6 Energy Conservation

6.1 Energy – the Basis of Life and Society

6.1.1 World Energy Development

Over the last 100 years global energy use has increased 16 times, and the global economy 14 times, almost proportional. Energy has been seen as a key resource for development. This increase is still going on more or less linearly. The Energy Information Administration (EIA) of the US Department of Energy (DOE) has studied the energy development for the first 20 years in the new century. Their predictions are as follows:

Between 1999 and 2020, total world energy use is projected to grow from 403 EJ (ExaJ $=10^{18}$ J) to 645 EJ (Figures 6.1a-c), a 60% increase. Developing countries as a whole are expected to account for 60% of the increment in total energy use over this 20 years period, the western industrialised countries 30%, and Central and Eastern Europe and the former Soviet Union (EE/FSU) 10%.

Fossil fuels today account for 80% of energy provision at large, and are expected to continue to be the major source of energy. Oil is expected to remain the dominant energy fuel, with 40% of the whole, as it has for decades. In the industrialised world, oil use increase is due to a growing transportation sector. In the developing world, oil consumption is projected to increase for all end uses. Natural gas is believed to be the fastest growing primary energy source worldwide, maintaining a growth of 3.2% annually. Gas is increasingly seen as the desired option for electric power, given the efficiency of combined-cycle gas turbines relative to coal- or oil-fired generation. The fact that it burns more cleanly than either coal or oil, makes it a more attractive choice, also for reducing greenhouse gas emissions.

Coal use worldwide is projected to increase at a rate of 1.7% per year between 1999 and 2020. Substantial declines in coal use are projected for Western Europe and the CEE/FSU coun-

In this Chapter

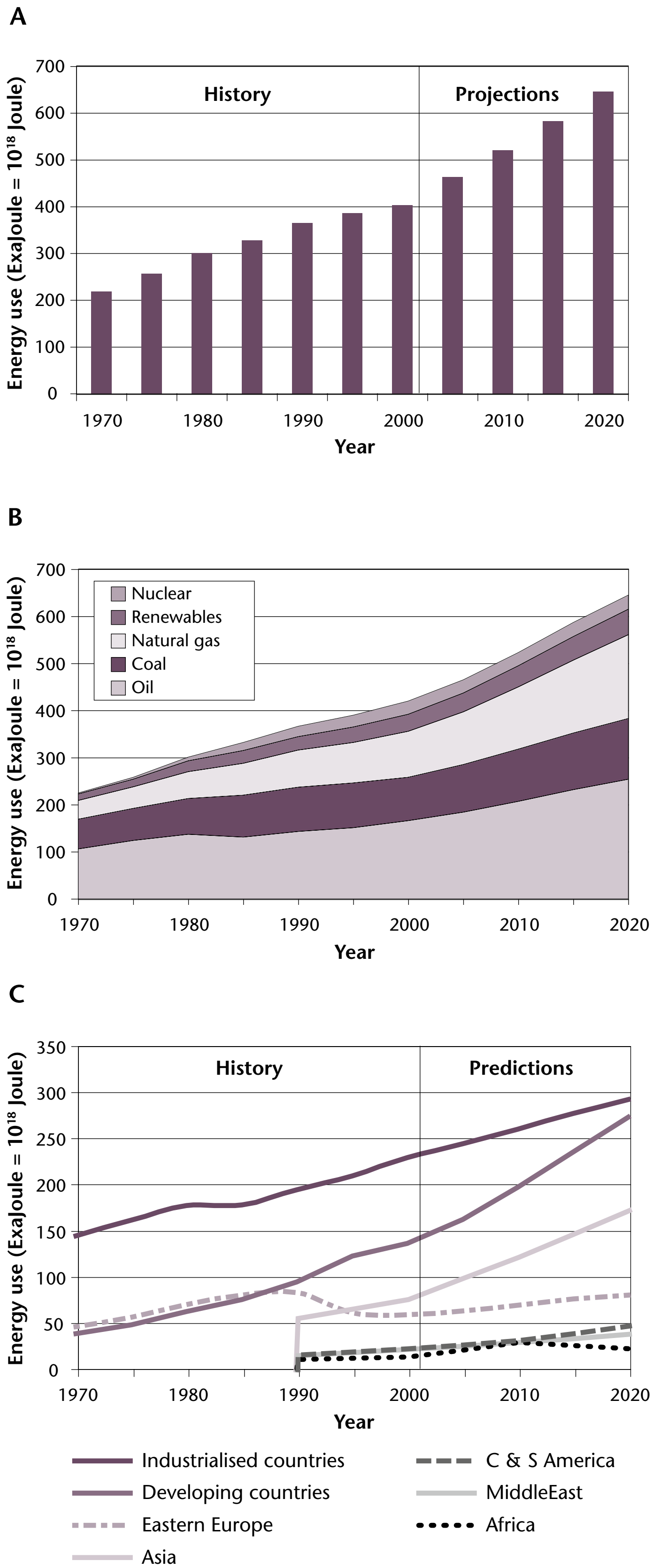

Figure 6.1 World energy consumption. The world energy consumption 1970-2002 as well as predictions by the Energy Information Administration (EIA) of the US Department of Energy (DOE) for the period 2003-2020. *A. World energy consumption 1970-2020. B. World energy consumption per fuel type 1970-2020. C. World energy consumption per region 1970-2020. The data are based on extrapolation of existing trends. A very different view based on the prediction of the Association for the Study of Peak Oil is shown in Chapter 2 of Book 3 in this series [Zibcinski et al, 2006]. [Sources. History: EIA, 2001 and EIA Office of Energy Markets and End Use, International Statistics Database. Projections: EIA, 2002].*

tries, where natural gas is increasingly being used to fuel new growth in electric power generation, and for the industrial and building sectors. In the developing world, however, coal use increases. 85% of the rise is projected for China and India.

Electricity generated from nuclear power is expected to increase by 11.3% in the period with the highest growth, 4.7% per year, in the developing world. Electricity from hydropower and other renewable energy sources is projected to grow by 2.1% annually. The renewable share of total energy use is expected to decline from 9% in 1999 to 8% in 2020. In the developing world large-scale hydroelectric power plants is expected to account for the largest share of growth, while wind, biomass and geothermal power will dominate in the industrialised world.

6.1.2 The Development in the EU and the Baltic Sea Region

The projection of the United States DOE is basically a projection of existing trends. This way to see the development is not shared by all.

First of all, independent researchers doubt that the oil reserves, which DOE assumes for its forecast, exist at all. They are not proven; it is just an assumption. Secondly, the limited oil supply and competition for the existing fossil fuel resources is believed to give a very substantial price increase. Peak Oil, the point in time when half of the existing resources have been used and production is declining, is projected to occur at 2008-2010. This is confronted with dramatically increased demand from China and other Asian countries. A new cost level for oil and gas will force western economies to look more seriously into energy saving measures and new sources of energy.

The increase in *total energy use* is obvious on a global scale but not on a national or regional. It is obvious that at some point in time energy use based on fuels have to stop increasing. In the more mature economies this is approaching. In the EU15 energy growth is declining. In Sweden the total energy use has been almost constant since the 1980s, if the surplus heat generated by nuclear power plants is not included.

For some time already, in fact since about the 1970s, economic value per used energy unit has been increasing. This is called *decoupling*. In the European Union the decoupling of the economy from energy has amounted to about 4% yearly. Increasing production without using more energy becomes more interesting as energy prices increase. A decoupling of economy from energy is very noticeable in housing, service and industry. It is still not obvious in the transport sector, but is expected to be so as oil prices soar.

The alternatives to fossils are also developing and become more interesting as oil prices mount. This is a question of *decarbonising* the energy flows, or, differently said, decoupling energy from carbon flows. This trend is visible in the industrialised world starting in the 1970s. In the EU the relationship of TWh/tonnes carbon has decreased 25% over the period. In Sweden, where a very clear policy to reduce oil dependency has been pursued since the oil price crisis in 1973, the share of fossils in the energy budget has decreased to less than half. The substitution includes nuclear power, hydropower and increased efficiency. In 2005 about 40% of the energy was based on oil.

6.1.3 Environmental Issues and World Energy Use

In the coming decades, environmental concerns could significantly affect patterns of energy use around the world. Global climate change is a wide-reaching environmental issue that is receiving increased attention in recent years. Carbon dioxide, the most prevalent greenhouse gas in the atmosphere, has two major anthropogenic (human-caused) sources: the combustion of fossil fuels and changes in land use. Net releases of carbon dioxide from these two sources are believed to be contributing to the rapid rise in atmospheric concentrations since pre-industrial times. Because estimates indicate that approximately 80% all anthropogenic carbon dioxide emissions currently come from fossil fuel combustion, world energy use has emerged at the centre of the climate change debate.

Based on expectations of regional economic growth and dependence on fossil energy, particularly in developing countries, the DOE study expects global carbon dioxide emissions to grow more rapidly over the period 1999-2020 than they did during the 1990s. Factors such as population growth, rising standards of living, and further industrialisation are expected to have a much greater influence on levels of energy consumption in developing countries than in industrialised nations. Energy-related emissions are projected to grow most rapidly in China, the country expected to have the highest rate of growth in per capita income and fossil fuel use over the coming period.

The DOE study expects carbon intensity – the amount of carbon dioxide emitted per dollar of gross domestic product, GDP (the inverse of decoupling) – to improve (decrease) throughout the world over the next two decades. The steepest rates of improvement are, for the most part, expected to occur among the transitional economies of Central and Eastern Europe and the former Soviet Union (CEE/FSU).

6.1.4 Implementing the Kyoto Protocol

The world community's effort to address global climate change has taken place largely under the auspices of the Climate Convention. It was adopted at the UN Conference on Environment and Development in Rio in May 1992 and entered into force in March 1994. The ultimate objective of the convention is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The details of implementation of this goal were finally agreed on in Tokyo in 1997 (the Kyoto Protocol). The terms of the Kyoto Protocol call for the participating countries to reduce their overall greenhouse gas emissions by at least 5% (EU 8%) below 1990 levels to 2008 to 2012. The Kyoto protocol entered into force in March 2005, when the Russian Federation ratified it.

In addition to any domestic emission reduction measures that countries may choose to implement, the Kyoto Protocol allows the use of four "flexibility mechanisms" (sometimes called "Kyoto mechanisms"):

International emissions trading (Article 17) allow participating countries to transfer some of their allowable emissions to other participating countries, beginning in 2008, for the cost of emission credits. For example, a participating country that reduces its 2010 greenhouse gas emissions level by 10 million metric tons carbon equivalent more than needed to meet its target level can sell the "surplus" emission reductions to other participating countries. This trade would lower the seller's allowable emissions level by 10 million metric tons of carbon equivalent and raise the buyers' allowances by the same amount in total. In the Baltic Sea region the CEE countries, especially Russia, where industrial production had decreased since 1990, will be able to sell emission rights.

Joint fulfilment of commitments (Article 4) allows participating countries that are members of an established regional grouping to achieve their reduction targets jointly, provided that their aggregate emissions do not exceed the sum of their combined Kyoto commitments. For example, EU countries have adopted a burden-sharing agreement that reallocates the aggregate Kyoto emission reduction commitment for the EU among the member countries.

The Clean Development Mechanism (CDM), (Article 12) allows participating countries, either through the government or a legal entity, to invest in emission reduction or sink enhancement projects in non-participating countries, gain credit for those "foreign" emissions reductions, and then apply the credits toward their own national emissions reduction commitments. The CDM, in principle, redistributes emission reductions from developing country parties to participating parties.

Joint implementation (JI), (Article 6) is similar to the clean development mechanism except that the investment in emission reduction projects must occur within the participating countries.

The Kyoto targets refer to overall greenhouse gas emission levels, which encompass emissions of carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Hence, a country may opt for relatively greater reductions of other greenhouse gases emissions and smaller reductions of carbon dioxide, or vice versa, in order to meet its entire Kyoto obligation. Currently, carbon dioxide emissions account for the majority of greenhouse gas emissions in most participating countries, followed by methane and nitrous oxide.

The governments will have to implement various incentives, such as carbon dioxide taxes or energy taxes, to reduce emissions in their countries. Some of these will be of significance to industry.

6.2 Improving Energy Use in Society

6.2.1 Energy for Transport – Alternatives

Transport is today using about 40% of the energy budget of industrial societies, a share that is increasing. In a car engine the heat released when combusting the fuel (gasoline or diesel) is used to generate the mechanical work needed to drive the car forward. This is a quite inefficient process. Up to 18% of the energy content in the fuel becomes kinetic energy. The yield is slightly higher in a Diesel motor in which the combustion temperature is higher.

Efforts to reduce energy use in transport have priority, but are the least successful today. A few measures are the following: Car motors can be made much more efficient and the mileage of a car can be improved by up to 50%. Alternative renewable fuels include ethanol and biogas. Today petrol in the European Union has 5% ethanol content. This may increase. Cars which can take either ethanol or petrol (flexi fuel cars) are increasing in popularity, and a conventional motor may easily be converted into one that runs on ethanol. So-called environmentally friendly cars have a number of advantages, no tax on ethanol, no parking fees in some cities etc. which will make them less expensive to drive. Electric cars, and hybrid vehicles (with both an electric and a combustion motor), are increasingly used. Electric energy can be transformed to movement (and vice versa when braking) with high efficiency. Drawbacks include the lack of efficient batteries, and high cost.

Transport on rail is at least one order of magnitude more energy efficient than road transport in traditional cars.

More efficient use of cars should be mentioned as a separate measure. This includes car pooling, but also that transport in industry not is dependent on owned cars, but rather that the service is bought from the car provider. A complete reorganisation of transport in society is the most far-reaching measure. A society in which the need for transport is decreasing, and the remaining transport is using mainly rail, would decrease energy use in this sector dramatically.

6.2.2 Electric Energy – More Efficient Lighting, Motors and Processes

Electricity accounts for close to 50% of national energy budgets. Electric energy is used for *lighting*, *movements* in electrical motors and a number of *industrial processes* such as electrolysis in which the final energy form is electricity. Industry spends more money on electric energy than on any other energy source. Big total savings can be realised through small savings in electricity consumption practices, thus increasing the ratio between production volume to energy costs.

In a house, electricity is used to heat the kitchen stove as well as in many cases for direct or indirect heating of the house. In industry many energy intensive processes rely on heat from direct firing of fossil fuels, but electricity is used in induction ovens where it is converted to heat.

But electricity is a higher form of energy. This becomes clear with the concept of *exergy*. Exergy expresses the capacity of energy to do work. Electricity has 100% capacity to do work and thus its exergy is 1. For heat the capacity to do work is dependent on temperature. Low temperature heat, which may be excellent to heat a building, has very little capacity to do work and has little exergy. It is clear that electric energy has to be carefully used and only exceptionally used for heating.

The equipment using electricity in industry as well as in households has developed to become more efficient. This is a considerable source of energy saving. In cities the local electricity companies may inform and encourage the inhabitants to buy and use more energy-saving products in order to lower the consumption of electricity.

The use of low energy *lamps* may reduce energy costs considerably. It is also important to turn off lamps when they are not needed. *Electric motors* – that is, movement – are often used less carefully in that they are either on or off. If the work output from the engine is regulated by rotation speed control, considerable savings are possible. Electricity using *processes* is more difficult to change.

6.2.3 Heating Energy – Saving, Upscaling and Downscaling

In many cases the final use of energy is in the form of *heat*. It is thus crucial that the use of heating in society is optimally organised. The largest share is the heating of housing, about 30% of total energy use in society. Traditionally heating was done independently for each house or even household, by an individual boiler using wood, coal, coke, etc. These burners were seldom efficient (temperature too low) and often gave rise to considerable pollutants in the flue gases, especially particles.

One measure which has proven to give large environmental gains in urban areas is district heating, that is to replace all small household heating systems with a large power plant, that is *upscaling*. By building a central power plant with improved process control, as well as cleaning equipment, and with an energy distribution net instead of a number of small household heaters, the amount of air pollutants drastically decrease. Central power plants may also use a fuel, which is difficult to use for a household, such as household waste or peat.

There are also a number of other ways to *save* energy, economise with the produced energy, as for instance controlling the temperature in our flats and houses. These measures are dependent on incentives, for example increased cost of heating. With proper insulation it is today possible to build houses which use very little or even no heating at all, so called passive energy houses (< 15 kWh/m²/year) or low energy houses (< 40 kWh/m²/year). Energy use in residential areas has been decreasing for several years.

It is also possible to save by finding proper local solutions, that is, *downscaling*. These include solar panels and heat pumps. Solar panels, producing hot water, in many cases are enough to provide a household with warm water. Solar panels are usually added to roofs and then do not require extra space. Of course these measures also apply to the heating of industrial buildings. Heat pumps use electricity to extract heat from the surrounding. The possible savings, compared to electric heating, are up to 2.5 times or a reduction of 60%. Here it is important that the electricity does not come from combustion. Then there is no systems gain. Alternatives include e.g. hydropower. Heat pumps may be very profitable if the heat is extracted from e.g. wastewater or surface water. Alternatives are so-called rock heat (from great depths) or even from the air.

6.2.4 Integrated Solutions

Energy together with materials, waste, and water make up the flows of a society, its metabolism. Considerable gains can be made by coordinating these flows. E.g. wastewater always carries some heat, which may be extracted by a heat pump. The sludge from a wastewater treatment plant may be fermented to produce biogas, which is an excellent source of energy, for example for buses or cars. Solid waste may be incinerated to produce district heating and cogenerated electricity.

Integrated solutions include the coordination of several facilities, sometimes referred to as industrial symbiosis. The steam produced in one factory may be sold to another factory, instead of just emitted. Several factories use extra heat for the district heating system in the city where they are located. Many times the waste in one production can be used in the next production. Slaughter house organic waste may be fermented to produce biogas.

Special solutions are also possible. In cities in the north of Sweden snow, collected when cleaning the streets in wintertime, is deposited in one place to be used for local cooling e.g. in a hospital during the rest of the year.

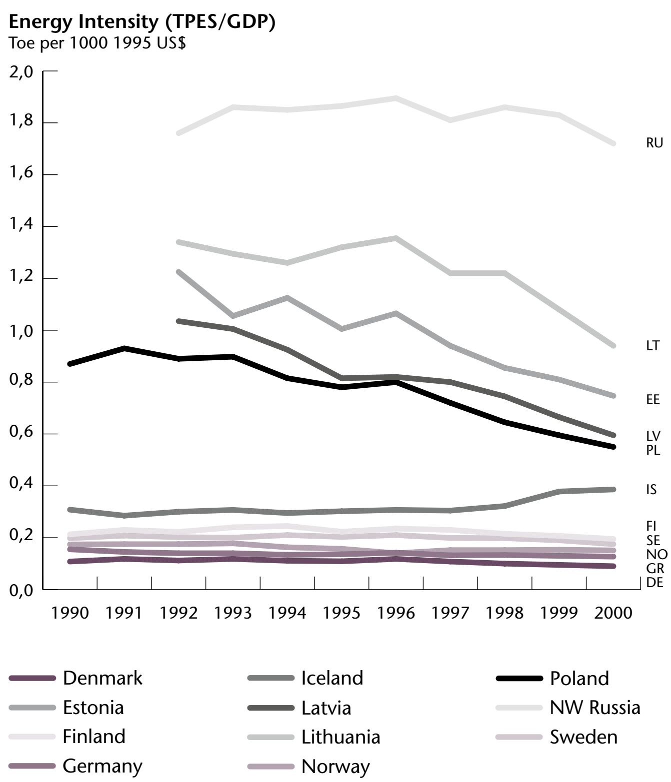

Figure 6.2 The development of energy intensities in Northern Europe, 1990-2000. *The development shows a general decline in the eastern european countries while the western countries exhibit a more stable situation. (TPES=Total Primary Energy Supply.) [Adapted from Baltic 21, 2003].*

6.3 Power Generation

6.3.1 Kinds of Energy Sources

There will always be a demand for primary energy. To meet the need for primary energy there are basically three classes of energy sources:

1. Fossil fuels – Coal, Oil, and Natural gas.
2. Nuclear power.
3. Renewable energy sources, i.e. energy from the sun. These are:
   - Hydropower, Biomass.
   - Wind, Solar energy, Wave and tidal energy, Geothermal energy.

It is useful to distinguish between *dispatchable* and *intermittent* sources of energy. Dispatchable sources can be stored – to be used later – and to some extent transported to the place where the energy is converted to heat or electricity. Power plants that convert solar radiation, wind or wave power directly into electricity cannot be dispatched since the flowing energy will be lost unless it is utilised when it is available. Solar radiation, wind, wave and tidal power sources are therefore considered as intermittent sources. To some extent the energy generated by an intermittent source can be stored however. Thus hot water can be stored as such, and electricity can be stored in a battery or used e.g. to pump water to a high level reservoir.

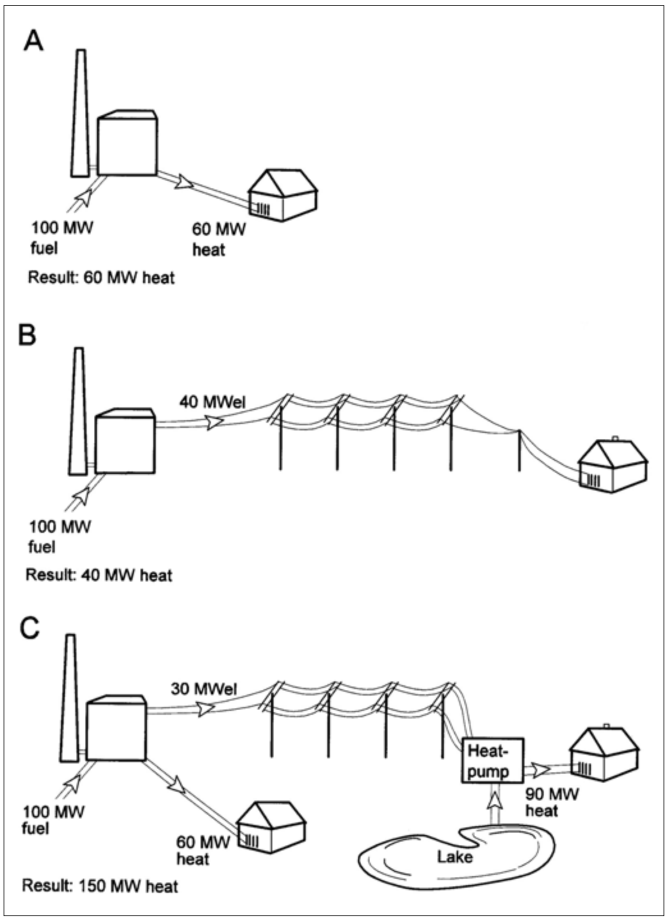

Figure 6.3 Comparison between three different alternatives for production of heating energy for households. *A "bad" energy plant (A). An energy plant where all produced electricity is used for heating purposes (B), and an energy plant where the produced electricity is used to run a heat pump (C). (Illustration: Gunnar Svedberg, Royal Institute of Technology)*

Fossil- and biomass-fuelled power plants – as well as other energy converters such as vehicle engines – are dispatchable since the energy is stored in the fuel. The use of biomass, especially in the form of wood chips and biopellets, has increased much recently. Biomass is produced in forestry, where the residual is taken care of, from energy forests and recently also from oat.

Hydropower stations are mostly dispatchable since they often have dam-capacity to allow storage of water so that the production of electricity can be regulated according to the demand. It is not likely that there will be any additional large hydropower plants in the Baltic Sea region. The capacity was taken into use in the early part of the 20th century. Proposals for new large hydropower plants have been developed for River Daugava close to Daugavpils in Latvia, and in River Wisla in Poland, but protests against these plans have been voiced, as they would destroy much of the natural beauties of these rivers. In northern Norway, Sweden and Finland expansion of hydropower also meets protests. In Sweden the four remaining large rivers are protected against exploitation by a parliamentary decision. The technology of small scale hydropower, to provide e.g. a neighbourhood with electricity, has developed recently in an interesting way.

Wind power stations and wind farms are increasing since the 1990s. Wind power will provide some 10-25% of electricity in many parts in the region, e.g. Denmark and north Germany. Wind energy is more efficient on a water surface and many wind farms are located outside the coasts. Wind power electricity is fed into the general net of the country and in this way can be stored, as hydropower is resting. As with hydropower, wind farms disturb the landscape.

Wave power technology is now developing in an interesting way and may have the capacity to be just as important as wind power in the future. Tidal power is of very limited significance generally and not at all possible in the Baltic Sea region. In regions with high tidal differences it is however a feasible technology. The Rance Valley Tidal Power Station close to St Malo in Normandy, France has an installed capacity of 240 MW, distributed on 24 turbines. The amplitude of the tide here is in the order of 13,5 m.

Solar panels have been mostly known as solutions for individual buildings, but solar panel fields also exist and are a growing energy sector. The largest today seem to be the one at Aeroe in southern Denmark. It provides all district heating needed for the town of Aeroe from March to November. Large solar panel fields are also working in Kungsbacka and Uppsala in mid Sweden. The technology for solar panels develops. Today they are quite efficient also in winter as long as the sun is shining. Heat may be stored as warm water in large spaces in the rock. In this sense they are semi-dispatchable. It provides much more heat per surface area, up to 50 times, than growing of biomass which then is incinerated. Geothermal energy, where it is available, is similar. Large geothermal power plants are found outside Szczecin in Poland and in Denmark.

Figure 6.4 Wind power is now rapidly expanding in the Baltic Sea region. *It is expanding in Denmark, northern Germany, and southern Sweden, where this wind power park is found. The environmental costs of wind power are mainly related to landscape intrusion. If fully exploited, wind power could not, it is projected, provide more than up to 7% of Sweden's electricity requirements.*

Photovoltaic cells convert sunlight to electricity. Recently the cost of the electricity, measured as euro per kWh, has decreased and is more competitive. Still photovoltaic is expected to be used mostly is special circumstances, for example in distant areas to which distribution of electricity is not practical.

6.3.2 Power Plants

Power plants are mostly based on burning of fuels. These are fossils, biomass (wood or peat), or waste. In general fossil fuels totally dominate the picture in most countries in the region.

When burning a fuel, the remains are generally various gases and a solid waste. What gases are produced and the amount of each depends on the fuel used, as well as the conditions during the combustion. The emissions from a combustion plant are thus influenced by the choice of fuel and conditions under which combustion takes place, i.e. process integrated measures. Another possibility is, of course, to use external cleaning technology.

The aim of a power plant is to supply us with energy in the form of heat and electricity. We can also use some other source of energy instead of the fossil fuel, for instance nuclear power. We must then realise that we have other environmental problems to consider.

Figure 6.3 shows some alternatives which gives very different results regarding the consumption of raw materials and, consequently, emissions of pollutants. From an environmental point of view the above mentioned outlook on the problem of supplying us with energy is considerably more important, compared to the discussion of how to increase the efficiency in an exhaust cleaning process by some percents.

6.3.3 Cogeneration

Cogeneration, also known as combined heat and power (generation) or CHP, is an efficient, clean, and reliable approach to generating (electric) power and thermal energy from a single fuel source. Cogeneration uses heat that is otherwise discarded from conventional power generation to produce thermal energy. This energy is used to provide cooling or heating for industrial facilities, district energy systems, and commercial buildings. By utilising this waste heat, cogeneration systems achieve typical effective energy efficiencies of 50% to 70%, a dramatic improvement over the average 33% efficiency of conventional fossil-fuelled power plants.

Cogeneration's higher efficiencies reduce air emissions of nitrous oxides, sulphur dioxide, mercury, particulate matter, and carbon dioxide, the leading greenhouse gas associated with climate change.

Case Study 6.1 Co- and Trigeneration

A factory requires 1 MW of electricity and 500 refrigeration tons* (RT) of heat/cooling. The gas turbine generates electricity required for the on-site energy processes as well as the conventional vapour compression chiller.

Assuming an electricity demand of 0.65 kW/RT, the compression chiller needs 325 kW of electricity to obtain 500 RT of cooling. Therefore, a total of 1325 kW of electricity must be provided to this factory. If the gas turbine efficiency has an efficiency of 30%, primary energy consumption would be 4417 kW.

A cogeneration system with an absorption chiller (thereby making this a "trigeneration" plant) can provide the same energy service (power and cooling) by consuming only 3,333 kW of primary energy, thereby saving nearly 25% in primary energy usage.

** Note: A refrigeration ton (RT) is defined as the transfer of heat at the rate of 3.52 kW, which is roughly the rate of cooling obtained by melting ice at the rate of one ton per day.*

Another example of a cogeneration process would be the automobile in which the primary fuel (gasoline) is burned in an internal combustion engine. This produces both mechanical and electrical energy (cogeneration). These combined energies, derived from the combustion process of the car's engine, operate the various systems of the automobile, including the drive-train or transmission (mechanical power), lights (electrical power), air conditioning (mechanical and electrical power), and heating of the car's interior when heat is required to keep the car's occupants warm. This heat, which is manufactured by the engine during the combustion process, was "captured" from the engine and then re-directed to the passenger compartment.

6.3.4 Trigeneration

Trigeneration is the simultaneous production of cooling, heating and power, in one process. Trigeneration, when compared to (combined-cycle) cogeneration, may be up to 50% more efficient than cogeneration. When found in a hospital, university, office-campus, military base, downtown or group of office buildings, a trigeneration plant has also been referred to as a *district energy system* or *integrated energy system* and as previously mentioned, can be dramatically more efficient and environmentally friendly than *cogeneration.*

The trigeneration energy process produces four different forms of energy from the primary energy source, namely, hot water, steam, cooling (chilled water) and power generation (electrical energy).

Trigeneration allows greater operational flexibility at sites with demand for energy in the form of heating as well as cooling. This is particularly relevant in tropical countries where buildings need to be air-conditioned and many industries require process cooling.

When a trigeneration energy and power system is installed *on-site*, that is, where the electrical and thermal energy is needed by the customer, so that the electrical energy does not have to be transported over long distances, and the thermal energy is utilised on-site, system efficiencies can reach and surpass 90%.

6.4 Saving Electric Energy

6.4.1 Strategic Choices

In the power industry, energy efficiency involves getting the most usable energy out of the fuels. At its best, energy efficiency improvements in the power industry can lead to postponing – or altogether avoiding – the construction of new power plants.

The efficient generation of power is only one way a power plant can pursue energy efficiency. New technologies, applied to the storage of energy and the transmission of energy, contribute to energy efficiency. For instance, the copper wires used in typical transmission lines lose a percentage of the electric energy passing through them because of resistance, which causes

Figure 6.5 Cogeneration. *Combustion for heat production may be coupled to electricity generation in turbines, as in this turbine hall. When the hot steam is pressed through the turbines electricity is generated. The steam is cooled to temperatures appropriate for the district heating system. With this combined system efficiency is close to the theoretical maximum. (Photo: Kjell-Arne Larsson)*

some of the electric energy to turn into heat. But "superconducting" materials have no resistance, and if they are used to transmit electricity in the future, very little of the electric energy will be lost.

Energy storage can also make an electric utility system operate more efficiently. The most familiar way to store electricity is using batteries, but many other technologies have been developed, ranging from pumping water uphill to trapping electrical current in superconducting wire loops.

Unlike other energy sources like natural gas, fuel oil, or gasoline, which are held in large storage tanks until they are needed, most of the electricity is generated at the moment it is needed. To meet changing electrical demands, some power plants must be kept idling in case they are needed. These plants are known as *spinning reserves*, and they waste energy. During times of high electrical demand, inefficient power plants may be brought on-line to provide extra power, and the transmission system may be stretched to near its limit, which also increases transmission energy losses.

On the other hand, the inability to store excess electricity during periods of low demand can force utilities to operate power plants at less than full power, which is usually less efficient. Energy storage allows excess electricity to be stored during slack times and used during periods of high demand. Energy storage can also help electric utilities to make the best use of intermittent energy sources, like wind and solar power.

Another way for utilities to meet these changing energy demands is to locate smaller power sources close to the customers that need the power. This concept, called *distributed generation*, helps take the load off of transmission lines and, because the electricity travels only short distance before it is used, there is little or no energy lost in the transmission of the electricity.

6.4.2 Power Factor Improvement

Power factor quantifies the reaction of alternating current (AC) electricity to various types of electrical loads. Inductive loads, as found in motors, drives and fluorescent lamp ballasts, cause the voltage and current to shift out of phase. Electrical utilities must then supply additional power, measured in kilovolt amps (kVA), to compensate for phase shifting.

The total power requirement constituents can be broken down into the resistive, also known as the real component, and reactive component. Useful work performance comes from the resistive component, measured in kilowatts (kW) by a watt-meter. The reactive component, measured in reactive kilovolt amps (kVAR), represents current needed to produce the magnetic field for the operation of a motor, drive or other inductive device but performs no useful work, and does not register on measurement equipment such as the watt meter. The reactive components significantly contribute to the undesirable heating of electrical generation and transmission equipment formulating real power losses to the utility.

Power factor derives from the ratio of real, usable power (kW), to apparent power (kVAR). Mathematically, power factor is expressed as:

$$PF = \frac{kW}{kVAR}$$

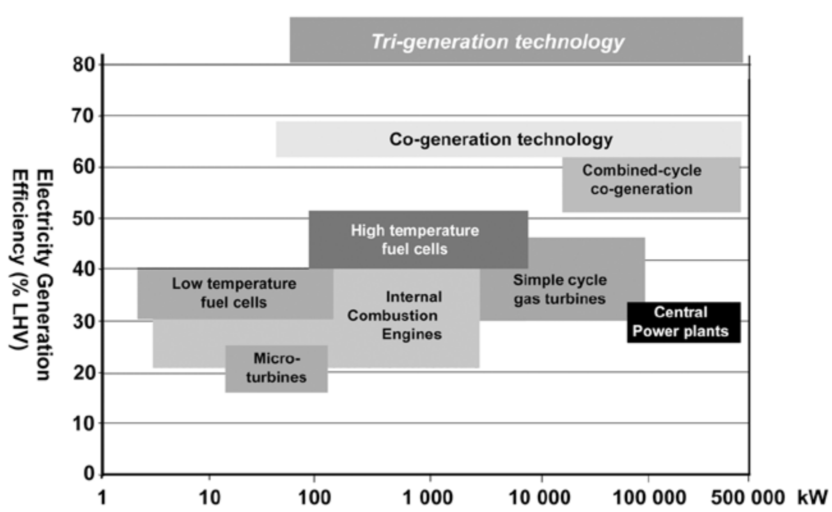

Figure 6.6 *Comparison of the over-all energy efficiency between different electricity generation technologies [Adapted from brochure: Trigeneration, EPA Combined Heat and Power Partnership, 1999.].*

Example: Consider a 480 volt 3-phase system with an assumed load and instrument readings as follows: the ammeter indicates 200 amps and wattmeter reads 120 kW. The power factor of the load can be expressed as follows:

The apparent power for a 3-phase circuit is given by the expression:

$$\text{kVA} = \frac{\text{E x I x } \sqrt{3}}{1000} = \frac{\text{480volts x 200amps x 1,73}}{1000} = 166{,}08\text{kVA}$$

Therefore:

$$\text{PF} = \frac{\text{kW}}{\text{kVA}} = \frac{120}{166{,}08} = 0{,}7224 = 72{,}25\%$$

From the above example it is apparent that by the decreasing power drawn from the line (kVA) the power factor can be increased.

Preventive measures involve selecting high-power-factor equipment. For example, when considering lighting, only high-power factor ballasts should be used for fluorescent and high intensity discharge (HID) lighting. Power factor of so-called normal-power factor ballasts is notoriously low, on the order of 40 to 55%.

When induction motors are being selected, the manufacturer's motor data should be investigated to determine the motor power factor at full load. In the past few years, some motor manufacturers have introduced premium lines of high-efficiency, high-power-factor motors. In some cases, the savings on power factor alone can justify the premium prices charged for such motors. Motors should also be sized to operate as closely as possible to full load, because the power factor of an induction motor suffers severely at light loads. Power factor decreases because the inductive component of current that provides the magnetising force, necessary for motor operation, remains virtually constant from no load to full load, but the in-phase current component that actually delivers work varies almost directly with motor loading.

6.4.3 Load Factor Improvements

Load factor is defined as the ratio of the average kilowatt load over a billing period to the peak demand. For example, if a facility consumed 800,000 kWh during a 30-day billing period and had a peak demand of 2,000 kW, the load factor is:

$$\text{Load Factor} = (800{,}000\text{kWh}/720\text{hrs})/2{,}000\text{kW} = 0.55 \text{ or } 55\%$$

The user will obtain the lowest electric cost by operating as close to a constant load as possible (load factor 100%). The closer a plant can approach this ideal situation, the lower the monthly demand charge will be. The key to a high-load factor and corresponding lower demand charge is to even out the peaks and valleys of energy consumption.

In order to level out peaks in the demand profile, it is necessary to reduce loads at peak times. Consequently it is necessary to identify the various loads that could be reduced during periods of high demand. Approaches that could be considered are:

Stagger Start-Up Loads – If a high-peak load is determined to result from the simultaneous start-up of several loads, such as might occur at the beginning of a shift, consideration can be given to staggering start-up of equipment to span two or more demand intervals.

Reschedule Loads – Peak demands are usually established at particular times during the day shift. A review of the operating schedule may show individual loads can be rescheduled to other times or shifts to even out demand. This technique can provide significant gains at little or no cost. For example, operation of an electric oven might be rescheduled to the evening shift if the oven is not needed full-time. Another example is conducting routine testing of the fire pump during periods when peak demands are not likely to occur.

Increase Local Plant Generation – When some electricity is generated by the plant, plant generation can be temporarily increased to limit demand. In some cases, any venting of excess low-pressure steam from the turbo-generator for short periods may represent a lesser penalty than the increased demand charge.

Install Automatic Demand Control – The power demand controller automatically regulates or limits operation in order to prevent set maximum demands from being exceeded. The type of controller best suited for a plant operation is that which will predetermine the demand limit and the demand interval. The overall usage of power is constantly monitored from the power company meter, the power usage of all the controlled loads is also monitored. By having this information the controller can calculate when an overrun of the desired demand limit will occur. The controller will delay any demand threatening to exceed the demand limit to allow time for loads to "level out".

6.5 Saving Thermal Energy – Heating Systems

6.5.1 Boilers

Thermal energy services in an industry consist of the supply of heating and cooling to an industrial process. A boiler is a device where energy extracted from some type of fuel is converted into heat that is distributed to needed places (to do useful work). In the process, the carrying media (circulating water or steam) gives up the heat and is cyclically reheated again and again.

An ideal model of a boiler operation is based on the Carnot cycle. The Carnot cycle is defined as two reversible isothermal and two reversible adiabatic processes. Heat is added to the cycle during the isothermal process at high temperature, T_H. Then follows an adiabatic process producing work as the working fluid is expanded to a lower pressure. During the next isothermal stage, heat is rejected to the low temperature reservoir at T_L. During the last phase the working fluid is adiabatically compressed to finish the cycle. The Carnot cycle is the most efficient cycle for the given low and high temperatures. Its efficiency is given by:

$$\eta = 1 - (T_L / T_H)$$

The efficiency of a real boiler is always lower than this ideal Carnot efficiency. The boiler efficiency can be improved and maintained through proper maintenance and monitoring of operation.

Some performance improvements are easily achieved. They are all dependent on proper maintenance or operation procedures.

Adjustment of air-to-fuel ratio. For each fuel type, there is an optimum value for the air/fuel ratio. The air/fuel ratio is the ratio of combustion air to fuel supplied to the burner. For natural gas boilers, this is 10% excess air, which corresponds to 2.2% oxygen in the flue gas. For coal-fired boilers, the values are 20% excess air and 4% oxygen.

Elimination of Steam Leaks. Significant savings can be realised by locating and repairing leaks in live steam lines and in condensate return lines. Leaks in the steam lines make steam to be wasted, resulting in higher steam production requirements from the boiler to meet the system needs. Condensate return lines that are leaky return less condensate to the boiler, increasing the quantity of required make-up water.

Maintenance of Steam Traps. A steam trap holds steam in the steam coil until the steam gives up its latent heat and condenses. In a flash tank system without a steam trap (or a malfunctioning trap), the steam in the process heating coil would have a shorter residence time and does not condense completely. The uncondensed high-quality steam would then be lost from the steam discharge pipe to the flash tank.

High Pressure Condensate Return Systems. As steam loses its heat content it is condensed into hot water, called condensate. A sudden reduction in the pressure of a pressurised condensate will cause the condensate to change phase into steam, more commonly called flashing. Flash tanks are often designed into a pressurised return system to allow flashing and to remove non-condensable gases from the steam. The resulting low-pressure steam in the flash tank can often be used as a low-temperature heat source. A more efficient alternative is to return the pressurised condensate directly to the boiler through a high-pressure condensate return system.

Figure 6.7 Boilers. *Boilers, mostly for providing hot water, are basic in most energy systems. In smaller or medium sized industries, residential areas or large buildings, boilers in the size of 100-1000 m³ with output energy of 10-500 MW are common. The proper maintenance and use of boilers is important for energy efficiency. Further improvement is possible by using a cogeneration equipment in the scale proper – also small equipments are available – to produce both heat and power (electricity). (Photo: iStockphoto)*

Conversion of boilers. An important means to improve energy management is to change boilers using oil to other fuels, such as gas or biofuels. This conversion reduces GHG emissions per output energy. By replacing the burners and changing the burner configuration the efficiency of the boiler can be greatly improved. Thus a more complete combustion of the fuel with right temperature, and a better distribution of the flue gases in the boiler can be achieved. The better distribution of gases will increase the overall heat transfer as well as prevent "hot spots" in the neighbourhood of the burner orifice that causes extensive formation of nitrogen oxides.

Fluidised bed combustion (FBC) has emerged as a viable alternative boiler design that has significant advantages over conventional firing system and offers multiple benefits. FBC boilers can burn fuel with a combustion efficiency of over 95% irrespective of ash content, and an overall efficiency of 84% (plus or minus 2%). High heat transfer rate over a small heat transfer area immersed in the bed result in overall size reduction of the boiler. FBC boilers can be operated efficiently with a variety of fuels. Air emissions can be reduced as SO_2 formation is minimised by the addition of limestone or dolomite for high sulphur coals or oil, while a low combustion temperature

Figure 6.8 Using heat pumps. *This large industrial heat pump is taking its heat from the flue gases from waste combustion at Vattenfall, Uppsala Energy. In the process the gas condenses and the heat extracted is transferred to the district heating system. In other large-scale applications heat is extracted from sewage water or surface water. The chilled water may be used for district cooling. Most heat pumps are smaller and used for individual homes. (Photo: Kjell-Arne Larsson)*

eliminates NO_x formation. Finally by operating the fluidised bed at elevated pressure, it can be used to generate hot pressurised gases to power a gas turbine. This can be combined with a conventional steam turbine to improve the efficiency of electricity generation and give a potential fuel savings of at least 4%.

6.5.2 Heat Recovery Systems

Heat recovery systems are installed to make use of some of the energy which otherwise would be lost to the surroundings. The systems use a hot media leaving the process to preheat other, or sometimes the same, media entering the process. Thus energy otherwise lost does useful work.

Ventilation, process exhaust and combustion equipment exhaust are the major sources of recoverable energy. Regardless of the amount or temperature of the energy discharged, recovery is impractical unless the heat can be effectively used somewhere else. Also, the recovered heat must be available when it is needed.

Heat recovery uses heat exchangers. Heat exchangers have been improved considerably in recent years, both for exchanges in gas and liquid phase. Heat exchangers are used in a great many processes.

Heat extracted from indoor air ventilated to the outdoors is used to heat the incoming air. This is a very important part of heat recovery. In modern buildings the air is exchanged once every hour and some 25% of the heat used to heat buildings is lost in ventilation. Heat exchangers are also used to recover heat from exhausts flue gases.

6.5.3 Pinch Technology

The design of a new process, or the optimisation of an existing process, is a complex task, due to interactions between the unit operations that make up the process. These interactions force the designer not to consider each unit operation individually, but the whole process system as a whole. This is especially important for analysis and optimisation of heat recovery systems.

Pinch technology presents a simple methodology for systematic analysis of processes and the surrounding utility systems with the help of the first and second laws of thermodynamics. The first law of thermodynamics provides the energy equation for calculating the enthalpy changes (ΔH) in the process streams passing through a heat exchanger. The second law stipulates that heat energy only may flow in the direction of warm to cold, whereby the direction of the flow of heat is determined. This prohibits “temperature crossovers” of the warm and cold stream profiles through the exchanger. The warm stream can only be cooled to, and the cold stream heated to a temperature defined by the “temperature approach” of the heat exchanger. This temperature approach is the minimum allowable temperature difference (ΔT_{min}) in the stream temperature profiles. The temperature level at which ΔT_{min} is observed in a process is referred to as the *“pinch point”*.

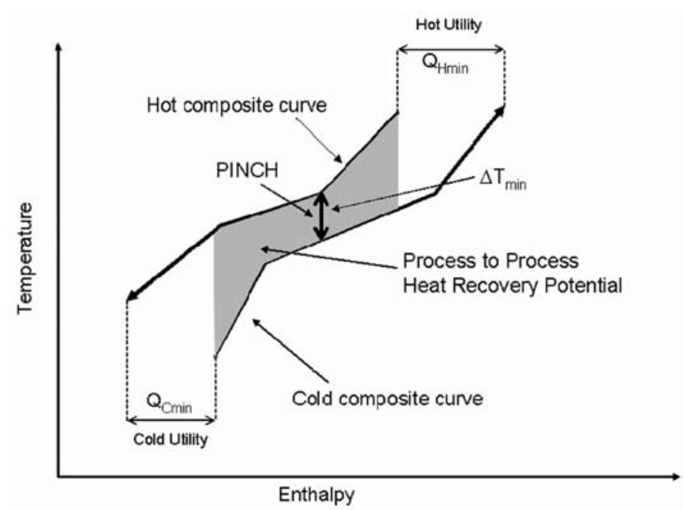

Figure 6.9 *Pinch Analysis Composite Curve diagram [Adapted from Cheresources, 2004]. http://www.cheresources.com/pinchtech1.shtml*

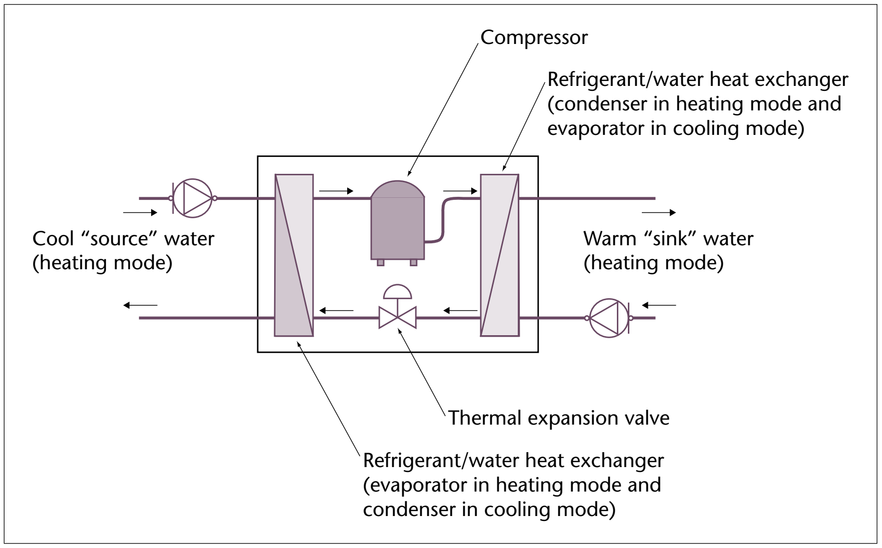

Figure 6.10 *Geothermal heat pump [adapted from U.S. DOE, 2003].*

The steps of a pinch analysis are:

1. Identification of hot, cold and utility streams in the process.
   - Hot streams are those that must be cooled or are available to be cooled.
   - Cold streams are those that must be heated.
   - Utility streams are used to heat or cool process streams.
     - A hot utility may be steam, hot water, flue gases etc.
     - A cold utility may be cooling water, air, refrigerant etc.
2. Thermal data calculation.
   - From the supply temperature (T_SºC), the target temperature (T_TºC) and the heat capacity flow rate (CP kW/ºC) of each stream the potential enthalpy change (ΔH) of the streams are calculated.
3. Selection of the initial ΔT_{min} value.
   - A minimum heat transfer driving force must always be allowed for a feasible heat transfer design. In mathematic terms, at any point in an exchanger $T_H - T_C \geq \Delta T_{min}$, where T_H is the hot stream temperature and T_C the cold stream temperature.
4. Construction of composite curves.

Composite curves consist of temperature-enthalpy profiles of heat availability in the process (the hot composite curve) and heat demands (the cold composite curve). We can then build the curves of hypothetical heat exchangers overlapping these hot and cold composite curves so that they are separated by a minimum temperature difference. The final horizontal overlapping of the composite curves is the maximum amount of energy that can be recovered and the enthalpy intervals not overlapping represent the enthalpy requirements that cannot be fulfilled with process streams and thus are the minimum required cooling and heating utilities for the process.

By applying the pinch analysis methodology to a complex process system the task of optimising the heat flows in the process system is greatly facilitated. In order to maximise energy recovery and minimise the energy (both heating and cooling) requirement an appropriate heat exchanger network is required. With the use of pinch analysis the design of the heat exchanger network becomes very systematic and methodical.

6.5.4 Heat Pumps

Heat pumps function by moving (or pumping) heat from one place to another. A heat pump takes heat from a heat source outside and pump it inside. Heat pumps use electricity to operate pumps that alternately evaporate and condense a refrigerant fluid to move that heat. In the heating mode, heat pumps are far more “efficient” at converting electricity into usable heat because the electricity is used to move heat, not to generate it.

The most common type of heat pump – an air-source heat pump – uses outside air as the heat source during the heating season and the heat sink during the air-conditioning season. Water-to-water heat pumps work the same way, except that the heat source/sink is the ground, ground water (geothermal heat pumps), or a body of surface water, such as a lake (surface water heat pumps). For large installations geothermal or surface water based heat pumps are the most common.

The efficiency or coefficient of performance (COP) (a ratio calculated by dividing the total heating capacity provided by the heat pump by the total electrical input) of water-to-water heat pumps is significantly higher than that of air-source heat pumps because the heat source is warmer during the heating season and the heat sink is cooler during the cooling season. Ground-source heat pumps are also known as geothermal heat pumps.

Ground-source heat pumps are environmentally attractive because they deliver so much heat or cooling energy per unit of electricity consumed. Water-to-water heat pumps connected to geothermal sources and low temperature, below 100ºC, loads typically have COPs in the range of 2.5 to 3.2. The best ground-source heat pumps are more efficient than high-efficiency gas combustion, even when the source efficiency of the electricity is taken into account.

6.5.5 Insulation

Although not generally viewed as a part of the mechanical design system, insulation is an important part of every piece of equipment or building where any transfer of fluids or gases takes place and that their temperature is required to be different then that of ambient air. Properly insulated pipes, tanks and other equipment can save substantial amounts of energy.

There are several opportunities in the industrial sector to realise energy savings by installing insulation in manufacturing facilities. Good insulation design and installation are very important in terms of performance and energy efficiency. It is essential to determine the most appropriate type and thickness of insulation for specific applications. The most cost-effective approaches involve insulating pipes and tanks.

Other obvious measures include covering surfaces of hot liquids – also water – and dimensioning the equipment correctly. Large pipes and tanks leak more heat to the surroundings than smaller, as diffusion is proportional to the surface area.

6.6 Saving Thermal Energy – Cooling Systems

6.6.1 Choosing the Right Source of Cold Temperature

For process cooling it is always best from the standpoint of energy conservation to use the lowest form of energy first. That is, for a piece of equipment or a process that is air cooled, first use outside air (an economizer) if the outside air temperature is low enough. The next step, in appropriate climates, would be to use direct evaporative cooling. This is a process in which air passing through water droplets (a swamp cooler) is cooled, as energy from the air is released through evaporation of the water. Evaporative cooling is somewhat more energy intensive than the economizer but still provides some relatively inexpensive cooling. The increase in energy use is due to the need to pump water.

Indirect evaporative cooling is the next step up in energy use. Air in a heat exchanger is cooled by a second stream of air or water that has been evaporatively cooled, such as by a cooling tower and coil. Indirect evaporative cooling may be effective if the wet-bulb temperature is fairly low. The wet-bulb temperature is the temperature indicated by a thermometer for which the bulb is covered by a film of water. As the film of water evaporates, the bulb is cooled. High wet-bulb temperatures correspond to higher air saturation conditions. For example, dry air has the ability to absorb more moisture than humid air, resulting in a lower, wet-bulb temperature.

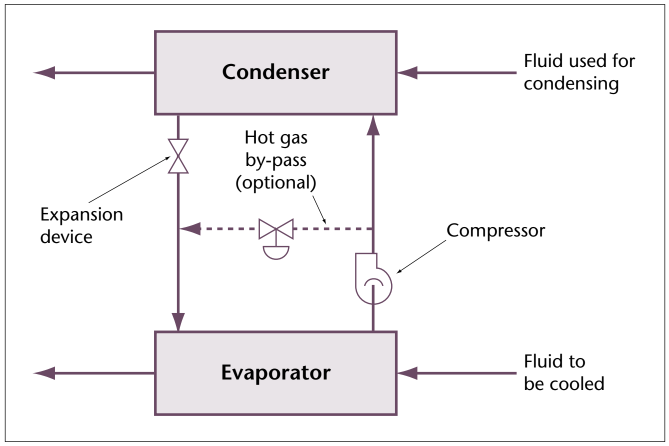

Figure 6.11 *Vapour-compression refrigeration system [Perry and Green, 1984].*

Indirect evaporative cooling involves both a cooling tower and swamp cooler, so more energy will be used than for the economizer and evaporative cooling systems because of the pumps and fans associated with the cooling tower. However, indirect cooling systems are still less energy intensive than systems that use a chiller. The final step would be to bring a chiller on line. Many plants have chillers that provide cooling for various plant processes. Chillers consist of a compressor, an evaporator, an expansion valve, and a condenser.

6.6.2 Cooling Towers

Cooling towers dissipate heat by evaporation of water that is trickling from different levels of the tower. Usually the water is sprayed into the air, so the evaporation is easier. Cooling towers conserve water, prevent discharge of heated water into natural streams and also avoid treating large amount of make-up water.

There are three types of cooling towers widely used today: mechanical forced-draft towers, induced draft towers and hyperbolic towers. Mechanical forced-draft is designed to provide an air supply at ground level and at amounts that are easily controlled by fans. In case of induced-draft towers the fan is mounted on the top of the tower. This arrangement improves air distribution and less make-up water is needed. The hyperbolic tower is based on the chimney effect. The effect of the chimney eliminates the need for fans that are necessary for both induced-draft and mechanical forced-draft cooling towers.

6.6.3 Absorption Refrigeration

Packed absorption liquid chillers are used to produce chilled liquid for air-conditioning and industrial refrigeration processes. The chillers are usually powered by low-pressure steam or hot water, which can be supplied by the plant boiler or by waste heat from a process.

In the absorption cycle, two distinct chemicals are used and the cycle is driven by heat. The most common absorption system fluids are water as the volatile fluid and lithium bromide brine as the absorber fluid.

6.6.4 Mechanical Refrigeration

Refrigeration machines provide chilled water or other fluid for both process and air conditioning needs. Of the three basic types of refrigeration systems (mechanical compression, absorption, and steam jet), mechanical compression is the type generally used. The other two have application only in special situations.

The mechanical compression refrigeration system consists of four basic parts; compressor, condenser, expansion device, and evaporator. A refrigerant, with suitable characteristics, is circulated within the system. Low-pressure liquid refrigerant is evaporated in the evaporator (cooler), thereby removing heat from the warmer fluid being cooled. The low-pressure refrigerant vapour is compressed to a higher pressure and a correspondingly higher saturation temperature. This higher pressure and temperature vapour is condensed in the condenser by a cooling medium such as cooling tower water, river water, city water, or outdoor air. The higher pressure and temperature refrigerant liquid is then reduced in pressure by an expansion device for delivery to the evaporator.

Figure 6.12 *Energy efficiency requires that pipelines are well-insulated. See also Case Study 4. (Photo: Waska Williams Jr. – North Slope Borough)*

6.6.5 District Cooling

By connecting to a trigeneration power plant delivering district cooling, an industry may cover its need for process or facility cooling in an energy and environmentally efficient manner. This is becoming increasingly used in e.g. restaurants and other services where cold rooms are used. It is obvious that just as with district heating, environmentally it is advantageous with a central facility that can be run with optimal efficiency, be well regulated, and equipped with proper environmental protection.

6.6.6 Insulation

Just as with heating systems, cooling systems need to be properly insulated. Insulation is an important part of every piece of equipment or building where any transfer of fluids or gases takes place and that their temperature is required to be different then that of ambient air. Properly insulated pipes, tanks and other equipment can save substantial amounts of energy. Good insulation design and installation are very important in terms of performance and energy efficiency. It is essential to determine the most appropriate type and thickness of insulation for specific applications.

Study Questions

1. Describe the world energy development and the development of the Baltic Sea region. How do regional peculiarities influence these processes?
2. List different kinds of energy sources.
3. What are the general terms of the agreement in the Kyoto Protocol? What role do the Baltic Sea countries play in this process?
4. Explain the concept of exergy.
5. What is the distinction between dispatchable and intermittent energy sources? Is this distinction absolute or are there ways of circumventing the problem of intermittent energy sources?
6. Explain the difference between cogeneration and trigeneration.
7. How can the energy efficiency of a boiler be improved?
8. What are the principles of pinch technology for analysis and optimisation of energy systems?
9. Describe different ways of saving electricity, heating and thermal energy.

Abbreviations

AC	Alternating Current.
CDM	Clean Development Mechanism.
CHP	Combined Heat and Power (cogeneration).
COP	Coefficient of Performance (efficiency).
DOE	US Department of Energy.
EIA	Energy Information Administration (of DOE).
EJ	ExaJoule (10E18 Joule).
GDP	Gross Domestic Product.
HID	High Intensity Discharge lighting.
JI	Joint Implementation.
kVAR	kiloVolt Amps Reactive (apparent power).
RT	Refrigeration Ton.
UNCED	UN Conference on Environment and Development.

Internet Resources

International Energy Agency (IEA),
an autonomous agency linked to the OECD
http://www.iea.org/

ASPO – The Association for the Study of Peak Oil and Gas
http://www.peakoil.net/

Energy Information Administration of the
US Dept. of Energy, DOE
http://www.eia.doe.gov/

U.S. Geological Survey World Petroleum Assessment 2000
http://pubs.usgs.gov/dds/dds-060/

European Commission Green Paper on Energy Efficiency
(Doing More With Less)
http://ec.europa.eu/energy/efficiency/index_en.htm

End Use Energy Efficiency; The Renewable Energy Unit of Institute for Environment & Sustainability of the European Commission Joint Research Centre (JRC)
http://energyefficiency.jrc.cec.eu.int/

Energy Saving Trust of UK
http://www.est.org.uk/

World Energy Efficiency Association
http://www.weea.org/

The Office of Energy Efficiency (OEE)
of the Natural Resources Canada – A centre of excellence for energy efficiency and alternative fuels information
http://oee.nrcan.gc.ca/english/

Energy Information Administration (EIA) of the US Government – A portal for energy savings with many links
http://www.eia.doe.gov/emeu/efficiency/energy_savings.htm

Save Energy Now is the US Department of Energy programme on Energy Efficiency and Renewable Energy
http://www1.eere.energy.gov/industry/saveenergynow/

American Council for an Energy-efficient economy
– Emerging Energy-Efficient Industrial Technologies
http://www.aceee.org/pubs/ie003.htm

Combined Heat and Power Association
http://www.chpa.co.uk/

Trigeneration Technologies
(Cogeneration Technologies, Texas USA)
http://www.cogeneration.net/Trigeneration_Technologies.htm

Pinch Analysis for the Efficient Use of Energy,
Water and Hydrogen – Natural Resources Canada
http://cetc-varennes.nrcan.gc.ca/fichier.php/codectec/En/2003-140/2003-140e.pdf

L'Usine Marémotrice de la Rance (French)
http://membres.lycos.fr/chezalex/projets/rance/sommaire_rance.htm