chiller to condense exhaust steam before returning the condensate to the boiler.
- Use electric pumps instead of steam ejectors when cost benefits permit
- Establish a steam efficiency-maintenance program. Start with an energy audit and follow-up, then make a steam efficiency-maintenance program a part of your continuous energy management program.

Furnaces

- Check against infiltration of air: Use doors or air curtains.
- Monitor O_2 /CO_2/CO and control excess air to the optimum level.
- Improve burner design, combustion control and instrumentation.
- Ensure that the furnace combustion chamber is under slight positive pressure.
- Use ceramic fibres in the case of batch operations.
- Match the load to the furnace capacity.
- Retrofit with heat recovery device.
- Investigate cycle times and reduce.
- Provide temperature controllers.
- Ensure that flame does not touch the stock.

Insulation

- Repair damaged insulation
  (A bare steam pipe of 150 mm diameter and 100 m length, carrying saturated steam at 8 kg/cm^2 would waste 25,000 litres furnace oil in a year.)
- Insulate any hot or cold metal or insulation.
- Replace wet insulation.
- Use an infrared gun to check for cold wall areas during cold weather or hot wall areas during hot weather.
- Ensure that all insulated surfaces are cladded with aluminum
- Insulate all flanges, valves and couplings
- Insulate open tanks
  (70% heat losses can be reduced by floating a layer of 45 mm diameter polypropylene (plastic) balls on the surface of 90 ^{0}C hot liquid/condensate).

Waste heat recovery

- Recover heat from flue gas, engine cooling water, engine exhaust, low pressure waste steam, drying oven exhaust, boiler blowdown, etc.
- Recover heat from incinerator off-gas.
- Use waste heat for fuel oil heating, boiler feedwater heating, outside air heating, etc.
- Use chiller waste heat to preheat hot water.
- Use heat pumps.
- Use absorption refrigeration.
- Use thermal wheels, run-around systems, heat pipe systems, and air-to-air exchangers.

ELECTRICAL UTILITIES

Electricity Distribution System

- Optimise the tariff structure with utility supplier
- Schedule your operations to maintain a high load factor
- Shift loads to off-peak times if possible.
- Minimise maximum demand by tripping loads through a demand controller
- Stagger start-up times for equipment with large starting currents to minimize load peaking.
- Use standby electric generation equipment for on-peak high load periods.
- Correct power factor to at least 0.90 under rated load conditions.
- Relocate transformers close to main loads.
- Set transformer taps to optimum settings.
- Disconnect primary power to transformers that do not serve any active loads
- Consider on-site electric generation or cogeneration.
- Export power to grid if you have any surplus in your captive generation
- Check utility electric meter with your own meter.
- Shut off unnecessary computers, printers, and copiers at night.

Motors

- Properly size to the load for optimum efficiency.
  (High efficiency motors offer of 4 - 5% higher efficiency than standard motors)
- Use energy-efficient motors where economical.
- Use synchronous motors to improve power factor.
- Check alignment.
- Provide proper ventilation
  (For every 10 ^{o}C increase in motor operating temperature over recommended peak, the motor life is estimated to be halved)
- Check for under-voltage and over-voltage conditions.
- Balance the three-phase power supply.
  (An imbalanced voltage can reduce 3 - 5% in motor input power)
- Demand efficiency restoration after motor rewinding.
  (If rewinding is not done properly, the efficiency can be reduced by 5 - 8%)

Drives

- Use variable-speed drives for large variable loads.
- Use high-efficiency gear sets.
- Use precision alignment.
- Check belt tension regularly.
- Eliminate variable-pitch pulleys.
- Use flat belts as alternatives to v-belts.
- Use synthetic lubricants for large gearboxes.
- Eliminate eddy current couplings.
- Shut them off when not needed.

Fans

- Use smooth, well-rounded air inlet cones for fan air intakes.
- Avoid poor flow distribution at the fan inlet.
- Minimize fan inlet and outlet obstructions.
- Clean screens, filters, and fan blades regularly.
- Use aerofoil-shaped fan blades.
- Minimize fan speed.
- Use low-slip or flat belts.
- Check belt tension regularly.
- Eliminate variable pitch pulleys.
- Use variable speed drives for large variable fan loads.
- Use energy-efficient motors for continuous or near-continuous operation
- Eliminate leaks in ductwork.
- Minimise bends in ductwork
- Turn fans off when not needed.

Blowers

- Use smooth, well-rounded air inlet ducts or cones for air intakes.
- Minimize blower inlet and outlet obstructions.
- Clean screens and filters regularly.
- Minimize blower speed.
- Use low-slip or no-slip belts.
- Check belt tension regularly.
- Eliminate variable pitch pulleys.
- Use variable speed drives for large variable blower loads.
- Use energy-efficient motors for continuous or near-continuous operation.
- Eliminate ductwork leaks.
- Turn blowers off when they are not needed.

Pumps

- Operate pumping near best efficiency point.
- Modify pumping to minimize throttling.
- Adapt to wide load variation with variable speed drives or sequenced control of smaller units.
- Stop running both pumps -- add an auto-start for an on-line spare or add a booster pump in the problem area.
- Use booster pumps for small loads requiring higher pressures.
- Increase fluid temperature differentials to reduce pumping rates.
- Repair seals and packing to minimize water waste.
- Balance the system to minimize flows and reduce pump power requirements.

- Use siphon effect to advantage: don't waste pumping head with a free-fall (gravity) return.

Compressors

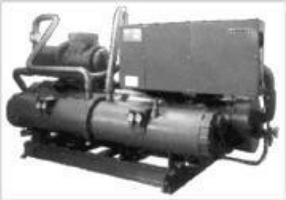
- Consider variable speed drive for variable load on positive displacement compressors.
- Use a synthetic lubricant if the compressor manufacturer permits it.
- Be sure lubricating oil temperature is not too high (oil degradation and lowered viscosity) and not too low (condensation contamination).
- Change the oil filter regularly.
- Periodically inspect compressor intercoolers for proper functioning.
- Use waste heat from a very large compressor to power an absorption chiller or preheat process or utility feeds.
- Establish a compressor efficiency-maintenance program. Start with an energy audit and follow-up, then make a compressor efficiency-maintenance program a part of your continuous energy management program.

Compressed air

- Install a control system to coordinate multiple air compressors.
- Study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple air compressors.
- Avoid over sizing -- match the connected load.
- Load up modulation-controlled air compressors. (They use almost as much power at partial load as at full load.)
- Turn off the back-up air compressor until it is needed.
- Reduce air compressor discharge pressure to the lowest acceptable setting. *(Reduction of 1 kg/cm^2 air pressure (8 kg/cm^2 to 7 kg/cm^2) would result in 9% input power savings. This will also reduce* compressed air leakage rates by 10%)
- Use the highest reasonable dryer dew point settings.
- Turn off refrigerated and heated air dryers when the air compressors are off.
- Use a control system to minimize heatless desiccant dryer purging.
- Minimize purges, leaks, excessive pressure drops, and condensation accumulation. *(Compressed air leak from 1 mm hole size at 7 kg/cm^2 pressure would mean power loss equivalent to 0.5 kW)*
- Use drain controls instead of continuous air bleeds through the drains.
- Consider engine-driven or steam-driven air compression to reduce electrical demand charges.
- Replace standard v-belts with high-efficiency flat belts as the old v-belts wear out.
- Use a small air compressor when major production load is off.
- Take air compressor intake air from the coolest (but not air conditioned) location. *(Every 5^{0}C reduction in intake air temperature would result in 1% reduction in compressor power consumption)*
- Use an air-cooled aftercooler to heat building makeup air in winter.
- Be sure that heat exchangers are not fouled (e.g. -- with oil).
- Be sure that air/oil separators are not fouled.
- Monitor pressure drops across suction and discharge filters and clean or replace filters promptly upon alarm.
- Use a properly sized compressed air storage receiver. Minimize disposal costs by using lubricant that is fully demulsible and an effective oil-water separator.

- Consider alternatives to compressed air such as blowers for cooling, hydraulic rather than air cylinders, electric rather than air actuators, and electronic rather than pneumatic controls.
- Use nozzles or venturi-type devices rather than blowing with open compressed air lines.
- Check for leaking drain valves on compressed air filter/regulator sets. Certain rubber-type valves may leak continuously after they age and crack.
- In dusty environments, control packaging lines with high-intensity photocell units instead of standard units with continuous air purging of lenses and reflectors.
- Establish a compressed air efficiency-maintenance program. Start with an energy audit and follow-up, then make a compressed air efficiency-maintenance program a part of your continuous energy management program.

Chillers



- Increase the chilled water temperature set point if possible.
- Use the lowest temperature condenser water available that the chiller can handle.
  (Reducing condensing temperature by 5.5 ^{0}C, results in a 20 - 25% decrease in compressor power consumption)
- Increase the evaporator temperature
  (5.5^{0}C increase in evaporator temperature reduces compressor power consumption by 20 - 25%)
- Clean heat exchangers when fouled.
  (1 mm scale build-up on condenser tubes can increase energy consumption by 40%)
- Optimize condenser water flow rate and refrigerated water flow rate.
- Replace old chillers or compressors with new higher-efficiency models.
- Use water-cooled rather than air-cooled chiller condensers.
- Use energy-efficient motors for continuous or near-continuous operation.
- Specify appropriate fouling factors for condensers.
- Do not overcharge oil.
- Install a control system to coordinate multiple chillers.
- Study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple chillers.
- Run the chillers with the lowest energy consumption. It saves energy cost, fuels a base load.
- Avoid oversizing -- match the connected load.
- Isolate off-line chillers and cooling towers.
- Establish a chiller efficiency-maintenance program. Start with an energy audit and follow-up, then make a chiller efficiency-maintenance program a part of your continuous energy management program.

HVAC (Heating / Ventilation / Air Conditioning)

- Tune up the HVAC control system.
- Consider installing a building automation system (BAS) or energy management system (EMS) or restoring an out-of-service one.
- Balance the system to minimize flows and reduce blower/fan/pump power requirements.
- Eliminate or reduce reheat whenever possible.
- Use appropriate HVAC thermostat setback.
- Use morning pre-cooling in summer and pre-heating in winter (i.e. -- before electrical peak hours).
- Use building thermal lag to minimize HVAC equipment operating time.

- In winter during unoccupied periods, allow temperatures to fall as low as possible without freezing water lines or damaging stored materials.
- In summer during unoccupied periods, allow temperatures to rise as high as possible without damaging stored materials.
- Improve control and utilization of outside air.
- Use air-to-air heat exchangers to reduce energy requirements for heating and cooling of outside air.
- Reduce HVAC system operating hours (e.g. -- night, weekend).
- Optimize ventilation.
- Ventilate only when necessary. To allow some areas to be shut down when unoccupied, install dedicated HVAC systems on continuous loads (e.g. -- computer rooms).
- Provide dedicated outside air supply to kitchens, cleaning rooms, combustion equipment, etc. to avoid excessive exhausting of conditioned air.
- Use evaporative cooling in dry climates.
- Reduce humidification or dehumidification during unoccupied periods.
- Use atomization rather than steam for humidification where possible.
- Clean HVAC unit coils periodically and comb mashed fins.
- Upgrade filter banks to reduce pressure drop and thus lower fan power requirements.
- Check HVAC filters on a schedule (at least monthly) and clean/change if appropriate.
- Check pneumatic controls air compressors for proper operation, cycling, and maintenance.
- Isolate air conditioned loading dock areas and cool storage areas using high-speed doors or clear PVC strip curtains.
- Install ceiling fans to minimize thermal stratification in high-bay areas.
- Relocate air diffusers to optimum heights in areas with high ceilings.
- Consider reducing ceiling heights.
- Eliminate obstructions in front of radiators, baseboard heaters, etc.
- Check reflectors on infrared heaters for cleanliness and proper beam direction.
- Use professionally-designed industrial ventilation hoods for dust and vapor control.
- Use local infrared heat for personnel rather than heating the entire area.
- Use spot cooling and heating (e.g. -- use ceiling fans for personnel rather than cooling the entire area).
- Purchase only high-efficiency models for HVAC window units.
- Put HVAC window units on timer control.
- Don't oversize cooling units. (Oversized units will "short cycle" which results in poor humidity control.)
- Install multi-fueling capability and run with the cheapest fuel available at the time.
- Consider dedicated make-up air for exhaust hoods. (Why exhaust the air conditioning or heat if you don't need to?)
- Minimize HVAC fan speeds.
- Consider desiccant drying of outside air to reduce cooling requirements in humid climates.
- Consider ground source heat pumps.
- Seal leaky HVAC ductwork.
- Seal all leaks around coils.
- Repair loose or damaged flexible connections (including those under air handling units).
- Eliminate simultaneous heating and cooling during seasonal transition periods.
- Zone HVAC air and water systems to minimize energy use.
- Inspect, clean, lubricate, and adjust damper blades and linkages.

- Establish an HVAC efficiency-maintenance program. Start with an energy audit and follow-up, then make an HVAC efficiency-maintenance program a part of your continuous energy management program.

Refrigeration

- Use water-cooled condensers rather than air-cooled condensers.
- Challenge the need for refrigeration, particularly for old batch processes.
- Avoid oversizing -- match the connected load.
- Consider gas-powered refrigeration equipment to minimize electrical demand charges.
- Use "free cooling" to allow chiller shutdown in cold weather.
- Use refrigerated water loads in series if possible.
- Convert firewater or other tanks to thermal storage.
- Don't assume that the old way is still the best -- particularly for energy-intensive low temperature systems.
- Correct inappropriate brine or glycol concentration that adversely affects heat transfer and/or pumping energy.
  If it sweats, insulate it, but if it is corroding, replace it first.
- Make adjustments to minimize hot gas bypass operation.
- Inspect moisture/liquid indicators.
- Consider change of refrigerant type if it will improve efficiency.
- Check for correct refrigerant charge level.
- Inspect the purge for air and water leaks.
- Establish a refrigeration efficiency-maintenance program. Start with an energy audit and follow-up, then make a refrigeration efficiency-maintenance program a part of your continuous energy management program.

Cooling towers

- Control cooling tower fans based on leaving water temperatures.
- Control to the optimum water temperature as determined from cooling tower and chiller performance data.
- Use two-speed or variable-speed drives for cooling tower fan control if the fans are few. Stage the cooling tower fans with on-off control if there are many.
- Turn off unnecessary cooling tower fans when loads are reduced.
- Cover hot water basins (to minimize algae growth that contributes to fouling).
- Balance flow to cooling tower hot water basins.
- Periodically clean plugged cooling tower water distribution nozzles.
- Install new nozzles to obtain a more-uniform water pattern.
- Replace splash bars with self-extinguishing PVC cellular-film fill.
- On old counterflow cooling towers, replace old spray-type nozzles with new square-spray ABS practically-non-clogging nozzles.
- Replace slat-type drift eliminators with high-efficiency, low-pressure-drop, self-extinguishing, PVC cellular units.
- If possible, follow manufacturer's recommended clearances around cooling towers and relocate or modify structures, signs, fences, dumpsters, etc. that interfere with air intake or exhaust.
- Optimize cooling tower fan blade angle on a seasonal and/or load basis.
- Correct excessive and/or uneven fan blade tip clearance and poor fan balance.
- Use a velocity pressure recovery fan ring.
- Divert clean air-conditioned building exhaust to the cooling tower during hot weather.

- Re-line leaking cooling tower cold water basins.
- Check water overflow pipes for proper operating level.
- Optimize chemical use.
- Consider side stream water treatment.
- Restrict flows through large loads to design values.
- Shut off loads that are not in service.
- Take blowdown water from the return water header.
- Optimize blowdown flow rate.
- Automate blowdown to minimize it.
- Send blowdown to other uses (Remember, the blowdown does not have to be removed at the cooling tower. It can be removed anywhere in the piping system.)
- Implement a cooling tower winterization plan to minimize ice build-up.
- Install interlocks to prevent fan operation when there is no water flow.
- Establish a cooling tower efficiency-maintenance program. Start with an energy audit and follow-up, then make a cooling tower efficiency-maintenance program a part of your continuous energy management program.

Lighting

- Reduce excessive illumination levels to standard levels using switching, delamping, etc. (Know the electrical effects before doing delamping.)
- Aggressively control lighting with clock timers, delay timers, photocells, and/or occupancy sensors.
- Install efficient alternatives to incandescent lighting, mercury vapor lighting, etc. Efficacy (lumens/watt) of various technologies range from best to worst approximately as follows: low pressure sodium, high pressure sodium, metal halide, fluorescent, mercury vapor, incandescent.
- Select ballasts and lamps carefully with high power factor and long-term efficiency in mind.
- Upgrade obsolete fluorescent systems to Compact fluorescents and electronic ballasts
- Consider daylighting, skylights, etc.
- Consider painting the walls a lighter color and using less lighting fixtures or lower wattages.
- Use task lighting and reduce background illumination.
- Re-evaluate exterior lighting strategy, type, and control. Control it aggressively.
- Change exit signs from incandescent to LED.

DG sets

- Optimise loading
- Use waste heat to generate steam/hot water /power an absorption chiller or preheat process or utility feeds.
- Use jacket and head cooling water for process needs
- Clean air filters regularly
- Insulate exhaust pipes to reduce DG set room temperatures
- Use cheaper heavy fuel oil for capacities more than 1MW

Buildings

- Seal exterior cracks/openings/gaps with caulk, gasketing, weatherstripping, etc.
- Consider new thermal doors, thermal windows, roofing insulation, etc.
- Install windbreaks near exterior doors.
- Replace single-pane glass with insulating glass.
- Consider covering some window and skylight areas with insulated wall panels inside the building.
- If visibility is not required but light is required, consider replacing exterior windows with insulated glass block.
- Consider tinted glass, reflective glass, coatings, awnings, overhangs, draperies, blinds, and shades for sunlit exterior windows.
- Use landscaping to advantage.
- Add vestibules or revolving doors to primary exterior personnel doors.
- Consider automatic doors, air curtains, strip doors, etc. at high-traffic passages between conditioned and non-conditioned spaces. Use self-closing doors if possible.
- Use intermediate doors in stairways and vertical passages to minimize building stack effect.
- Use dock seals at shipping and receiving doors.
- Bring cleaning personnel in during the working day or as soon after as possible to minimize lighting and HVAC costs.

Water & Wastewater

- Recycle water, particularly for uses with less-critical quality requirements.
- Recycle water, especially if sewer costs are based on water consumption.
- Balance closed systems to minimize flows and reduce pump power requirements.
- Eliminate once-through cooling with water.
- Use the least expensive type of water that will satisfy the requirement.
- Fix water leaks.
- Test for underground water leaks. (It's easy to do over a holiday shutdown.)
- Check water overflow pipes for proper operating level.
- Automate blowdown to minimize it.
- Provide proper tools for wash down -- especially self-closing nozzles.
- Install efficient irrigation.
- Reduce flows at water sampling stations.
- Eliminate continuous overflow at water tanks.
- Promptly repair leaking toilets and faucets.
- Use water restrictors on faucets, showers, etc.
- Use self-closing type faucets in restrooms.
- Use the lowest possible hot water temperature.
- Do not use a central heating system hot water boiler to provide service hot water during the cooling season -- install a smaller, more-efficient system for the cooling season service hot water.
- Consider the installation of a thermal solar system for warm water.
- If water must be heated electrically, consider accumulation in a large insulated storage tank to minimize heating at on-peak electric rates.
- Use multiple, distributed, small water heaters to minimize thermal losses in large piping systems.
- Use freeze protection valves rather than manual bleeding of lines.

- Consider leased and mobile water treatment systems, especially for deionized water.
- Seal sumps to prevent seepage inward from necessitating extra sump pump operation.
- Install pretreatment to reduce TOC and BOD surcharges.
- Verify the water meter readings. (You'd be amazed how long a meter reading can be estimated after the meter breaks or the meter pit fills with water!)
- Verify the sewer flows if the sewer bills are based on them

Miscellaneous

- Meter any unmetered utilities. Know what is normal efficient use. Track down causes of deviations.
- Shut down spare, idling, or unneeded equipment.
- Make sure that all of the utilities to redundant areas are turned off -- including utilities like compressed air and cooling water.
- Install automatic control to efficiently coordinate multiple air compressors, chillers, cooling tower cells, boilers, etc.
- Renegotiate utilities contracts to reflect current loads and variations.
- Consider buying utilities from neighbors, particularly to handle peaks.
- Leased space often has low-bid inefficient equipment. Consider upgrades if your lease will continue for several more years.
- Adjust fluid temperatures within acceptable limits to minimize undesirable heat transfer in long pipelines.
- Minimize use of flow bypasses and minimize bypass flow rates.
- Provide restriction orifices in purges (nitrogen, steam, etc.).
- Eliminate unnecessary flow measurement orifices.
- Consider alternatives to high pressure drops across valves.
- Turn off winter heat tracing that is on in summer.

EFFICIENCY OF ENERGY CONVERSION

The National Energy Strategy reflects a National commitment to greater efficiency in every element of energy production and use. Greater energy efficiency can reduce energy costs to consumers, enhance environmental quality, maintain and enhance our standard of living, increase our freedom and energy security, and promote a strong economy.

(*National Energy Strategy, Executive Summary*, 1991/1992)

Increased energy efficiency has provided the Nation with significant economic, environmental, and security benefits over the past 20 years. To make further progress toward a sustainable energy future, Administration policy encourages investments in energy efficiency and fuel flexibility in key economic sectors. By focusing on market barriers that inhibit economic investments in efficient technologies and practices, these programs help market forces continually improve the efficiency of our homes, our transportation systems, our offices, and our factories.

(*Sustainable Energy Strategy*, 1995)

Our principal criterion for the selection of discussion topics in Chapter 3 was to provide the necessary and sufficient thermodynamics background to allow the reader to grasp the concept of energy efficiency. Here we first want to become familiar with energy conversion devices and heat transfer devices. Examples of the former include automobile engines, hair driers, furnaces and nuclear reactors. Examples of the latter include refrigerators, air conditioners and heat pumps. We then use the knowledge gained in Chapter 3 to show that there are natural (thermodynamic) limitations when energy is converted from one form to another. In Parts II and III of the book, we shall then see that additional technical limitations may exist as well. This is especially true for the practically important conversion of heat to work. Finally, here we quantify efficiency and show why some energy conversion devices are more efficient than others. Higher energy efficiency translates directly into lower energy cost. We shall illustrate this statement in the present chapter and then use the same type of analysis throughout the remainder of the book.

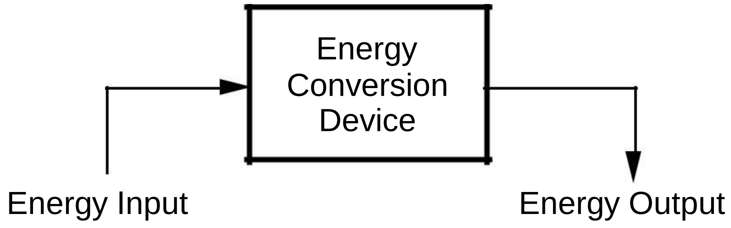
Energy Conversion Devices and Their Efficiency

A device is a piece of equipment that serves a specific purpose. An energy conversion device converts one form of energy into another. It is an important element of progress of society. In fact, one can discuss the history of civilization in terms of landmarks in the development of energy conversion devices, as illustrated below:

Landmark Event	*Approximate Date*
Emergence of man	4,000,000 B.C.
Emergence of human civilization	5000 B.C.
Development of the water wheel	350 A.D.
Development of the windmill	950 A.D.
Invention of the cannon	1318 A.D.
Development of first atmospheric steam engine (Newcomen)	1712 A.D.
Development of modern steam engine (Watt)	1765 A.D.
Development of high-pressure steam engine (Trevithick)	1802 A.D.
Development of the automobile engine (Daimler)	1884 A.D.
Operation of first nuclear power plant	1954 A.D.

The Industrial Revolution began when James Watt invented the steam engine in 1765; today we live in the “nuclear age,” marked by the existence of devices (reactors or bombs) that convert nuclear energy into other energy forms.

An energy conversion device is represented schematically in Figure 4-1. It may be a very simple gadget, such as an electric toy automobile (which converts electricity into mechanical energy), or a very complex machine, such as an automobile engine (which converts the chemical energy of gasoline into mechanical energy). As shown in Figure 3-3 for systems in general, these devices will be pretty much black boxes for us. We shall not place undue emphasis on how they work; we shall concentrate on *what* they accomplish. In other words, energy supply (output) and demand (input), at this microscale, will be our focus. This is illustrated in Figure 4-1. Energy supply and demand at the macroscale (United States and the world), which will be the focus of our discussion in Parts II and III of the book, are very much dependent on the balance between energy input and output in the devices that we use in our homes and at work.



Energy Output = Energy Input   (1st Law)

Useful Energy Output   Energy Input   (2nd Law)

FIGURE 4-1. Schematic representation of an energy conversion device.

The efficiency of an energy conversion device is a quantitative expression of this balance between energy input and energy output. It is defined as follows:

$$\text{Device efficiency} = \frac{\text{Useful energy output}}{\text{Energy input}}$$

The key word in the above definition is ‘useful’. Were it not for this word, of course, the definition would be trivial, as shown in Figures 3-3 and 4-1. The First Law of Thermodynamics tells us that energy is conserved in all its transformations. So the ratio of energy output to energy input is always unity, or 100%.

The meaning of the word ‘useful’ depends on the purpose of the device. For example, if the device is an electric heater, the useful energy output is heat, and the energy input is electricity. Electricity is converted to heat. Heat is also obtained from electricity in a light bulb, as we well know. But this is *not* the useful energy obtained from a light bulb; the purpose of a light bulb is to convert electricity into light. Table 4-1 summarizes the useful energy output and energy input for some common energy conversion devices. Figures 4-2 and 4-3 are illustrations of how to use the information provided in Table 4-1 for the case of two ubiquitous devices, an electric motor and a furnace. We may know, or may be interested in knowing, how they work, but this is not necessary for our purposes. For becoming an energy-informed and (perhaps more importantly) energy-conscious member of society, all one needs is the information provided in Table 4-1.

TABLE 4-1
Tasks performed by common energy conversion devices

Energy Conversion Device	Energy Input	Useful Energy Output
Electric heater	Electricity	Thermal energy
Hair drier	Electricity	Thermal energy
Electric generator	Mechanical energy	Electricity
Electric motor	Electricity	Mechanical energy
Battery	Chemical energy	Electricity
Steam boiler	Chemical energy	Thermal energy
Furnace	Chemical energy	Thermal energy
Steam turbine	Thermal energy	Mechanical energy
Gas turbine	Chemical energy	Mechanical energy
Automobile engine	Chemical energy	Mechanical energy
Fluorescent lamp	Electricity	Light
Silicon solar cell	Solar energy	Electricity
Steam locomotive	Chemical	Mechanical
Incandescent lamp	Electricity	Light

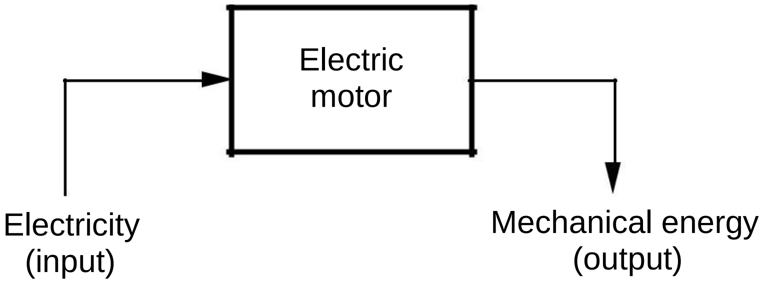


FIGURE 4-2. Energy conversion in an electric motor (electric-to-mechanical).

Illustration 4-1. An electric motor consumes 100 watts (W) of electricity to obtain 90 watts of mechanical power. Determine its efficiency (E).

Solution.
Because power is the rate of energy utilization, efficiency can also be expressed as a power ratio. The time units cancel out, and we have

$$\text{Efficiency} = \frac{\text{Useful energy output}}{\text{Energy input}} = \frac{\text{Useful power output}}{\text{Power input}}$$

Therefore, the efficiency of this electric motor is:

$$E = \frac{\text{Mechanical energy (power) output}}{\text{Electric energy (power) input}} =$$

$$= \frac{90\text{ W}}{100\text{ W}} = \frac{90\ \frac{\text{J}}{\text{s}}}{100\ \frac{\text{J}}{\text{s}}} = \frac{90\text{ J}}{100\text{ J}} = 0.9 = 90\%$$

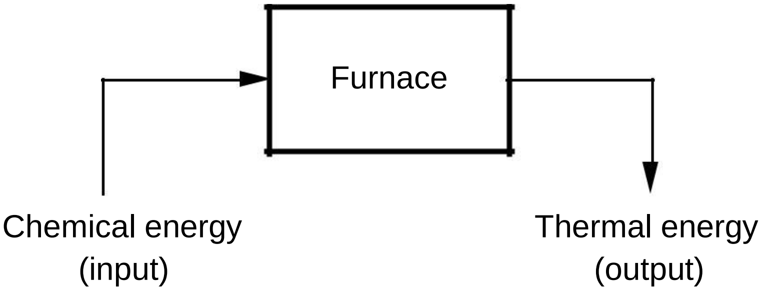


FIGURE 4-3. Energy conversion in a furnace (chemical-to-thermal).

Illustrations 4-1 and 4-2, while very simple, should be studied carefully. They carry two important messages. First, the efficiency of an energy conversion device is a *quantitatively* unitless (or dimensionless) number between 0 and 1 (or between 0 and 100%). Obviously, the larger this number is, the higher the efficiency of the device will be; however, a number greater than one would contradict the First Law of Thermodynamics. The second message is both formal and substantive. Its formal part has to do with the cancellation of units (see

- 15-17). It is not sufficient to convert energy quantities into the same units, for example BTU to joules or calories to kilowatthours. The units must also be of the *same energy form*. It is not possible, for example, to cancel out chemical BTU and thermal BTU. In substantive terms, the efficiency is not a *qualitatively* unitless number. Even when its units are not explicitly stated, as in Illustration 4-1, we should remember what they are, from knowledge of the device's function (as shown in Table 4-1 and illustrated in Figures 4-1, 4-2 and 4-3).

Illustration 4-2. A gas furnace has an efficiency of 75%. How many BTU will it produce from 1000 BTU of natural gas.

Solution.
The function of a gas furnace is to convert the chemical energy of the gas into heat (thermal energy), as shown in Table 4-1 and illustrated in Figure 4-3.

Therefore, we have:

$$\text{Useful energy output} = [\text{Energy input}]\ [\text{Efficiency}]$$

$$= [1000\ \text{BTU (chemical energy)}]\ \left[\frac{75\ \text{BTU (thermal energy)}}{100\ \text{BTU (chemical energy)}}\right]$$

$$= 750\ \text{BTU (thermal energy)}$$

The concept of efficiency thus embodies both laws of thermodynamics. It reflects the quantitative equality and the qualitative difference of the various energy forms. Its understanding requires some knowledge of thermodynamics; once understood, it is only this concept – from the entire field of thermodynamics – that is necessary for understanding the principal energy issues facing society today.

Table 4-2 summarizes the energy efficiencies of a number of common energy conversion devices. They are listed in order of decreasing efficiency. The numbers shown are typical but they can be different for different models of the same type of device (depending on details of its design) or for the same device, depending on whether it is used and maintained properly. For example, your car engine will be more efficient if you change the oil regularly.

Why some numbers are high and others are low can be understood, at least in part, from the information provided in Chapter 3. The ‘easiest’ conversions are those that are in the direction of increasing entropy, and in particular those that produce heat (thermal energy). We just need to rub our hands and convert mechanical energy into heat. So the electric drier and the electric heater are very efficient. Home furnaces also produce heat, but gas furnaces are typically more efficient than oil furnaces, which in turn are often more efficient than coal furnaces. The reason for this is that it is easiest to burn the gas completely within the furnace, and it is most difficult to burn coal. In other words, the largest part of the chemical energy of the gas ends up as useful heat in our home. This is discussed in more detail in Chapters 6-9. Note also the low efficiencies of such common devices as the steam turbine and automobile engine. The reason for this is explored next.

TABLE 4-2

Efficiencies of common energy conversion devices

Energy Conversion Device	Energy Conversion	Typical Efficiency, %
Electric heater	Electricity/Thermal	100
Hair drier	Electricity/Thermal	100
Electric generator	Mechanical/Electricity	95
Electric motor (large)	Electricity/Mechanical	90
Battery	Chemical/Electricity	90
Steam boiler (power plant)	Chemical/Thermal	85
Home gas furnace	Chemical/Thermal	85
Home oil furnace	Chemical/Thermal	65
Electric motor (small)	Electricity/Mechanical	65
Home coal furnace	Chemical/Thermal	55
Steam turbine	Thermal/Mechanical	45
Gas turbine (aircraft)	Chemical/Mechanical	35
Gas turbine (industrial)	Chemical/Mechanical	30
Automobile engine	Chemical/Mechanical	25
Fluorescent lamp	Electricity/Light	20
Silicon solar cell	Solar/Electricity	15
Steam locomotive	Chemical/Mechanical	10
Incandescent lamp	Electricity/Light	5

Heat Engines and System Efficiency

The Industrial Revolution began with the invention of a heat engine (the steam engine). We live today in the era of revolutions in electronics and communications, but the heat engine continues to play a key role in modern society. It converts heat to work. It deserves our special attention.

In Chapter 3 we explored the natural limitations in the conversion of heat to work. Simply stated, this energy conversion goes against nature and nature imposes a ‘tax’ on it. Part of the energy input is wasted. It is used to increase the entropy of the surroundings.

Therefore, the useful energy output is necessarily smaller than the energy input. In other words, the efficiency of a heat engine is always less than 100%.

A logical question to ask at this point is: why are heat engines so important in our society? The answer was anticipated in Figure 3-1. Even though most of the energy on our planet comes directly from the sun, we do not know how to harness solar energy directly and efficiently. (Some progress is being made, however, as we shall see in Chapter 17.) Instead we have to rely on the chemical energy of fossil fuels for most of our energy needs. The problem with chemical energy is that it is a potential energy form; so it must be converted to other forms before we can use it. The only way we know to exploit this stored solar energy is to release it by burning the fossil fuels. This process is called combustion and it is described in more detail in Chapter 6. The chemical energy of fossil fuels is thus converted to heat, and it is primarily this heat that we use in heat engines to obtain work.

Most heat engines use a fossil fuel, or a product derived from it – such as natural gas, coal or gasoline – to provide the heat, which is then converted to work. So, in essence, they consist of two sub-systems, as illustrated in Figure 4-4. We thus need to introduce the concept of *system efficiency*. By a system here we again mean a well-defined space (see p.

- in which not one, but at least two energy conversions take place. It consists of two or more energy conversion devices.

The efficiency of a system is equal to the product of efficiencies of the individual devices (sub-systems).

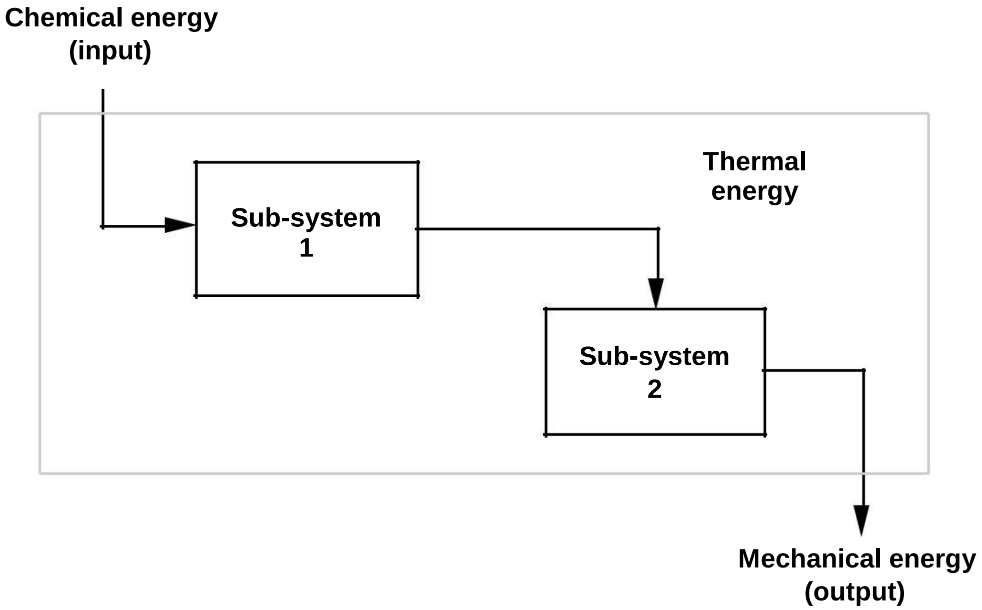


FIGURE 4-4. Energy conversion in a heat engine.

Illustration 4-3. Calculate the efficiency of a power plant if the efficiencies of the boiler, turbine and generator are 88, 40 and 98%, respectively.

Solution.

$$E_{\text{power plant}} = [E_{\text{boiler}}]\,[E_{\text{turbine}}]\,[E_{\text{generator}}] =$$

$$= (0.88)\,(0.40)\,(0.98) = 0.35\ (35\%)$$

Note that the efficiency of the system is lower than any one of the efficiencies of the individual components of the system. In the case of this electric power plant, only 35% of the chemical energy input is converted to electricity. The rest is lost to the environment, mostly as heat (to keep nature happy, by satisfying the Second Law of Thermodynamics).

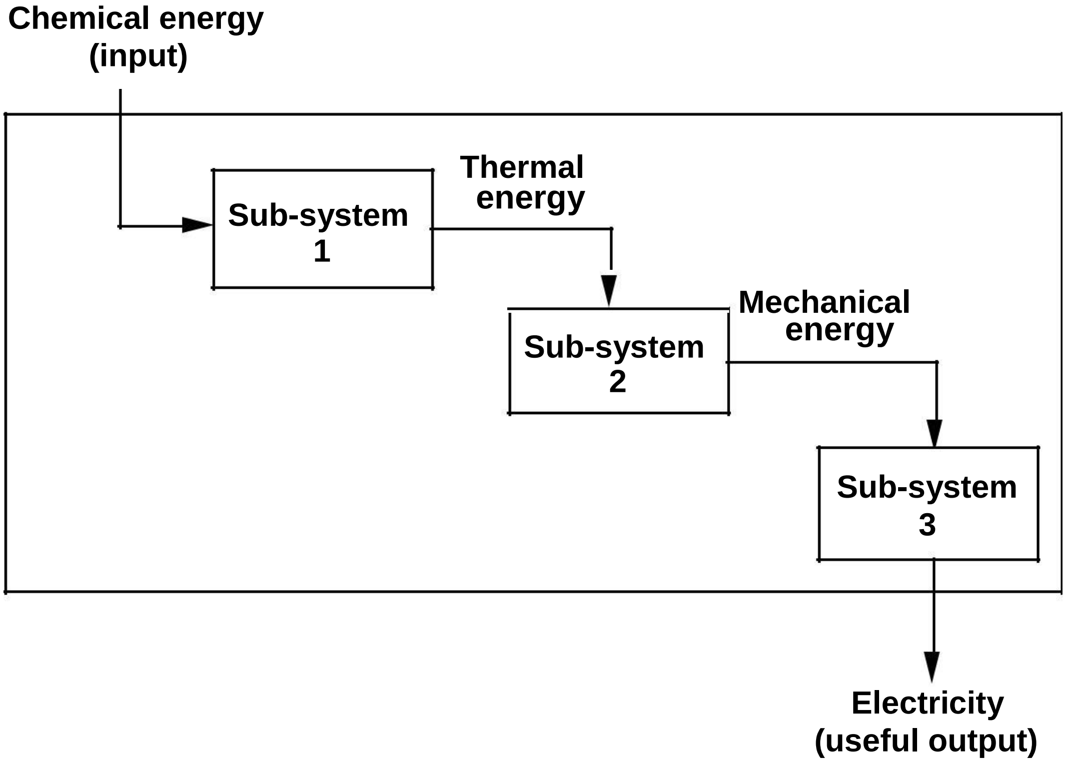


FIGURE 4-5. Energy conversion in an electric power plant.

One of the most important energy conversion systems in our modern society is the electric power plant. It is shown schematically in Figures 4-5 and 4-6. The chemical energy is first converted to thermal energy in the boiler; thermal energy is then converted to mechanical energy in the turbine; finally, mechanical energy is converted to electricity in the generator. System efficiency is, therefore,

$$E_{\text{power plant}} = [E_{\text{boiler}}]\,[E_{\text{turbine}}]\,[E_{\text{generator}}] =$$

$$= \left[\frac{\text{Thermal energy}}{\text{Chemical energy}}\right]\left[\frac{\text{Mechanical energy}}{\text{Thermal energy}}\right]\left[\frac{\text{Electric energy}}{\text{Mechanical energy}}\right] = \frac{\text{Electric energy}}{\text{Chemical energy}}$$

The heart (and the 'bottleneck', as we shall see) of the electric power plant is the boiler. It is shown in Figure 4-7. In the boiler a fuel is burned and the heat from the hot combustion products is transferred to the water that flows through the tubes surrounding the combustion chamber. The water boils and is converted to steam. The steam reaches a high temperature and a high pressure, of the order of 1000 °F and 1000 pounds per square inch (roughly sixty times greater than atmospheric pressure); it contains a lot of thermal energy. This steam is directed to the turbine, which consists of a bladed wheel set on a shaft. The impulse of the high-velocity steam causes the rotation of the blades of the turbine, which in turn causes the rotation of the shaft. In this process, the steam becomes 'exhausted'; it loses its energy, and its temperature decreases. It is transformed back to water in the condenser and recirculated into the boiler to repeat the cycle. The rotation of the shaft of the turbine within a magnetic field of the electric generator produces electricity, according to the principles of electromagnetic induction. We need not elaborate this statement further; consider the generator to be a black box that converts mechanical energy to electricity.

The elaborate water cooling system, shown in Figure 4-6, is a necessary component of the power plant. In fact, when a cooling tower is used for this purpose, as shown in Figure 4-6, it is the most prominent part of the plant. It satisfies the Second Law of Thermodynamics, as discussed in Chapter 3. The entropy decreases within the power plant (within system limits shown in Figure 4-5). So it must increase in the surroundings; the surroundings in this case are the river and the atmosphere, as shown in Figure 4-6, whose temperature increases.

It is the temperature decrease between the steam in the boiler and the water in the condenser that provides the energy for the conversion of heat to work in the turbine. To understand how this happens, the following analogy is helpful even though it is not totally valid (p. 45).

Consider the water wheel in Figure 4-8. It converts the potential energy of the falling water into the mechanical (or kinetic) energy of the wheel shaft. On the basis of the discussion in Chapter 3, we know that the design shown in Figure 4-8a is not very efficient. Only a limited conversion of potential energy to kinetic energy occurs before the water hits the wheel. The arrangement shown in Figure 4-8b is much more efficient. It takes advantage of the conversion of most of the water's potential energy to kinetic energy. The analogy of this situation with the conversion of heat to work is illustrated in Figure 4-

- Water at high level falls to a lower level and loses some of its potential energy, which is converted to kinetic energy. In other words, the “driving force” for the conversion of potential energy to kinetic energy is the difference in height of the two water reservoirs. Water at high temperature (for example, steam) ‘falls’ to a lower temperature level (for example, liquid water) and loses some of its thermal energy, which is converted to mechanical energy. Therefore, the driving force for the conversion of heat to work is the temperature difference between the two thermal reservoirs. The larger this driving force, the greater the conversion of potential energy to kinetic energy, and of heat to work.

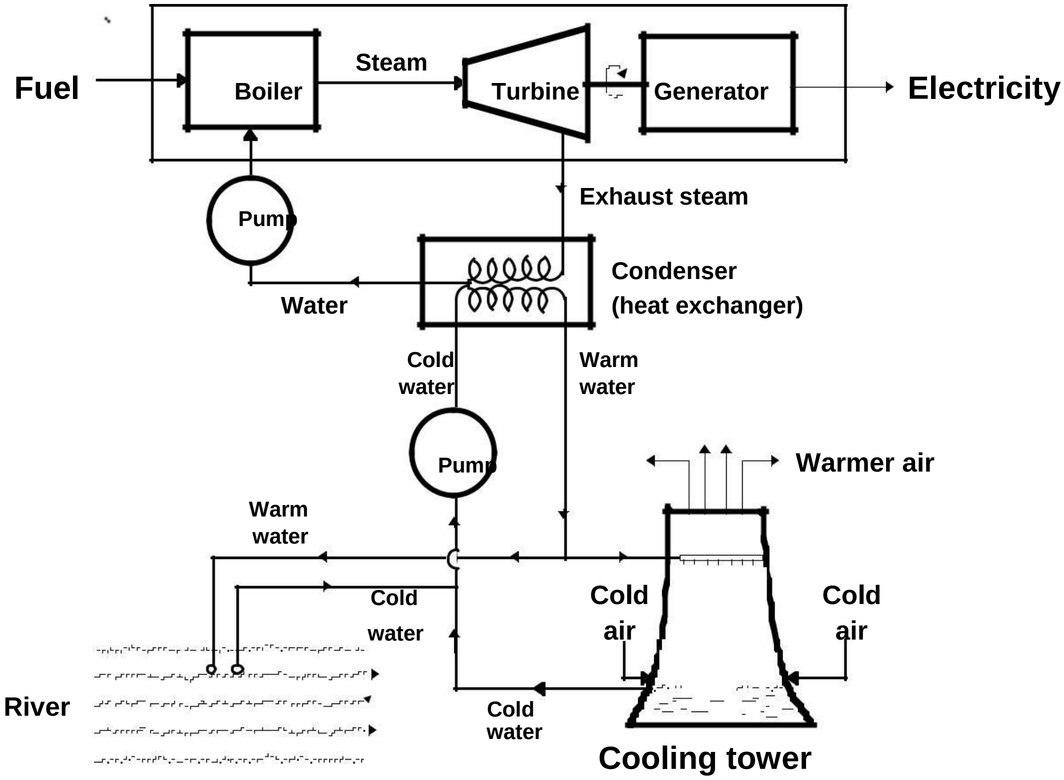


FIGURE 4-6
Schematic representation of an electric power plant.

FIGURE 4-7. Schematic representation of a steam boiler. [Source: Fowler, op. cit.]

Figure 4-10 is a schematic representation of a heat engine. Any “working fluid” can be used, not necessarily water, but water is commonly used because of its availability and convenience. All we really need to know to determine the (maximum) efficiency of the engine are the high temperature (T_H) and the low temperature (T_L) of the two reservoirs.

FIGURE 4-8. Energy conversion (from potential to kinetic) in a water wheel.

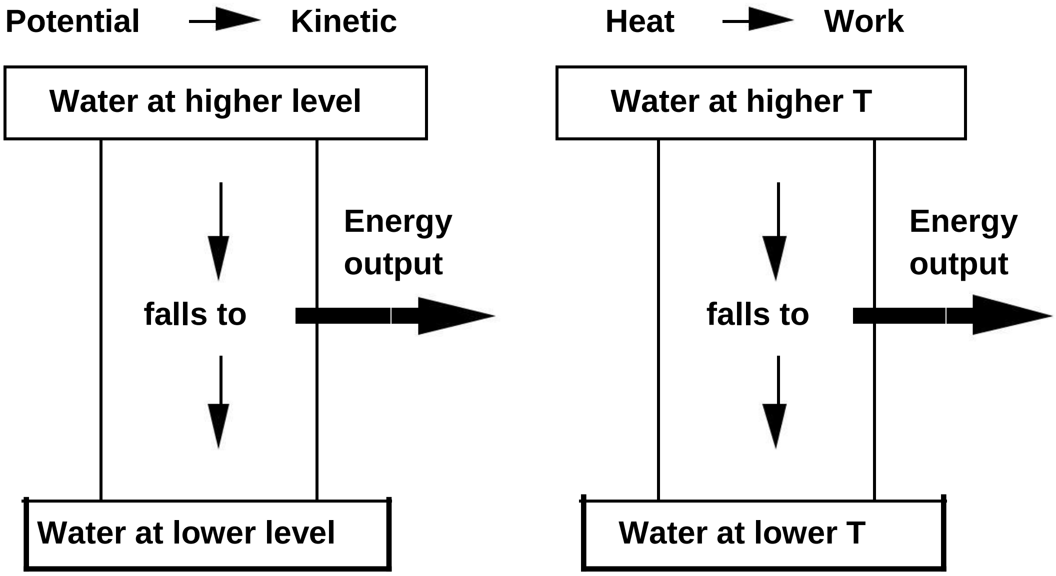


FIGURE 4-9. Analogy between energy conversion in a water wheel and a heat engine.

FIGURE 4-10. Schematic (thermodynamic) representation of a heat engine.

From thermodynamic analysis, which we do not need to go into, it is possible to define the *maximum (or ideal) heat engine efficiency* (E_{max}).

$$E_{max} = \frac{\text{Maximum useful work output}}{\text{Energy input}} = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$$

Illustration 4-4. In a power plant, the steam from the boiler reaches the turbine at a temperature of 700 °C. The spent steam leaves the turbine at 100 °C. Calculate the maximum efficiency of the turbine. Compare it to the typical value listed in Table 4-2.

Solution.
From the above expression and noting that 700 °C = 973 K and 100 °C = 373 K, we have:

$$E_{max} = \frac{973\ \text{K} - 373\ \text{K}}{973\ \text{K}} = 1 - \frac{373}{973} = 0.62\ \ (62\%)$$

This is, as expected, larger than the typical efficiency of about 45% shown in Table 4-2.

Here the temperatures are expressed in absolute units. Two important consequences of this definition need to be emphasized: (1) the maximum efficiency increases with decreasing T_L, reaching 100% only when $T_L = 0$ K; and (2) the difference $T_H - T_L$ is in the numerator and the larger it is, the higher the efficiency will be.

Illustration 4-5. An automobile engine could operate between 2200 °C (the combustion temperature of gasoline) and 20 °C (ambient temperature). If it did, what would its maximum efficiency be? Compare this value to that shown in Table 4-2, for a typical car engine.

Solution.

$$E_{max} = \frac{2473\text{ K} - 293\text{ K}}{2473\text{ K}} = 1 - \frac{293}{2473} = 0.88 \ \ (88\%)$$

This values is much higher than that of a typical engine (25%). In Chapter 20, we shall come back to this issue.

Heat Transfer Devices and Their Efficiency

In contrast to energy conversion devices, which convert one energy form into another, the energy transfer devices just transfer the *same* form of energy from one place to another. Here we shall only be interested in devices that transfer heat. We call them heat movers. The refrigerator, air conditioner and heat pump are familiar examples that we shall analyze in more detail here.

Let us examine the refrigerator. We know that it consumes energy, because it is plugged into the electric outlet. What does it do with the electricity? Well, we also know that it is cold inside the refrigerator, say 10 °C. In the freezer, it is even colder, say -5 °C. The air in the kitchen is at about 25 °C. Hence, the refrigerator uses energy to maintain its temperature lower than that of the surroundings. When we open the door of the refrigerator, heat flows spontaneously from the kitchen to the refrigerator. The electric energy consumed by the refrigerator is used to reverse this process, to pump heat from inside (low-temperature reservoir or ‘source’) to the outside air (high-temperature reservoir or ‘sink’). This is illustrated in Figure 4-11.

The air conditioner and the heat pump accomplish exactly the same task as the refrigerator. This is illustrated in Figure 4-12. They pump heat ‘uphill’, from T_L to T_H. In the case of the air conditioner, the sink is the air inside the house (say, at 60 °F), and the source is the outside air (say, at 90 °F).

The heat pump is an energy transfer device that may be very convenient for residential comfort in certain geographical areas. There are two heat exchangers instead of one (a condenser and an evaporator instead of just a condenser). A special liquid (freon or antifreeze) is used as the working fluid because water would, of course, freeze in winter. In winter, its T_L is the outdoor air (say, at 20 °F), and T_H is the indoor air (say, at 65 °F). Electricity is used to increase the energy of this liquid, by compressing it, and the compressed liquid delivers this energy to the house by condensing in the internal heat exchanger. The external heat exchanger is necessary to bring it back into the gaseous state (by evaporation) so that it can be compressed again and the cycle repeated. In summer, the pump functions as an air conditioner, with T_L being the inside air and T_H the outside air. The interior heat exchanger is now the evaporator and the exterior one is the condenser. Evaporation is a process that requires energy input. So the warm inside air flows past this freon evaporator, it transfers to it some of its energy and thus becomes cooler.

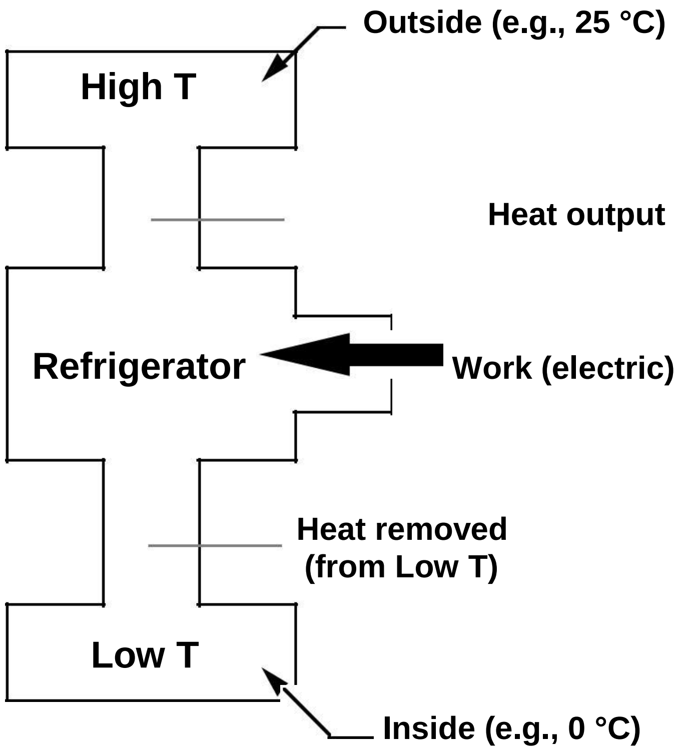


FIGURE 4-11. Schematic (thermodynamic) representation of a refrigerator.

FIGURE 4-12. Schematic (thermodynamic) representation of a heat mover.

The efficiency of a heat mover is called the *coefficient of performance,* or COP. The reason for this will be apparent soon. It is defined in the same way as the efficiency of an energy conversion device:

$$\mathrm{COP} = \frac{\text{Useful energy output}}{\text{Energy input}}$$

There is one important difference between energy conversion devices and energy transfer devices. In a conversion device, only a portion of the energy input is obtained as useful energy output, and the efficiency is necessarily a number between zero and one. In a transfer device, the useful energy output is the quantity of heat extracted from T_L, and this is not a portion of the energy input. In fact, the useful energy output can exceed the energy input, and this is why heat pumps can be extremely attractive for space heating purposes. So the coefficient of performance (sometimes also called “energy efficiency ratio”) can be a number larger than one and this does not violate the First Law of Thermodynamics. Obviously, the larger it is, the more efficient the heat mover will be.

From thermodynamic analysis, which again we do not need to go into, it is possible to define the *maximum (or ideal) coefficient of performance* ($\mathrm{COP}_{\mathrm{max}}$). The definition depends on whether the heat mover is used as a heater or as a cooler. If it is a heater, then the definition is:

Illustration 4-6. Determine the coefficient of performance of a refrigerator that consumes 800 watts of power to remove heat at a rate of 5 BTU per second.

Solution.

$$\text{COP} = \frac{\text{Useful energy output}}{\text{Energy input}} = \frac{5\ \frac{\text{BTU}}{\text{s}}}{800\ \text{W}} = \frac{5\ \frac{\text{BTU}}{\text{s}}}{800\ \frac{\text{J}}{\text{s}}}\ \frac{1055\ \text{J}}{1\ \text{BTU}} = 6.6$$

The meaning of this number is that for every watt of electric power used to drive this heat mover, 6.6 watts of heat are delivered to the high-temperature reservoir (air in the kitchen) and 5.6 watts are extracted from the low-temperature reservoir (refrigerator).

$$\text{COP}_{\text{max}} = \frac{T_H}{T_H - T_L}$$

If the mover is a cooler, then the definition is:

$$\text{COP}_{\text{max}} = \frac{T_L}{T_H - T_L}$$

As in the case of maximum efficiency, the temperature in these definitions has to be expressed in absolute units (kelvin, K).

This may sound unnecessarily complicated, but here is the “bottom line.” In contrast to the maximum efficiency of a conversion device, note that the temperature difference (T) between the two reservoirs is in the denominator of the above expressions. This has very important practical implications. For a conversion device, the larger the T is, the more efficient it will be. For a heat mover, the opposite is true: the smaller the T is, the more efficient it will be. Obviously, a refrigerator ‘works’ more on a hot summer day when the kitchen temperature is 95 °F than on a winter day when the kitchen temperature is 65 °F.

Illustration 4-7 shows that the heat pump is a better buy in milder climates. Typical COP values of heat pumps are much lower than the ideal ones, and may be as low as 3-4.

Comparison of Efficiencies

Now that we have introduced all the thermodynamics that we need, we can illustrate its usefulness in comparing energy alternatives. For example, let us consider the case of electric home heating using different primary energy sources. We have a common useful energy output (electric home heating), and we are evaluating the most important alternatives

Illustration 4-7. Compare the heating efficiencies (maximum COP) of the same heat pump installed in Miami and in Buffalo. In Miami, since the climate is milder, assume that T_H is 70 °F and that T_L is 40 °F. In Buffalo, assume that T_H is the same, but that T_L (the outside temperature) is much lower, say (on average), 15 °F.

Solution.

The temperatures, converted into kelvins, are the following: 70 °F = 294 K; 40 °F = 277 K; 15 °F = 263 K. Since the heat pump is used as a heater, we have the following expression for the maximum COP:

$$\text{Miami: } \text{COP}_{\max} = \frac{T_H}{T_H - T_L} = \frac{294}{294 - 277} = 17.3$$

$$\text{Buffalo: } \text{COP}_{\max} = \frac{294}{294 - 263} = 9.5$$

available as energy input (coal, petroleum and natural gas). This is illustrated in Figure 4-

- The only way to produce electricity commercially from these primary sources is to convert their chemical energy to heat, then heat to work, and finally work to electricity (see Figure 4-5). Now, before we can use these primary sources in a power plant, they need to be extracted from the earth, processed and transported. This is illustrated in Figure 4-14 and described in some detail in Chapters 7-9. The efficiencies of each one of these operations are different and their estimates are shown in Figure 4-14. Once these fuels reach the power plant, the efficiency of conversion of their chemical energy to electricity is approximately the same, if the power plant is designed to burn that particular fuel.

Once produced at the power plant, electricity needs to be transported to our homes. The efficiency of this operation is relatively high, say, about 90%. When it reaches our homes, electricity is converted to heat at 100% efficiency because this is a conversion of low-entropy energy to high-entropy energy. So the overall (system) efficiencies for the three cases considered are calculated as follows:

$$E_{\text{coal}} =$$

$$[E_{\text{extraction}}]\,[E_{\text{processing}}]\,[E_{\text{transport}}]\,[E_{\text{power plant}}]\,[E_{\text{transmission}}]\,[E_{\text{electric heater}}]$$

$$= (0.66)\,(0.92)\,(0.98)\,(0.35)\,(0.90)\,(1.00) = 0.19 \quad (19\%)$$

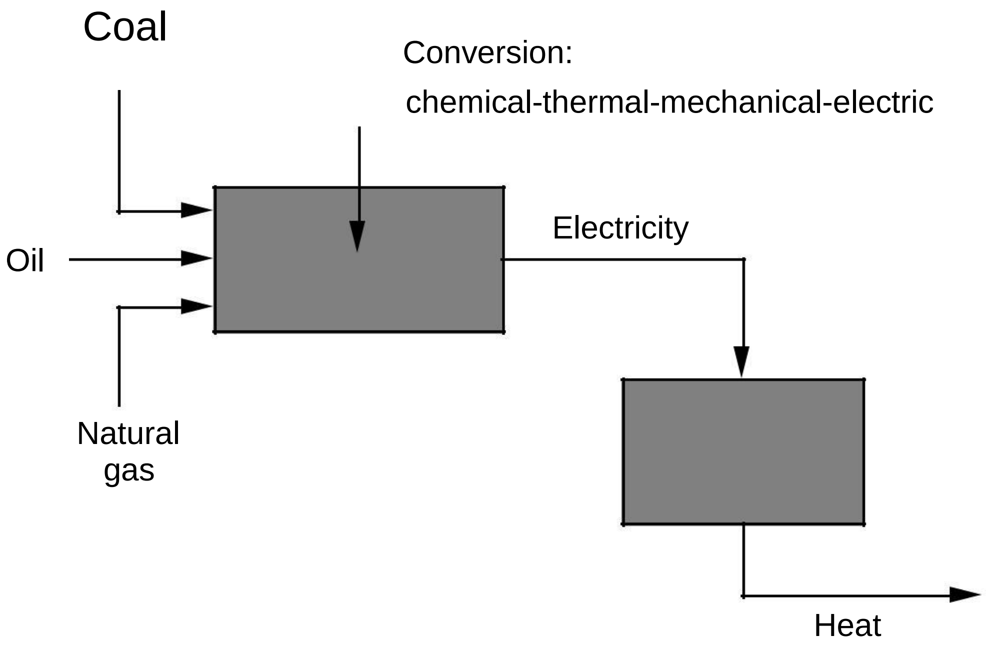


FIGURE 4-13
Analysis of electric home heating using different primary energy sources.

E_{oil} =

- $[E_{extraction}]\ [E_{processing}]\ [E_{transport}]\ [E_{power\ plant}]\ [E_{transmission}]\ [E_{electric\ heater}]$
- (0.35) (0.88) (0.95) (0.35) (0.90) (1.00) = 0.09 (9%)

E_{gas} =

- $[E_{extraction}]\ [E_{processing}]\ [E_{transport}]\ [E_{power\ plant}]\ [E_{transmission}]\ [E_{electric\ heater}]$
- (0.73) (0.97) (0.95) (0.35) (0.90) (1.00) = 0.21 (21%)

These results mean that in our homes we have available only 21, 19 and 9% of the chemical energy of natural gas, coal and petroleum, respectively. The rest is wasted. From this simple analysis, we can reach an important conclusion about the use of coal, oil and natural gas in power plants (if the efficiencies given in Figure 4-14 are correct). Primarily because of the low thermodynamic efficiency of oil extraction (35%, compared to 66 and 73% for extraction of coal and natural gas), it makes more (technical) sense to use coal or natural gas than to use oil. This is the conclusion that a utility executive would reach if he or she were concerned about the optimum allocation of fossil fuels.

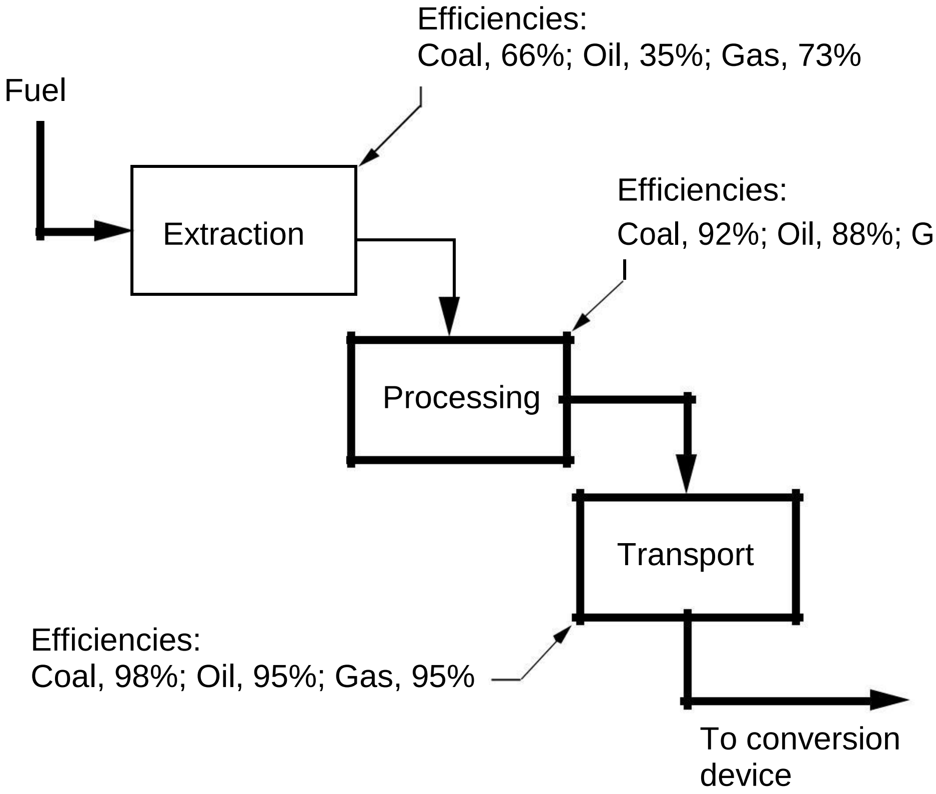


FIGURE 4-14. Schematic (thermodynamic) representation of fuel preparation for use in an energy conversion device. Typical efficiencies are also included.

Note also that all the efficiencies are relatively low. It is convenient to use electric heating in our homes, but we see that it is thermodynamically inefficient. We shall see later that it is also quite expensive. And if we stop to think about it for a minute, it really makes sense that it should be inefficient. What are we doing in the scheme shown in Figure 4-13? First we burn the fuels to obtain heat, which is what we want in the first place, and then we convert that heat to electricity and finally electricity back to heat. If we remove this convenient but inefficient constraint, the situation changes. This is illustrated in Figure 4-

- Now we are interested in using the various fossil fuels to heat our homes directly. The conversion of chemical energy to thermal energy is accomplished in a furnace. Typical efficiencies of coal, oil and gas furnaces are given in Table 4-2. So, the system efficiencies are now obtained as follows:

$$E_{coal} =$$

$$= [E_{extraction}]\ [E_{processing}]\ [E_{transport}]\ [E_{furnace}] =$$

$$= (0.66)\ (0.92)\ (0.98)\ (0.55) = 0.33 \quad (33\%)$$

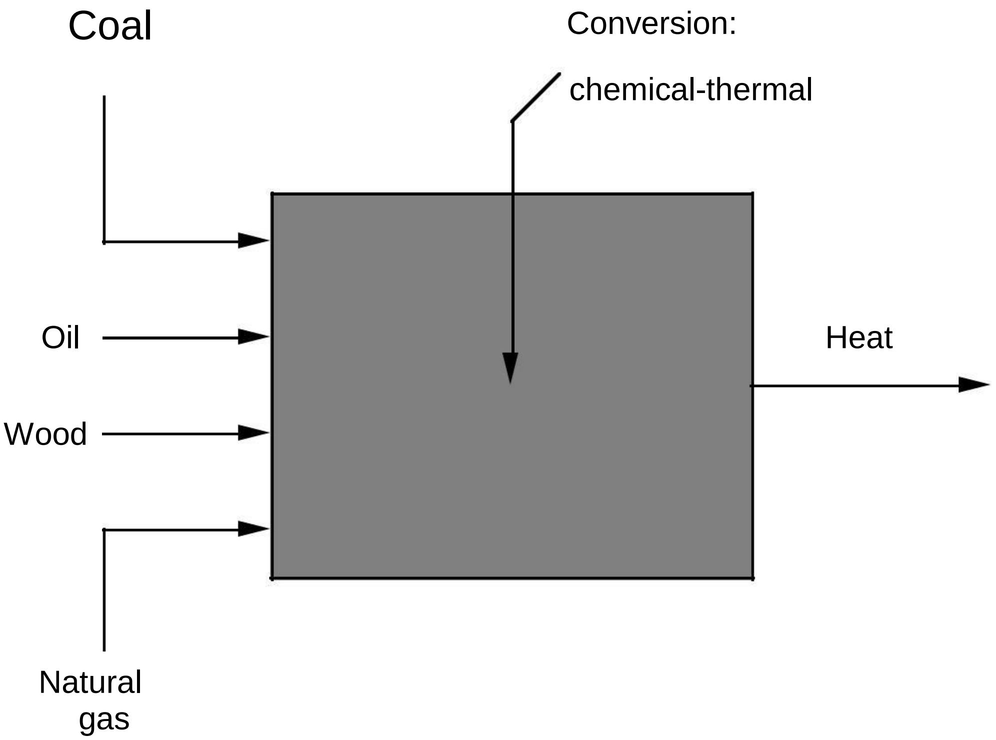


FIGURE 4-16. Analysis of home heating using different primary energy sources. (Wood is also included, mostly as an aesthetic complementary fuel, but not a major source of energy in modern society.)

$$E_{oil} =$$

$$= [E_{extraction}]\ [E_{processing}]\ [E_{transport}]\ [E_{furnace}] =$$

$$= (0.35)\ (0.88)\ (0.95)\ (0.65) = 0.19 \quad (19\%)$$

$$E_{gas} = [E_{extraction}]\,[E_{processing}]\,[E_{transport}]\,[E_{furnace}] = (0.73)\,(0.97)\,(0.95)\,(0.85) = 0.57 \quad (57\%)$$

Now, natural gas turns out to be a clear (thermodynamic) winner, with by far the highest efficiency.

The calculations shown above are meant to accomplish two objectives. First, they illustrate an important fact: among the fossil fuels, natural gas is the most attractive one for home heating purposes. Second, they illustrate the usefulness and power of the concept of efficiency. We do not need to know any details of the technology used to bring energy to our homes; if we know the various efficiencies, we can assess the relative technical merits of the different methods available. And what is more important, as we shall see later, we can also assess their relative economic merits. Therefore, the theoretical development that we conclude here (at last, the reader may say!) was not an academic exercise. Now we are ready to make *practical use* of this simple thermodynamic tool.

Energy Conservation in Domestic Sector for Better Utilization of Power – Indian Context

Abstract: There is a wide gap in the supply and demand of power in India and bridging the gap by installing new power stations is not going to take place in near future. The other alternative is to conserve every watt of energy. Energy conservation in domestic sector is a good point to start as about 20% of the total energy generated is utilized for domestic purpose, which is a considerable share. In this paper Indian electrical market and domestic power utilization are critically analyzed with respect to cost, efficiency and need and various methods to conserve the energy are suggested without much investment and sacrifice of comfort.

- **INTRODUCTION**

Electrical Energy is undisputedly the most vital element for industrial growth of any country. India is one of the many developing countries, which is suffering from acute power shortages. Almost all the states of India are not able to manage the demand from the three main sectors, viz. domestic, agriculture and industrial sectors. The recent industrial growth due to economic reforms further worsened the situation. This results in exhaustion of fossil fuels and causes ecological imbalance. Various factors including political pressures resulted in irrational distribution of the power among the various sectors, giving higher priority to domestic sector at the cost of the other two sectors.

Domestic power consumption in India takes about 1/5th of the total power consumption, which is substantially high. Previously the power was subsidized in all the states of India and people (mis)used power liberally without worrying about efficiency of the appliances. Because of the economic reforms, the subsidy is being withdrawn in power sector in a phased manner throughout India and the power tariff is steadily increasing and the people began to realize the need for energy conservation. Even the Government of India made an act for energy conservation in 2001, which shows the seriousness of the power situation. Since domestic sector use the power in variety of applications, this is a potential area to be considered for energy optimization. By reducing the domestic energy consumption, the other sectors will get more power thereby helping the country to prosper further. As a side effect, it improves the ecological balance (Narasimham, S.V.L, Dr , and Ramalinga Raju, M, 2001.)also. In this connection an analysis is made on the consumers’ choice and various measures are suggested in this paper to improve energy efficiency. Andhra Pradesh – a state of India, which has a population of about 70 millions, is considered for statistics, which represent the general conditions of any other state in India.

• DOMESTIC POWER CONSUMPTION IN ANDHRA PRADESH

Andhra pradesh per capita consumption statewide is 480KWH per annum. Tables1 and 2 show the growth of domestic consumers and their connected load in the last 5 years (International Copper Promotion Council (India), Hand Book, 2001) and consumption pattern of the power in domestic sector (Chaudhary S.R., 2002.).

Year	***No. of Consumers (Connections)***	***Connected Load (Mw)***	***% Growth in connected load***
1996-97	6,803,038	3756	
1997-98	7,300,553	4028	7.34
1998-99	7,694,653	4246	5.4
1999-00	8,124,786	5039	18.67
2000-01	10,258,475	6327	25.56

Table 1: Growth of domestic consumers & connected load in Andhra Pradesh

Application	*%of consumption*
Lighting	40
Fanning	22
Refrigeration	12
Heating/Air conditioning	14
Audio/Video	07
Others	05

Table 2: The consumption pattern of the power in domestic sector

- **INDIAN MARKET**

Cost is the most crucial factor in consumer choice. Many times cost supersede quality even though the equipment is inferior in quality, inefficient and hazardous. In recent times, quality awareness is slowly increasing thanks to the multi national companies for their better quality products at relatively lower prices. In this regard various domestic electrical equipment commonly used in Indian houses are critically analyzed and alternatives are suggested wherever possible

3.1 Lamps

Indian domestic illumination is totally dominated by the incandescent lamps of varying wattage (40W/60W/80W/100W). Despite their inefficiency, they are still preferred in lower income groups just because of their very low initial cost. Fluorescent lamps are also popular and are used mainly in the utility areas like reading rooms, bedrooms and living rooms, though they are costlier by more than 10 to 15 times than incandescent lamps. Even in the fluorescent lamps, aluminium chokes are predominant, which cost much less compared to copper choke.

In India, about 80 percent of the domestic lighting is through incandescent lamps. Hence it is one area that should be concentrated most for conservation of energy. Nowadays use of CFLs (Compact Fluorescent Lamp) is steadily increasing because of their very low power consumption, long life and better illumination over incandescent lamps. However CFLs may not be a replacement when illumination is required for precision work. Table 4 shows the comparison of the various popular types of lamps (Kushare,B..E and Bapat R.B., Energy Conservation-Demand side perspective, 2002.)From table 3, one can observe that the incandescent lamp is a source for energy wastage because of its low luminous efficiency. Following calculation shows how economic to replace incandescent with Fluorescent Tube Light (FTL) and with CFL. For calculations it is assumed that the operation hours are 5 Hours per day and the cost of Energy as Rupees 3/- per Kwh though it is much higher if the consumption is more.

Type of lamp	P.F.	Powerconsumption(watts)	Output lumens	EfficiencyLumens/watt
Incandescent 100W	1.0	100	1200	12.0
Fluorescent tube lamp 40W	0.6	52.48	2460	46.87
Fluorescent tube lamp 40W with electronic choke	0.98	33.17W	2890	68.0
CFL 15W	0.90	19.6W	900	45.91

Table 3: Comparison of various types of lamps

3.1.1 Replacement with FTL

Cost of FTL with copper choke:	Rs. 275/-
Cost of Incandescent lamp:	Rs. 15/-
Difference in cost:	Rs. 260/-
Power consumed by Incandescent lamp:	100W
Power consumed by FTL:	52.48W
Saving in power:	47.52W
Payback period:	1 year

3.1.2 Replacement with CFL:

Cost of CFL:	Rs. 40/-
Cost of Incandescent lamp:	Rs. 15/-
Difference in cost:	Rs. 25/-
Power consumed by Incandescent lamp:	100W

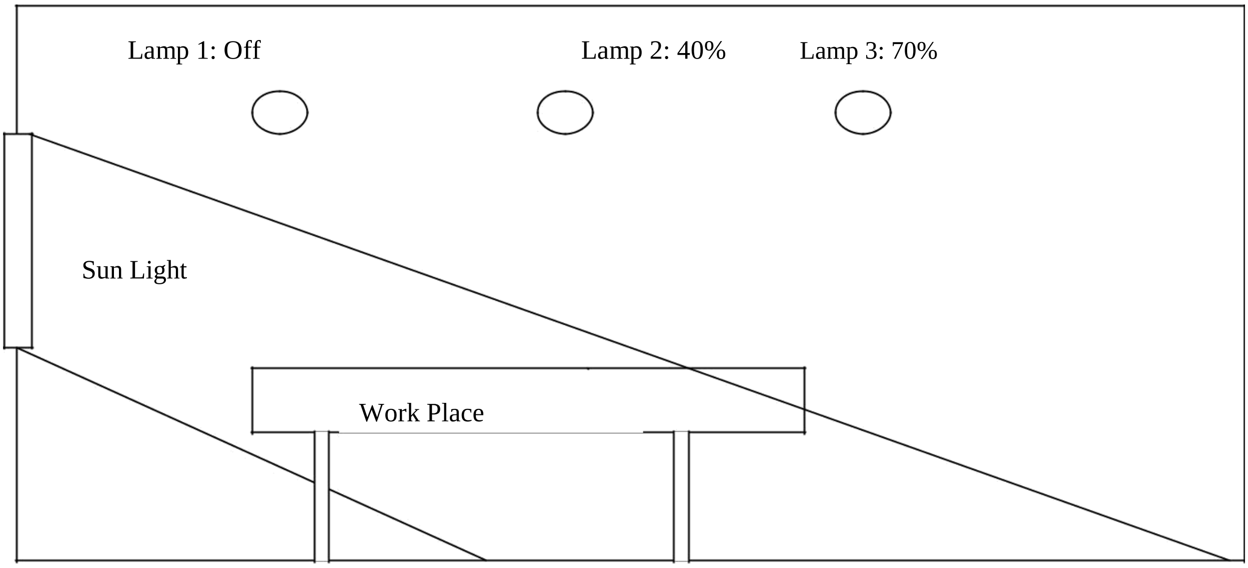


Figure 1. Typical room layout with sun light

Power consumed by CFL: 19.6W

Saving in power: 80.4W

Payback period: 21 days

In both the cases, it can be observed that the savings are very impressive and hence replacement of incandescent lamps is highly recommended. The payback period is inversely proportional to the period of usage.

3.1.2 Replacement with CFL

Cost of CFL: Rs. 40/-

Cost of Incandescent lamp: Rs. 15/-

Difference in cost: Rs. 25/-

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Power consumed by CFL: 19.6W

Saving in power: 80.4W

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In both the cases, it can be observed that the savings are very impressive and hence replacement of incandescent lamps is highly recommended. The payback period is inversely proportional to the period of usage. Another method to conserve energy in this area is to use the natural light effectively so that the period of usage of lamps may be minimized. Following figure shows how the daylight can be used to augment the electrical lighting.

3.2 Fans and Regulators

Fans, once a luxury, became essential now for Indian climatic conditions where temperatures rise to as high as 45^0C in summer. In India, fans available at varying cost ranging from as low as Rs. 400/- to Rs. 1500/-. Cheap fans normally use substandard core laminations and aluminium windings. Standard fans are made with quality material but cost two to three times. The power consumption varies from 60Watts to 90Watts depending on the quality of the fan. Though electronic regulators are available in the market at costs ranging from Rs. 50/- to Rs. 250/- (low cost electronic regulators don't contain proper shielding to prevent RF interference), the conventional regulators are predominant chiefly because they come along with the fan. The user has no choice for opting for an electronic regulator. At medium speeds, a saving of about 14Watts was observed with the use of electronic regulator.

Replacement of low efficient fan with series regulator with high efficient fan with electronic regulator is highly recommended. Following is a comparison of economics of a high cost fan (HCF) and low cost fan (LCF), at a nominal 8 hours a day.

Cost of HCF with electronic regulator: Rs. 1650/-

Cost of LCF: Rs. 450/-

Difference in Cost: Rs. 1200/-

Power consumption of HCF

At medium speed: 50W

Power Consumption of LCF	
At medium speed:	90W
Power savings:	40W
Payback period:	2.3 years

3.3 Refrigerators

Refrigerator is another common appliance in middle and upper classes in India. Single door refrigerators take a share of more than 80 percent and almost all are right hinged (operated with right hand). These are available in variety of capacities and models, but the most popular among them is the single door 165 liters capacity. Almost all the refrigerators have right hinged doors (operated with right hand). Operation of the refrigerator with right hand takes longer time since door opening and handing the contents is to be done by right hand only. This is particularly true with cooking items since they are normally touched with right hand only in India. This leads to loss of cooling and can be saved to some extent if a left hinged door is provided.

Refrigerators in India are mostly used for preservation of food items and for cold water. If two separate compartments are provided, there can be good energy savings since the loss of cooling due to door opening is confined to that compartment only. In fact, a tap may be provided for cold water, which minimizes the openings of the door by about 60%. Normally, defrosting is done only when the deep freezer is completely choked with ice, which hampers the effectiveness thus making a refrigerator inefficient. Another common flaw is insufficient space behind the refrigerator, which deteriorates the heat transfer. The vendors should educate the consumers to ensure periodical defrosting and not to place the refrigerators close to the walls. Now a days “No Frost” models are available, which are very efficient and consume less power than the normal models.

3.4 Water heaters and solar heaters

Immersion heaters, storage geysers and running water heaters (instant water heaters) are available in India. Immersion water heaters are the cheapest and are widely used despite the fatal risk involved just because of its cost. Solar water heaters are not available in many places because of their prohibitively high initial investment. These are used only in luxury hotels, guesthouses and cottages, as the Government made it a principle to install them in these places to conserve energy.

Augmenting the geyser with solar water heater greatly reduces the power consumption (as much as 80%) as solar energy is available for more than 10months a year, which raises the temperature to an adequate level. Following example shows the cost savings by the use of a solar water heater. Cost of solar heater (100 Liters): Rs. 8500/-

Heat required to raise temperature from 20^0C to 45^0C (Ambient to required temperature) for

100 liters :	2500 Kcal
Energy required: 2500/860:	2.906 KWH
Energy Required per Annum	
(300 days):	872.1 KWH
Savings @ 80% of the	
Energy Consumption:	697.7KWH
Savings in Rupees:	Rs. 2093/-
Payback period:	4 years

Apart from the energy savings, the hot water can be used for other purposes like washing and cooking during the summer when hot water is not necessary for bath.

3.5 Water Pumps

Many houses are fitted with a 350W (1/2 HP) or 750W (1 HP) motor depending on the overhead tank capacity. Most of the motors are controlled manually and average usage is about two hours a day. Overflow of tank is a common phenomenon in India since the use of automatic water level controllers is not yet popular.and on average there will be a loss of at least 10 minutes per day per motor in the form of overflow. An automatic water level controller is available for about Rs. 500/- to 800/-. The following calculation shows the savings if an automatic water controller is installed. Cost of water level controller: 500/-

Motor rating::	750 W
Energy waste per day	
@ 10 minutes of overflow :	125WH
Payback period:	3.6 years

The savings will increase with the increase of the rating of the motor and the time of overflow. This also increases the comfort level and conserves the water resources.

4. CONCLUSIONS

Energy conservation is inevitable and should become a habit to every citizen. Disciplined usage of electrical energy saves a considerable amount to individuals, and considerable power to the nation, which can be used for industrial growth, which is currently worst hit sector by the acute power cuts. Various methods are suggested for conservation of energy in the domestic sector. Though Indian context is taken as an example, it may be applied to every country, which is suffering from power shortage.