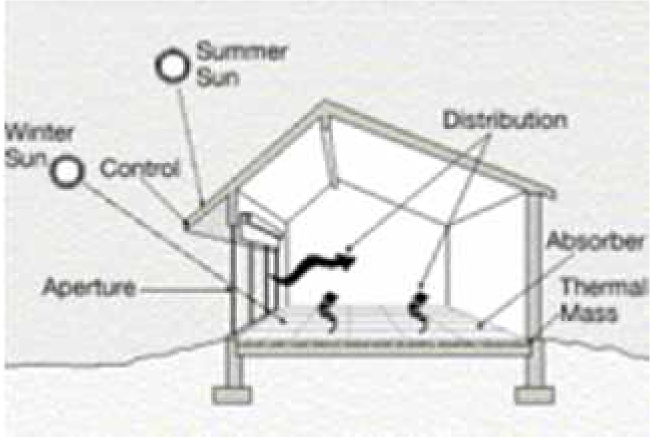
Energy conservation

Lecture one

Definitions and Element of Energy Conservation

Dr.K.Al-khishali



Energy Conservation

Definitions and Element of Energy Conservation

This article is about decreasing energy consumption.

Sustainable energy

Sustainable energy is the sustainable provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs. Technologies that promote sustainable energy include renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, geothermal energy, and tidal power, and also technologies designed to improve energy efficiency.

Renewable Energy

- ❖ Anaerobic digestion
- ❖Biomass
- ❖Geothermal
- ❖Hydroelectricity
- ❖ Solar
- ❖ Tidal
- ❖Wind

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Anaerobic digestion

Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen.[١] It is used for industrial or domestic purposes to manage waste and/or to release energy. Much of the fermentation used industrially to produce food and drink products, as well as home fermentation, uses anaerobic digestion. Silage is produced by anaerobic digestion..

The digestion process begins with bacterial hydrolysis of the input materials to break down insoluble organic polymers, such as carbohydrates, and make them available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide.[2] The methanogenic archaea populations play an indispensable role in anaerobic wastewater treatments.[3]

Biomass

Biomass, as a renewable energy source, is biological material from living, or recently living organisms.[١] As an energy source, biomass can either be used directly, or converted into other energy products such as biofuel.

In the first sense, biomass is plant matter used to generate electricity with steam turbines & gasifiers or produce heat, usually by direct combustion. Examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. In the second sense, biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including biofuels. Industrial biomass can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo,[٢] and a variety of tree species, ranging from eucalyptus to oil palm (palm oil.(

Biofuel

A **biofuel** is a type of fuel whose energy is derived from biological carbon fixation. Biofuels include fuels derived from biomass conversion, as well as solid biomass, liquid fuels and various biogases.[١] Biofuels are gaining increased public and scientific attention, driven by factors such as oil price hikes, the need for increased energy security, and concern over greenhouse gas emissions from fossil fuels.

Bioethanol is an alcohol made by fermentation, mostly from carbohydrates produced in sugar or starch crops such as corn or sugarcane. Cellulosic biomass, derived from non-food sources such as trees and grasses, is also being developed as a feedstock for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil. Current plant design does not provide for converting the lignin portion of plant raw materials to fuel components by fermentation.

Biodiesel

Biodiesel is made from vegetable oils and animal fats. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using .transesterification and is the most common biofuel in Europe
In ٢٠١٠ worldwide biofuel production reached ١٠٥ billion liters (٢٨ billion gallons US), up ١٧% from ٢٠٠٩,[٢] and biofuels provided ٢,٧% of the world's fuels for road transport, a contribution largely made up of ethanol and biodiesel.[citation needed] Global ethanol fuel production reached ٨٦ billion liters (٢٣ billion gallons US) in ٢٠١٠, with the United States and Brazil as the world's top producers, accounting together for ٩٠% of global production. The world's largest biodiesel producer is the European Union, accounting for ٥٣% of all biodiesel production in ٢٠١٠.[٢] As of ٢٠١١, mandates for blending biofuels exist in ٣١ countries at the national level and in ٢٩ states/provinces.[٣] According to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by ٢٠٥٠.[[٤

Biogas

Typical composition of biogas[86]

Matter	%
Methane, CH_4	50–75
Carbon dioxide, CO_2	25–50
Nitrogen, N_2	0–10
Hydrogen, H_2	0–1
Hydrogen sulfide, H_2S	0–3
Oxygen, O_2	0–2

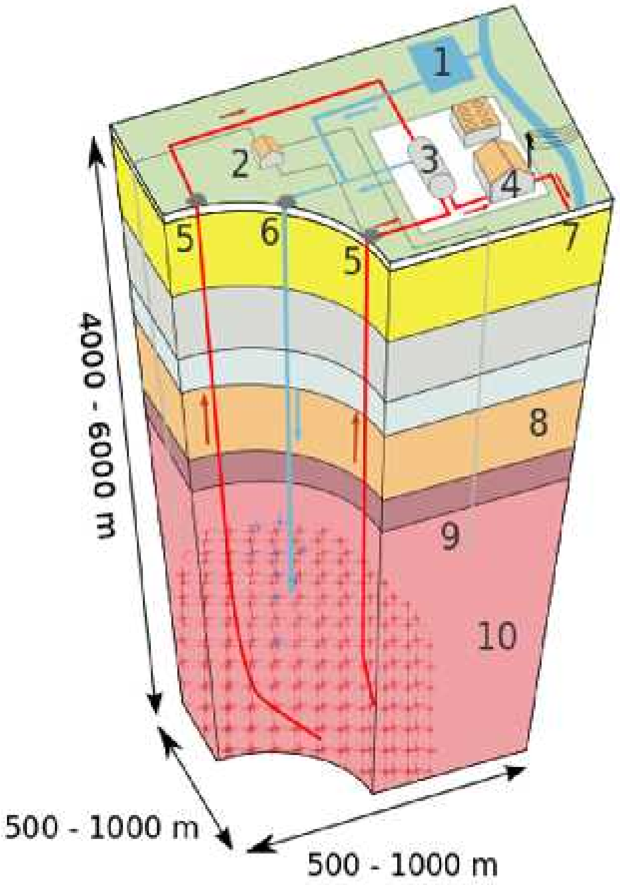
Biogas is the ultimate waste product of the bacteria feeding off the input biodegradable feedstock

Geothermal

Geothermal energy is thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. The Geothermal energy of the Earth's crust originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%).[1][2] The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. The adjective *geothermal* originates from the Greek roots *γη (ge)*, meaning earth, and *θερμος (thermos)*, meaning hot.

From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times, but it is now better known for electricity generation. Worldwide, about 10,715 megawatts (MW) of geothermal power is online in 24 countries. An additional 28 gigawatts of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination and agricultural applications.[4]

Geothermal power is cost effective, reliable, sustainable, and environmentally friendly,[5] but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have dramatically expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation.



Enhanced geothermal system 1:Reservoir 2:Pump house 3:Heat exchanger 4:Turbine hall 5:Production well 6:Injection well 7:Hot water to district heating 8:Porous sediments 9:Observation well 10:Crystalline bedrock

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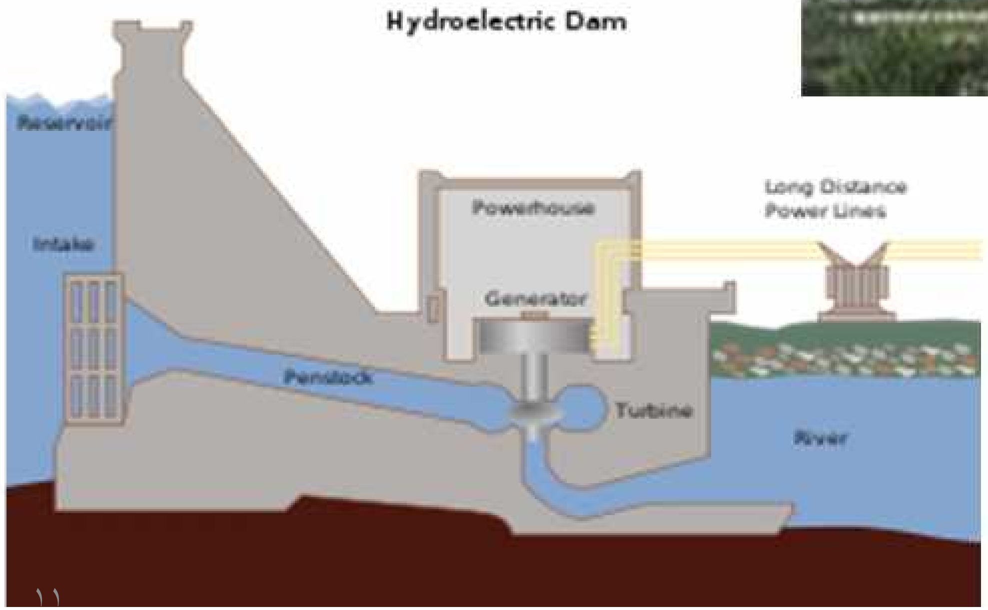
Hydroelectricity

Hydroelectricity is the term referring to electricity generated by hydropower; the production of electrical power through the use of the gravitational force of falling or flowing water. It is the most widely used form of renewable energy, accounting for 16 percent of global electricity consumption, and 3,427 terawatt-hours of electricity production in 2010, which continues the rapid rate of increase experienced between 2003 and 2009.[1]

Hydropower is produced in 150 countries, with the Asia-Pacific region generating 32 percent of global hydropower in 2010. China is the largest hydroelectricity producer, with 721 terawatt-hours of production in 2010, representing around 17 percent of domestic electricity use. There are now three hydroelectricity plants larger than 10 GW: the Three Gorges Dam in China, Itaipu Dam in Brazil, and Guri Dam in Venezuela.[1]

The cost of hydroelectricity is relatively low, making it a competitive source of renewable electricity. The average cost of electricity from a hydro plant larger than 10 megawatts is 3 to 5 U.S. cents per kilowatt-hour.



The Three Gorges Dam is the largest operating hydroelectric power station, at 22,500 MW

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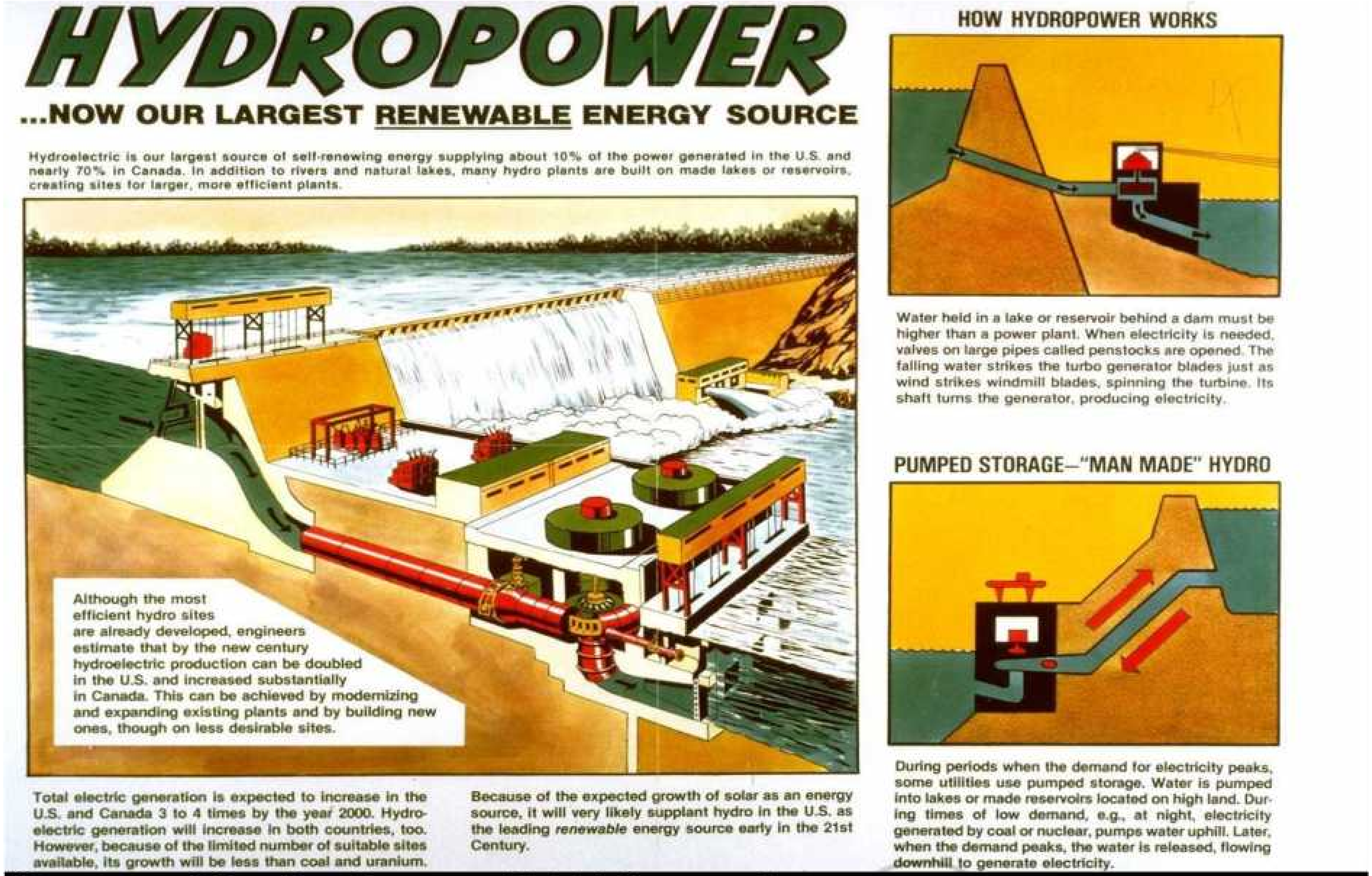

HYDROPOWER

...NOW OUR LARGEST RENEWABLE ENERGY SOURCE

Hydroelectric is our largest source of self-renewing energy supplying about 10% of the power generated in the U.S. and nearly 70% in Canada. In addition to rivers and natural lakes, many hydro plants are built on made lakes or reservoirs, creating sites for larger, more efficient plants.

Although the most efficient hydro sites are already developed, engineers estimate that by the new century hydroelectric production can be doubled in the U.S. and increased substantially in Canada. This can be achieved by modernizing and expanding existing plants and by building new ones, though on less desirable sites.

Total electric generation is expected to increase in the U.S. and Canada 3 to 4 times by the year 2000. Hydroelectric generation will increase in both countries, too. However, because of the limited number of suitable sites available, its growth will be less than coal and uranium.

Because of the expected growth of solar as an energy source, it will very likely supplant hydro in the U.S. as the leading *renewable* energy source early in the 21st Century.

HOW HYDROPOWER WORKS

Water held in a lake or reservoir behind a dam must be higher than a power plant. When electricity is needed, valves on large pipes called penstocks are opened. The falling water strikes the turbo generator blades just as wind strikes windmill blades, spinning the turbine. Its shaft turns the generator, producing electricity.

PUMPED STORAGE—"MAN MADE" HYDRO

During periods when the demand for electricity peaks, some utilities use pumped storage. Water is pumped into lakes or made reservoirs located on high land. During times of low demand, e.g., at night, electricity generated by coal or nuclear, pumps water uphill. Later, when the demand peaks, the water is released, flowing downhill to generate electricity.

(Courtesy of Carolina Power and Light Company)

Solar

11 MW solar power plant near Serpa, Portugal

Solar heating systems are a well known second-generation technology and generally consist of solar thermal collectors, a fluid system to move the heat from the collector to its point of usage, and a reservoir or tank for heat storage and subsequent use. The systems may be used to heat domestic hot water, swimming pool water, or for space heating.[12] The heat can also be used for industrial applications or as an energy input for other uses such as cooling equipment.

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Tidal wave

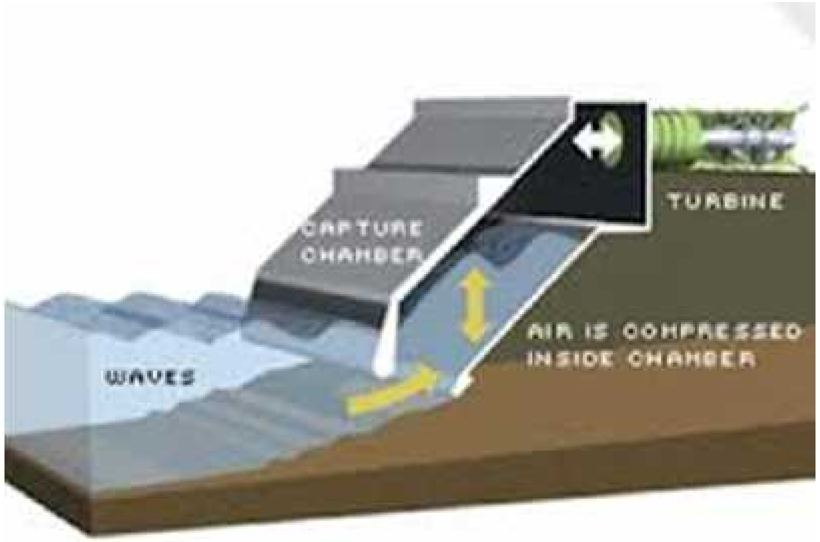
The term **tidal wave** may refer to:a gigantic wave caused by the force of the moon and sun

A tidal bore, which is a large movement of water formed by the funnelling of the incoming tide into a river or narrow bay

A storm surge, or tidal surge, which can cause waves that breach flood defences

A tsunami also called tidal wave, or harbor wave, although this usage is not favored by the scientific community due to tsunamis not being tidal.

A Megatsunami, which is an informal term to describe a tsunami that has initial wave heights that are much larger than normal tsunamis



❖Wind

Wind power is the conversion of wind energy into a useful form of energy, such as using: wind turbines to make electricity, windmills for mechanical power, windpumps for water pumping or drainage, or sails to propel ships.

A large wind farm may consist of several hundred individual wind turbines which are connected to the electric power transmission network. Offshore wind farms can harness more frequent and powerful winds than are available to land-based installations and have less visual impact on the landscape but construction costs are considerably higher. Small onshore wind facilities are used to provide electricity to isolated locations and utility companies increasingly buy back surplus electricity produced by small domestic wind turbines.[1]

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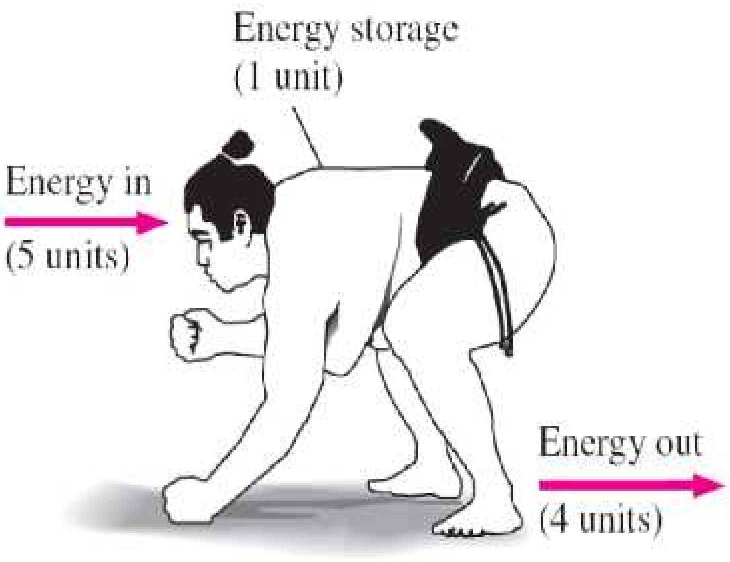
Energy "activity, operation"

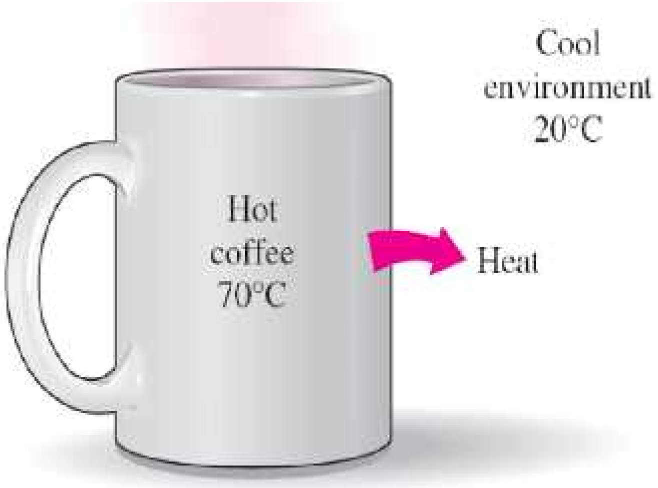
is an indirectly observed quantity that is often understood as the ability of a physical system to do work on other physical systems.[2][3] Since work is defined as a force acting through a distance (a length of space), energy is always equivalent to the ability to exert pulls or pushes against the basic forces of nature, along a path of a certain length.

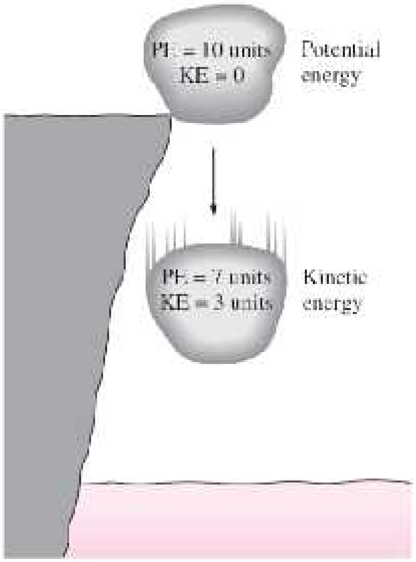
The total energy contained in an object is identified with its mass, and energy cannot be created or destroyed. When matter (ordinary material particles) is changed into energy (such as energy of motion, or into radiation), the **mass** of the system does not change through the transformation process. However, there may be mechanistic limits as to how much of the matter in an object may be changed into other types of energy and thus into work, on other systems. Energy, like mass, is a scalar physical quantity. In the International System of Units (SI), energy is measured in joules, but in many fields other units, such as kilowatt-hours and kilocalories, are customary. All of these units translate to units of work, which is always defined in terms of forces and the distances that the forces act through.
A system can transfer energy to another system by simply transferring matter to it.
when energy is transferred by means other than matter-transfer, the transfer produces changes in the second system, as a result of work done on it. This work manifests itself as the effect of force(s) applied through distances within the target system. For example, a system can emit energy to another by transferring (radiating) electromagnetic energy, but this creates forces upon the particles that absorb the radiation.

A system may transfer energy to another by physically impacting it, but in that case the energy of motion in an object, called kinetic energy.

Transfer of thermal energy by heat occurs by both of these mechanisms: heat can be transferred by electromagnetic radiation, or by physical contact in which direct particle-particle impacts transfer kinetic energy.







potential energy. A simple example of potential energy is the work needed to lift an object in a gravity field, up to a support. Each of the basic forces of nature is associated with a different type of potential energy, and all types of potential energy (like all other types of energy) appears as system mass, whenever present. For example, a compressed spring will be slightly more massive than before it was compressed. Likewise, whenever energy is transferred between systems by any mechanism, an associated mass is transferred with it.

Any form of energy may be transformed into another form. For example, all types of potential energy are converted into kinetic energy when the objects are given freedom to move to different position (as for example, when an object falls off a support).

Exergy

In thermodynamics, the **exergy** of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir.[1] When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero. Determining exergy was also the first goal of thermodynamics.

Energy is never destroyed during a process; it changes from one form to another (*see First Law of Thermodynamics*). In contrast, exergy accounts for the irreversibility of a process due to increase in entropy (*see Second Law of Thermodynamics*). Exergy is always destroyed when a process involves a temperature change.

Anergy

This destruction is proportional to the entropy increase of the system together with its surroundings. The destroyed exergy has been called **anergy**.[1] For an isothermal process, exergy and energy are interchangeable terms, and there is no anergy.

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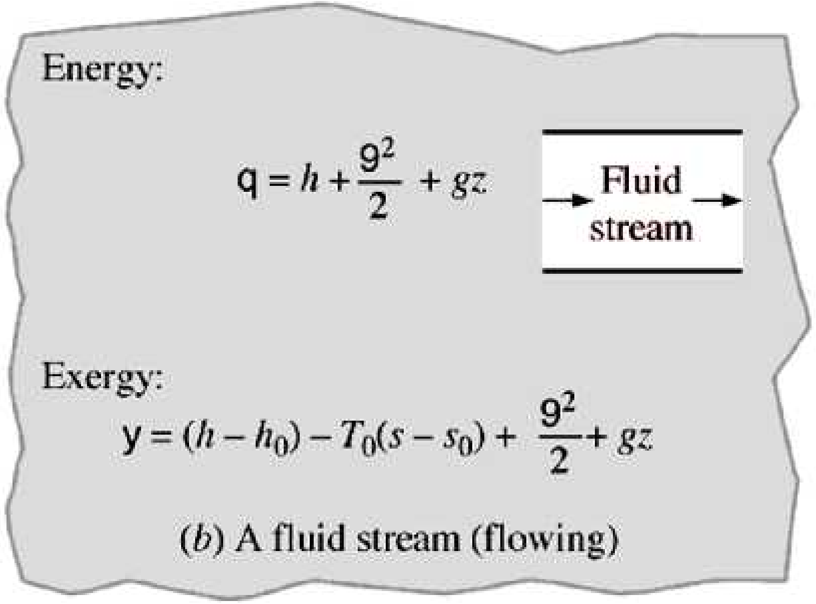
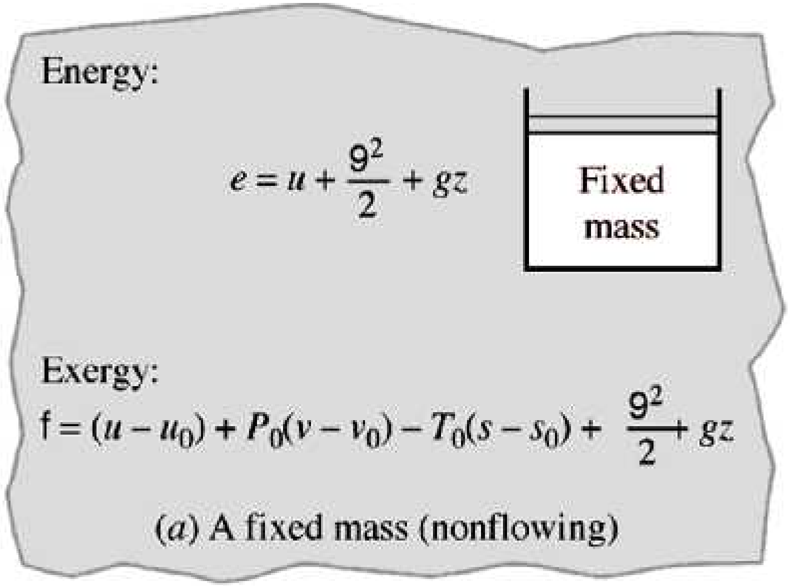
The *Energy* and *Exergy* contents of (a) a Fixed Mass and (b) a Fluid System



(*b*) A fluid stream (flowing)



(*a*) A fixed mass (nonflowing)

Forms of energy

In the context of physical sciences, several forms of energy have been defined. These include:

- Thermal energy, thermal energy in transit is called heat
- Chemical energy
- Electric energy
- Radiant energy, the energy of electromagnetic radiation
- Nuclear energy
- Magnetic energy
- Elastic energy
- Sound energy
- Mechanical energy
- Luminous energy
- Mass ($E=mc^2$)

- The above list of the known possible forms of energy is not necessarily complete. Whenever physical scientists discover that a certain phenomenon appears to violate the law of energy conservation, new forms may be added, as is the case with dark energy, a hypothetical form of energy that permeates all of space and tends to increase the rate of expansion of the universe.

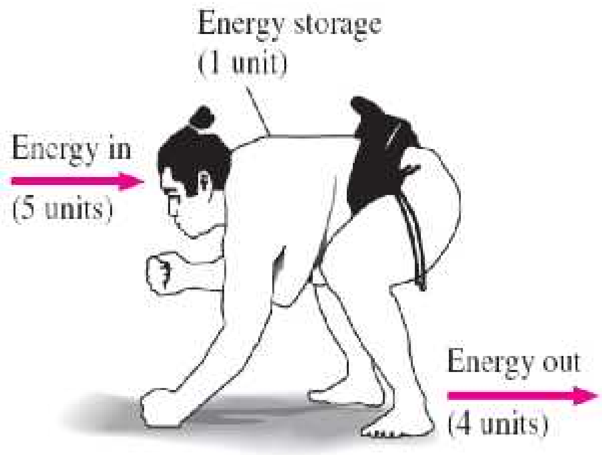
Classical mechanics distinguishes between potential energy, which is a function of the position of an object, and kinetic energy, which is a function of its movement. Both position and movement are relative to a frame of reference, which must be specified: this is often (and originally) an arbitrary fixed point on the surface of the Earth,

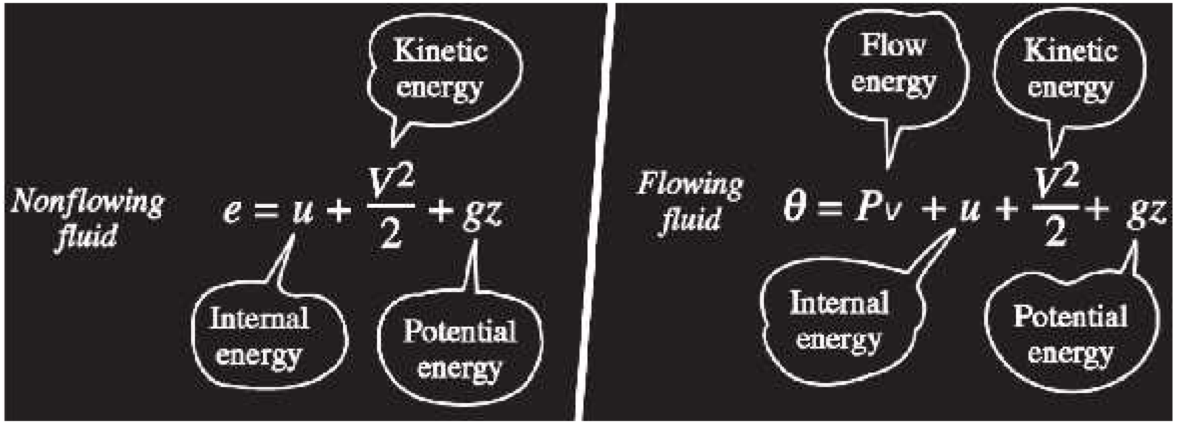
Transformations of energy

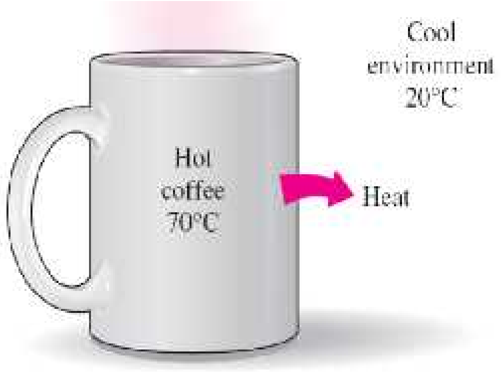
One form of energy can often be readily transformed into another with the help of a device- for instance, a battery, from chemical energy to electric energy; a dam: gravitational potential energy to kinetic energy of moving water (and the blades of a turbine) and ultimately to electric energy through an electric generator. Similarly, in the case of a chemical explosion, chemical potential energy is transformed to kinetic energy and thermal energy in a very short time. Yet another example is that of a pendulum. At its highest points the kinetic energy is zero and the gravitational potential energy is at maximum. At its lowest point the kinetic energy is at maximum and is equal to the decrease of potential energy. If one (unrealistically) assumes that there is no friction, the conversion of energy between these processes is perfect, and the pendulum will continue swinging forever.

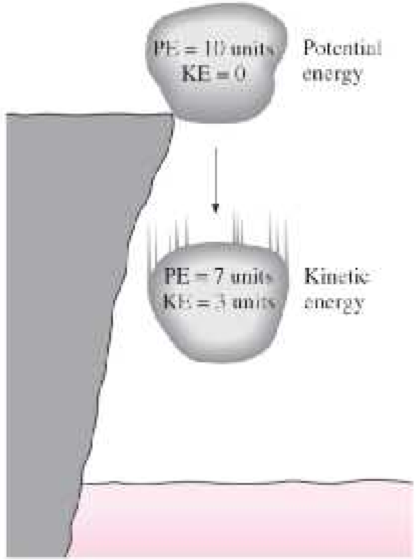
Matter may be destroyed and converted to energy (and vice versa), but mass cannot ever be destroyed; rather, mass remains a constant for both the matter and the energy, during any process when they are converted into each other.

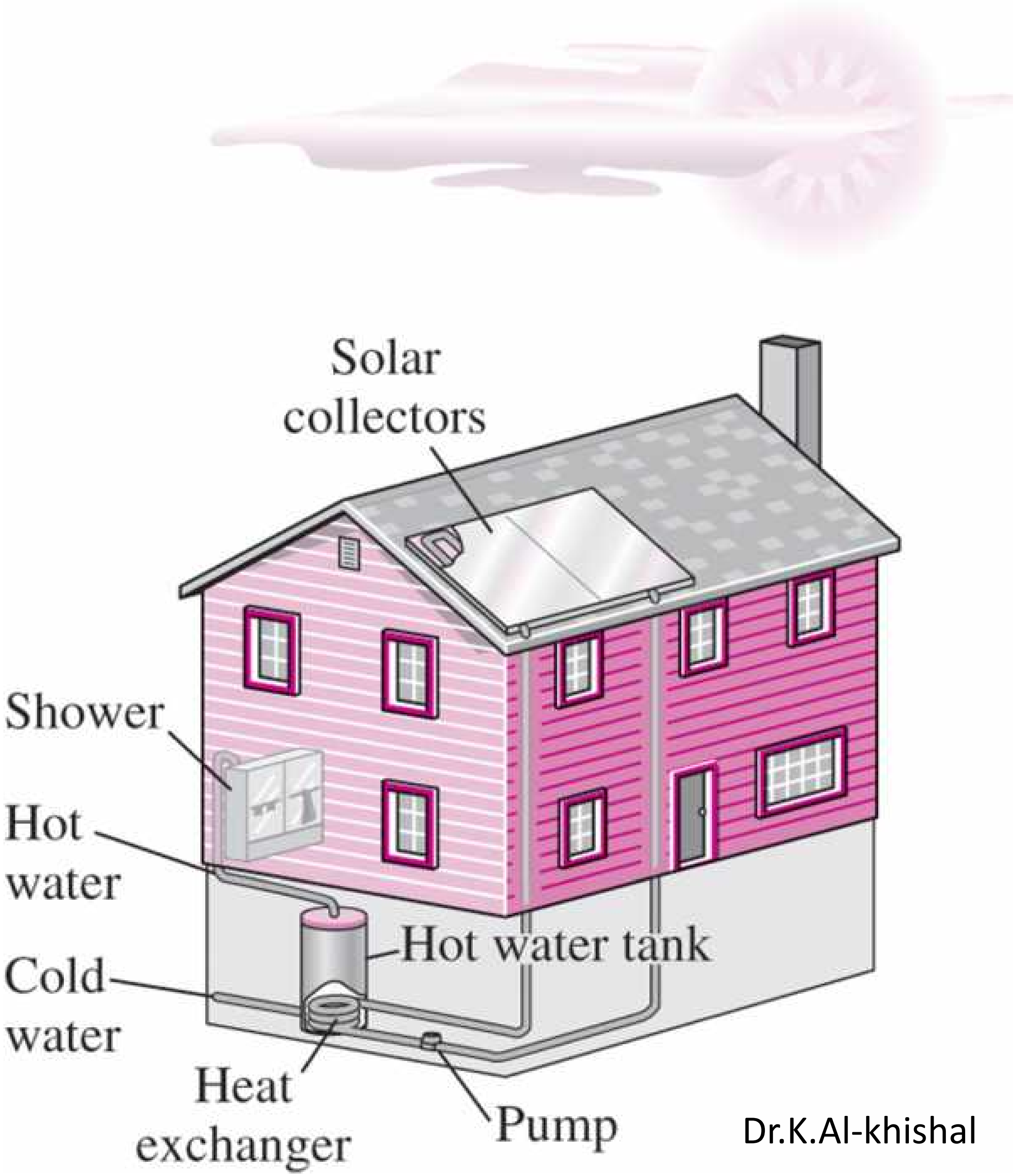
In a typical lightning strike, 500 megajoules of electric potential energy are converted into 500 megajoules (total) of light energy, sound energy, thermal energy, and so on.






Cool
environment
20°C
Hot
coffee
70°C
Heat


PE = 10 units
KE = 0
Potential
energy
PE = 7 units
KE = 3 units
Kinetic
energy


Solar
collectors
Shower
Hot
water
Hot water tank
Cold
water
Heat
exchanger
Pump

Q1) What is meant by Sustainable energy ?

Answer : It is the sustainable provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs. Technologies that promote sustainable energy include renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, geothermal energy, and tidal power, and also technologies designed to improve energy efficiency.

Q2) explaining breifly 5 types of renewable energy sources with the necessary drawings.

Answer: hydroelectricity, solar energy, wind energy, wave power, geothermal energy, and tidal power,

Q3) What is meant by Anaerobic digestion Biomass Geothermal Hydroelectricity Solar Tidal Wind Biomass biofuel biodiesel biogas . Give the necessary information and drawings.

Answer:

Q4) What is Energy Exergy and Anargy . Give the necessary relations and drawings

Q5) What are the forms of energy? Give the necessary drawings and explanation of each one .

•**Answer:** Thermal energy, thermal energy in transit is called heat Chemical energy

•Electric energy Radiant energy, the energy of electromagnetic radiation

•Nuclear energy Magnetic energy Elastic energy Mechanical energy

•Luminous energy Mass ($E=mc^2$)

•**Q6) What is meant by transformation of energy?**

Energy conservation

LectureTwo

Monitoring and modeling energy flow systems

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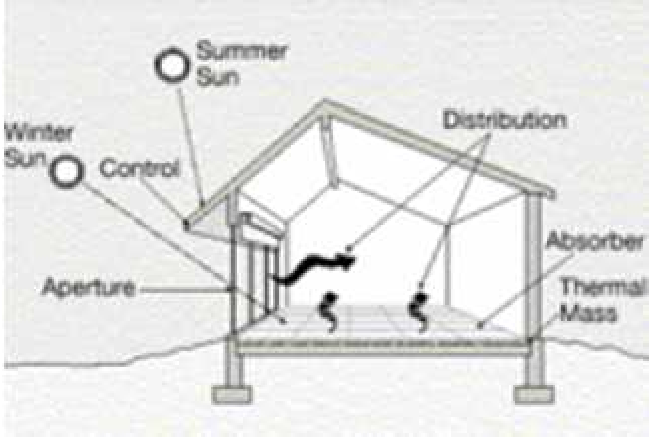

This is Environmental Control

Environmental Control allows people with disabilities to control functions in their own living space. This could include opening doors and windows for instance, or functions such as controlling a door intercom system, lights, a telephone, bed functions, TV, DVD player, cable TV boxes, and the stereo.

Transmitters operate using infrared light (IR) to control functions wirelessly. This is a safe, powerful, and user-friendly system which provides the user with complete independence.

Modeling ENERGY FLOW systems

An assessment of the energy flows of a building equipped with machine tools and discusses options to optimize its energy efficiency. The energy flows in the buildings are recorded based on collected data and measurement results. Based on the measurements and the assumptions made, the energy flows shown in fig. 4 arise. For the energy consumptions of office equipment, lights, safety installations, central IT-systems, etc.

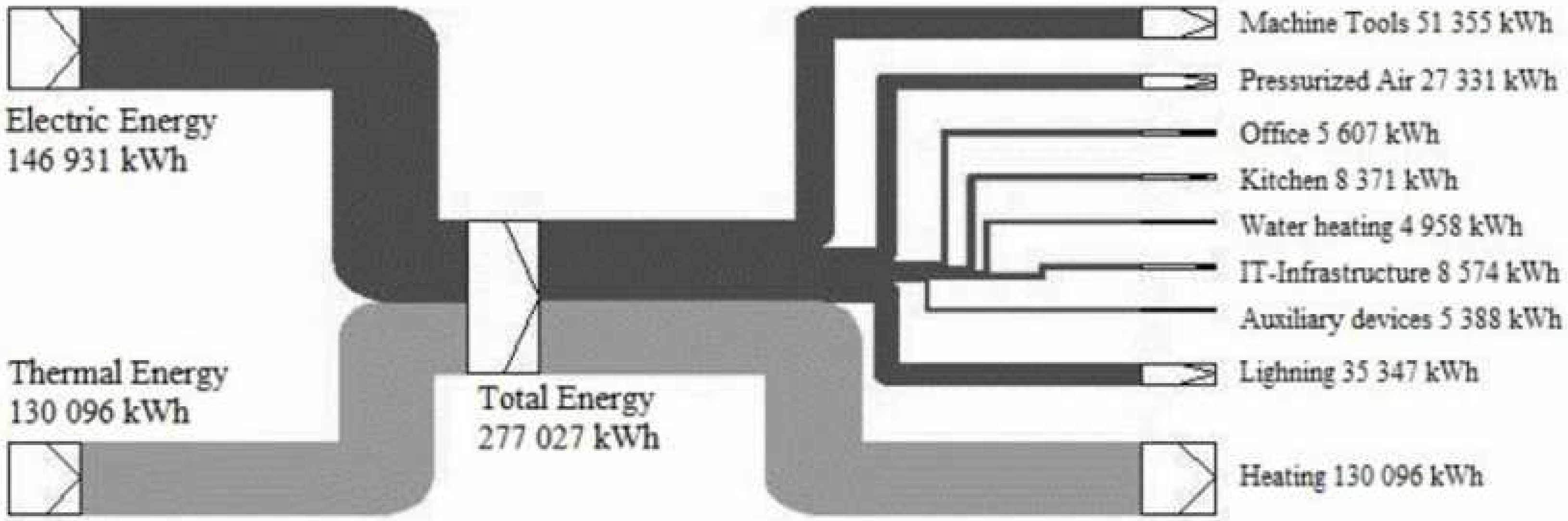

Fig. 4: Energy Flows in the Building, present status

All available data of the existing building were collected, with special focus on:

- Building structure and building services
  - o General data about the building e.g. location, size
  - o Wall construction, windows
  - o Ventilation devices
  - o Heating systems
- Employees, machine tools and equipment
- Thermal energy demand
- Electric energy demand

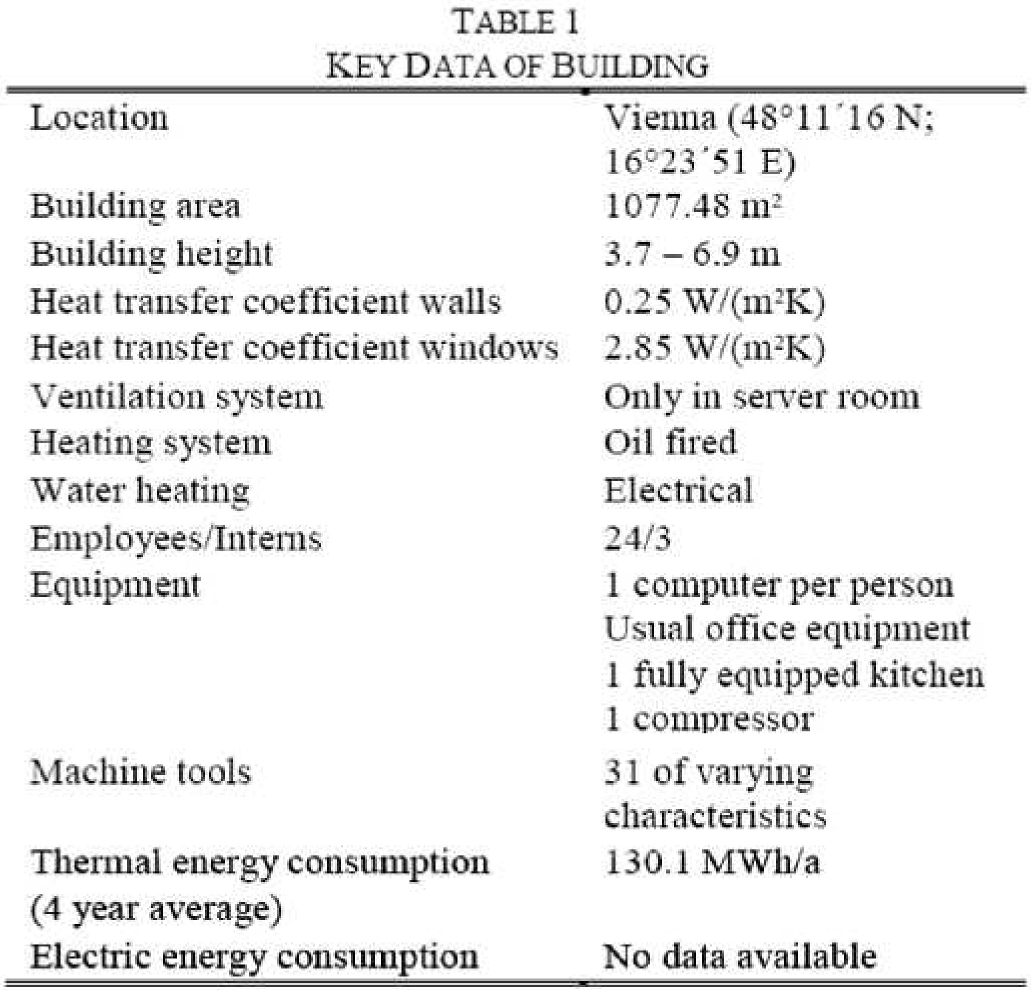

TABLE 1
KEY DATA OF BUILDING

Location	Vienna (48°11´16 N; 16°23´51 E)
Building area	1077.48 m^2
Building height	3.7 – 6.9 m
Heat transfer coefficient walls	0.25 $W/(m^2K)$
Heat transfer coefficient windows	2.85 $W/(m^2K)$
Ventilation system	Only in server room
Heating system	Oil fired
Water heating	Electrical
Employees/Interns	24/3
Equipment	1 computer per person Usual office equipment 1 fully equipped kitchen 1 compressor
Machine tools	31 of varying characteristics
Thermal energy consumption (4 year average)	130.1 MWh/a
Electric energy consumption	No data available

To assess the usefulness of optimization measures, the building was first simulated in the existing condition. The parameters of the simulation were selected in order that the simulation results showed consistency with the results of the measurements. To specify the waste heat emitted by the machine tools a balance was drawn around the system “machine tool” see fig(٥). : Energy and mass balance around machine tool

The entering electric energy can leave the machine only as thermal energy or stored in the work piece and chips. This stored energy consists of the energy spent generating a new surface and the deformation of the chips. Calculations according to [10] showed that these parts of the energy are only a small fraction of the thermal energy leaving the balance. Therefore we assumed that all the electric energy consumed by the machine tools is converted into heat, which again is distributed into the room. Unfortunately the waste heat of the machine tools is at a very low temperature level and the machines have internal cooling circuits, which makes the use of the waste heat in a thermal system impossible.

Table 2 gives an overview of the characteristics of the simulation carried out in TRNSYS. Fig. 4: Energy Flows in the Building, present status Recent Researches in Geography, Geology, Energy, Environment and Biomedicine
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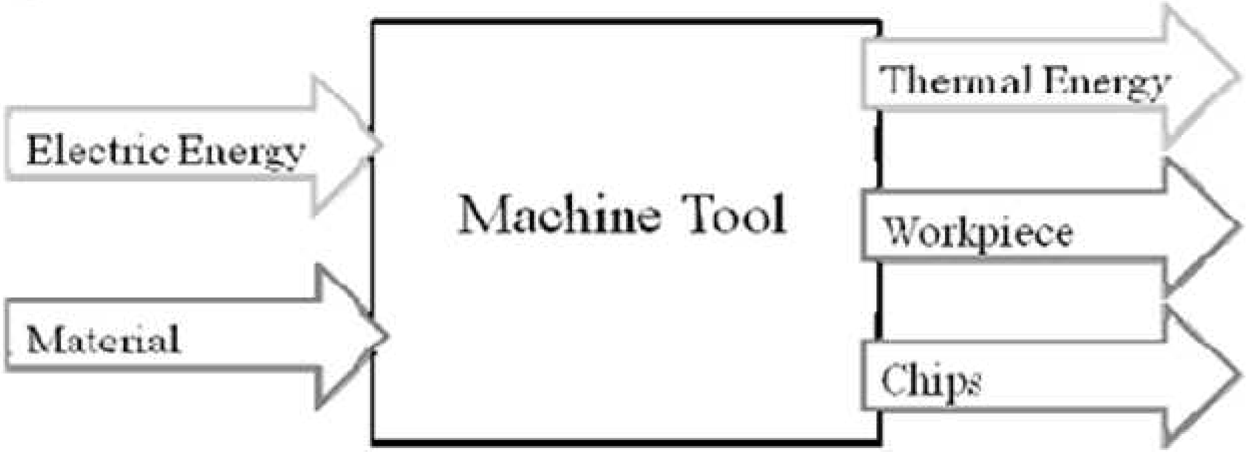

Fig. 5: Energy and mass balance around machine tool

In the next step optimization measures were implemented in the simulation. At first 8 cm of further isolation was applied to the outside walls and ceiling and the heating control strategy was changed from outside temperature controlled to room temperature controlled. This lead to a reduction of the thermal energy demand for heating from 120.7 kWh/(m²a) to 75.7 kWh/(m²a) according to the simulation. Along with that, the thermal comfort in the building was enhanced because the new control strategy prevented frequent overheating.

Furthermore, photovoltaic cells and a solar collector for water heating were installed on the roof. The implementation of advanced technologies to cover the energy demand, such as geothermal energy or large thermal storage devices was not possible due to environmental restrictions. Table 3 and 4 summarize the most important technical data of the installed systems.

According to the simulation the photovoltaic cells produced 37.6 MWh of electric energy during the year of which 34 MWh were consumed by the facility itself and 3,7 MWh were supplied into the grid. The solar collector produced 2.9 MWh of thermal energy during the year and reached a solar fraction of 81.3% when combined with a heat storage boiler of 1 m³ (largest possible due to room geometry).

According to the simulation 46.4 MWh or 16.7% of the total energy consumption could be saved by reducing the heating demand through improved control strategies. 37.4 MWh or 13.5% of the energy demand drawn from the grid could be substituted by solar energy converted in photovoltaic and solar collectors installed on the building (service water was heated electrically).

Based on these results Fig. 6 shows the energy flows calculated by the simulation after the implementation of all the suggested optimization strategies. It shows a reduced thermal energy consumption from oil and electric energy sources due to the energy savings and the substitution by photovoltaic cells and solar collectors on the input side.

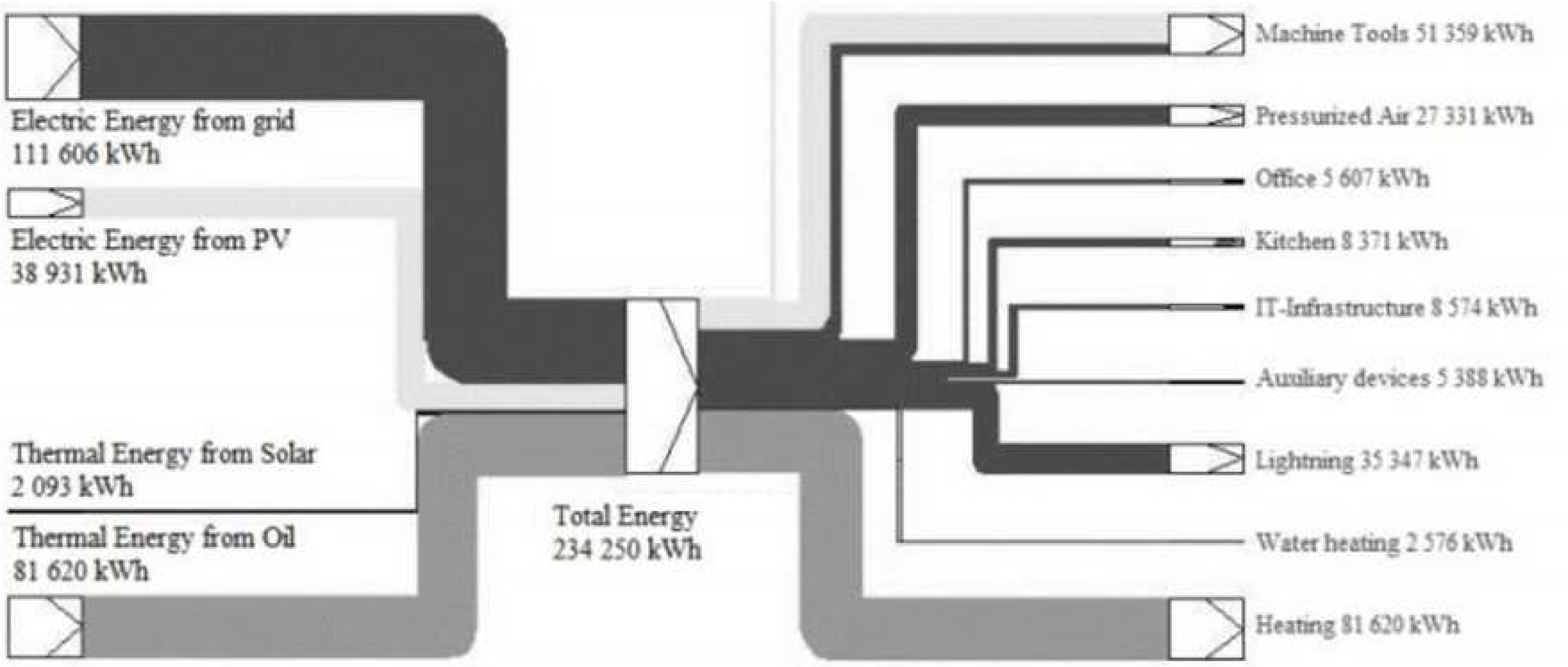

Fig. 6: Energy Flows in the Building, after optimization

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Q7) What is meant by Environmental Control?

Q8) Suggest a reduction of energy for the following building. give the necessary information needed for this purpose. Draw the final shape of the system obtained.

Q9) What are the factors effecting the modeling the energy flow in a building

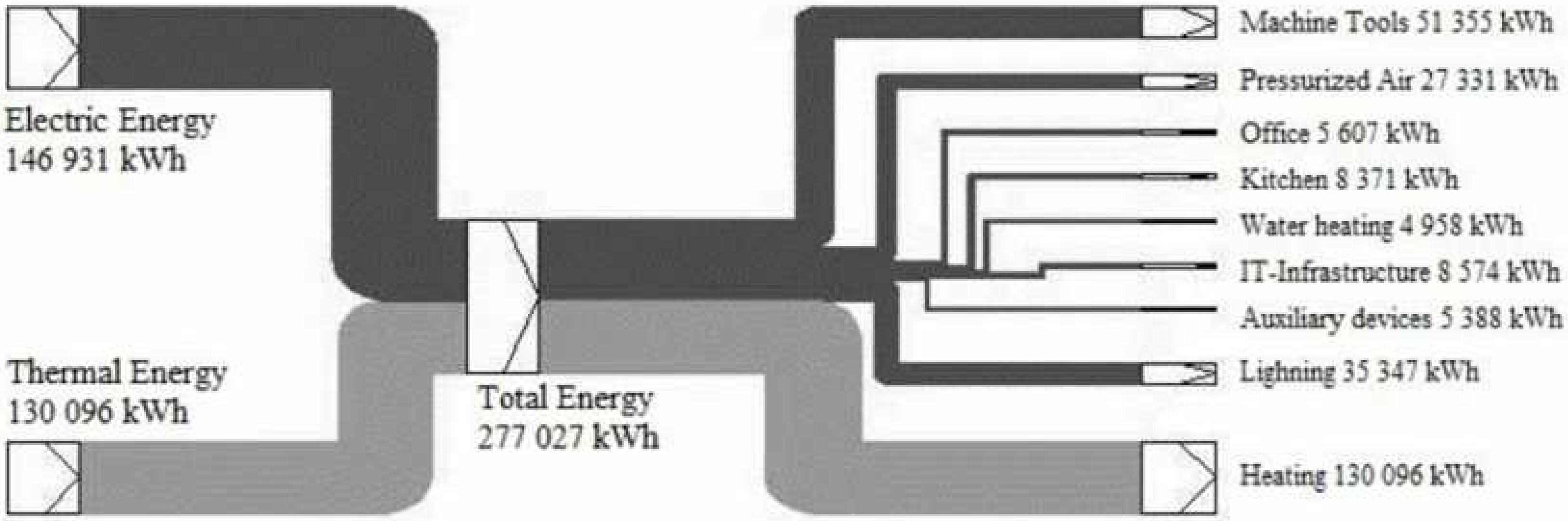
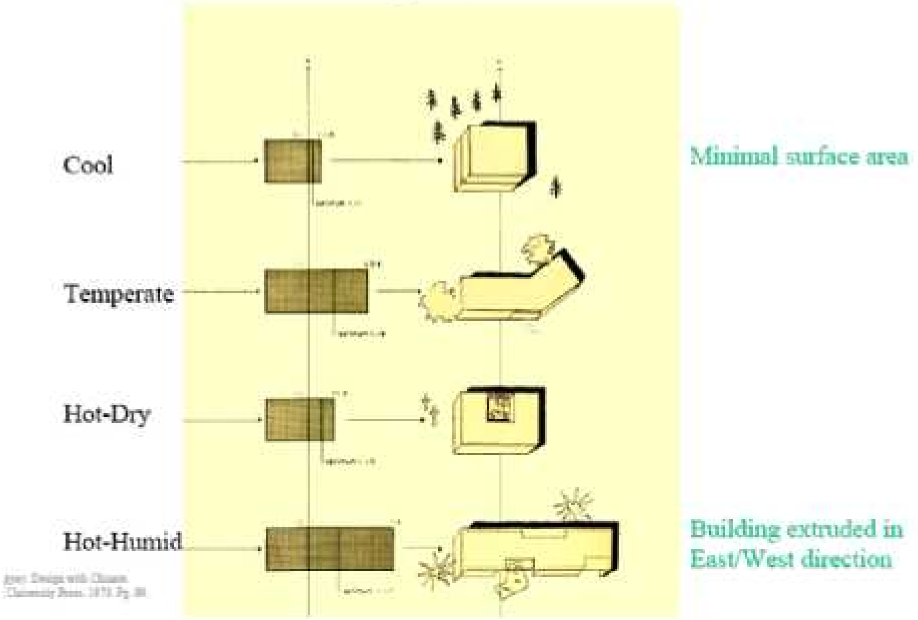
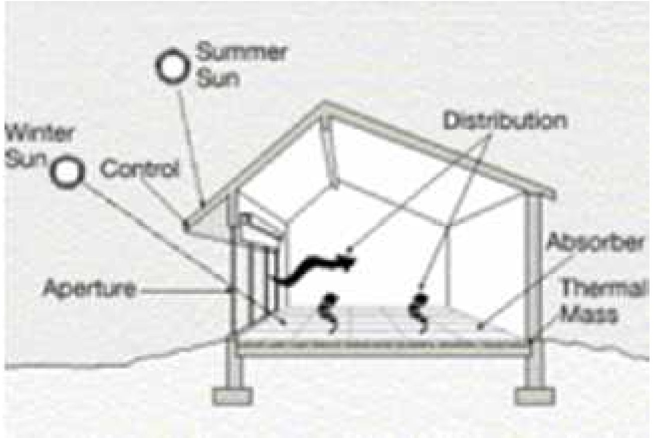


Fig. 4: Energy Flows in the Building, present status

Energy conservation

Form, Massing and Orientation





Lecture Three

Energy conservation in building corresponding to human comfort

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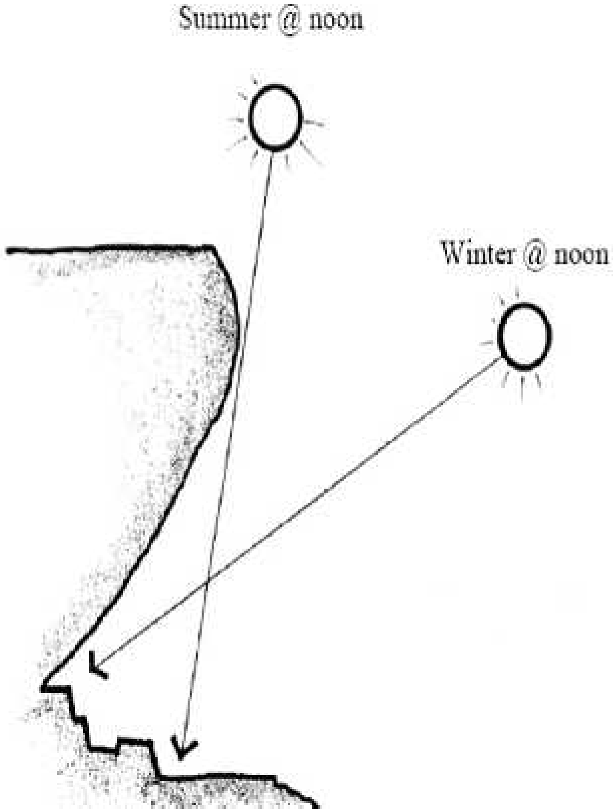

Solar Impact on Architecture

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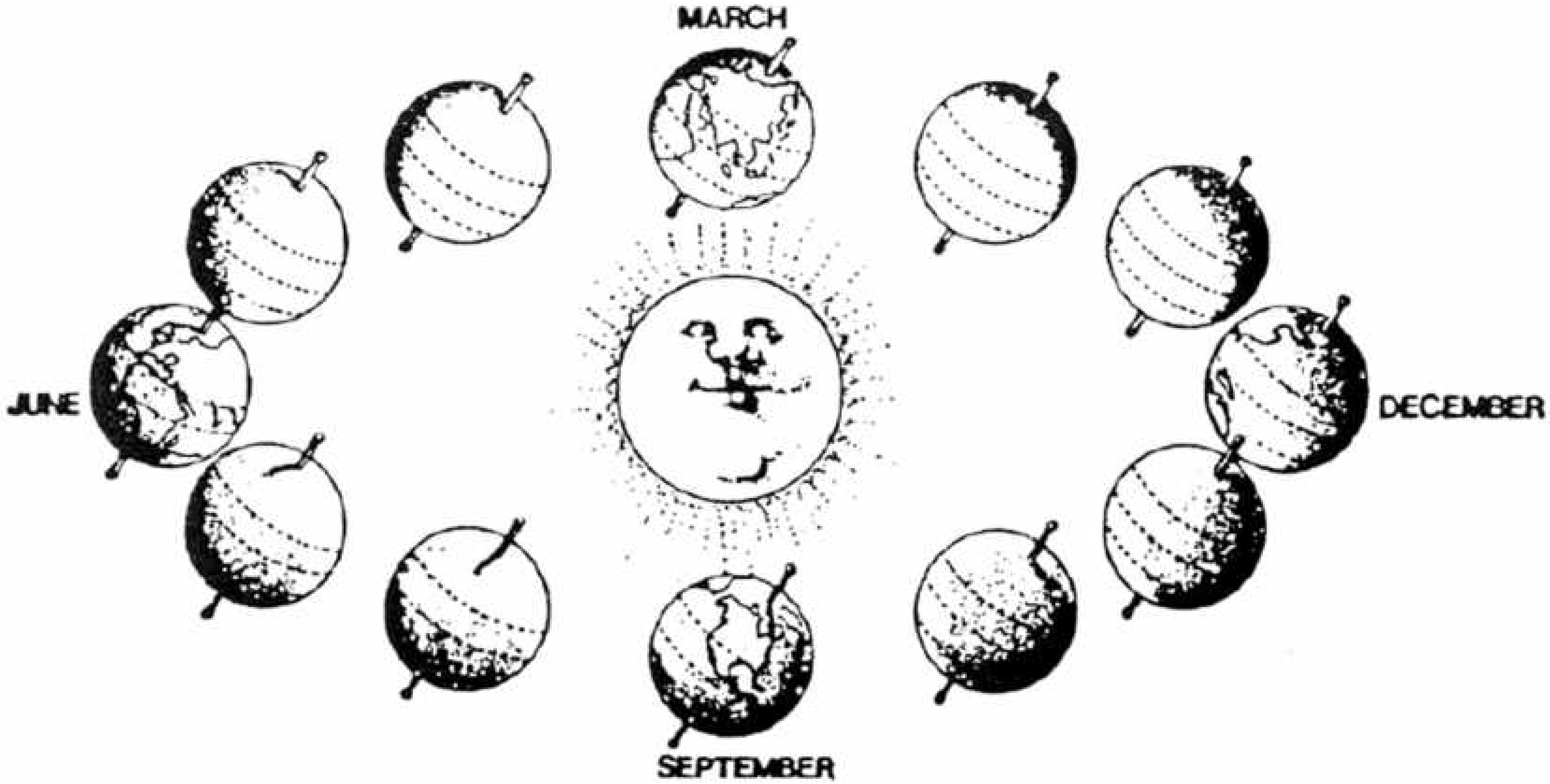
Solar Geometry: Celestial Perspective



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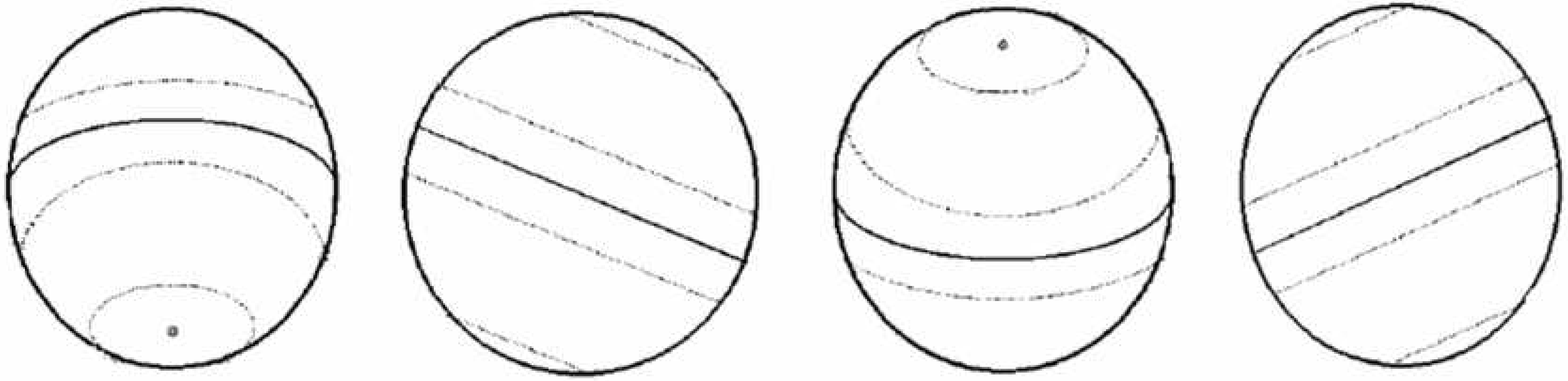
View of Earth from Sun



Dec.

Shortest day in N.H.

Longest day in S.H.

March

Equal day and night every where on planet

June

Longest day in N.H.

Shortest day in S.H.

Sept.

Equal day and night every where on planet

Latitude Variation

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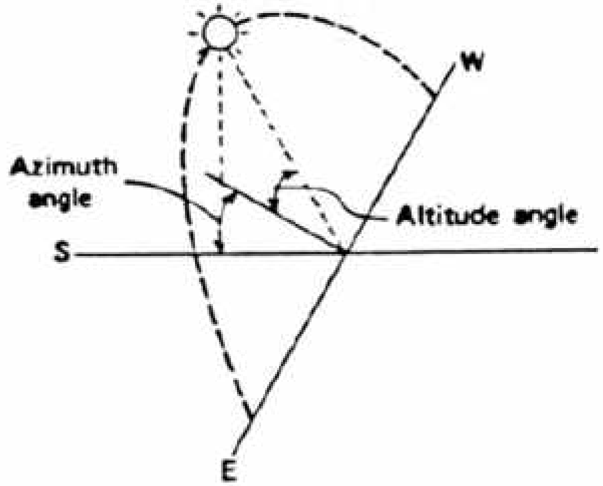
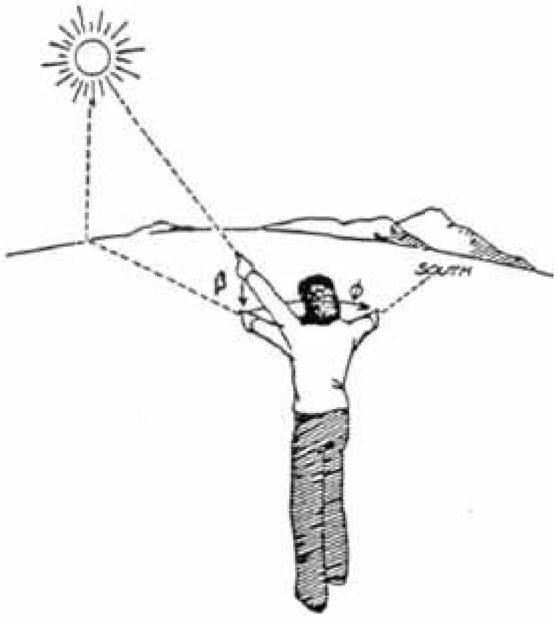
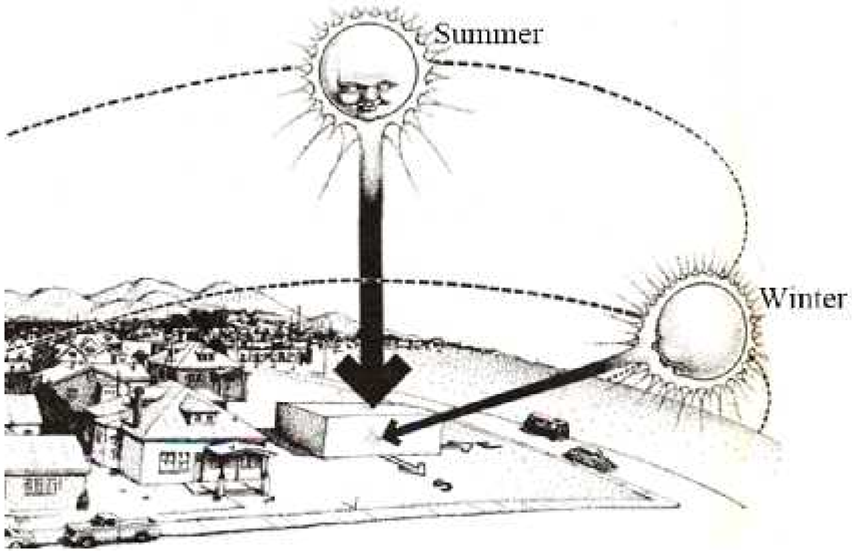
Altitude Angle & Azimuth Angle

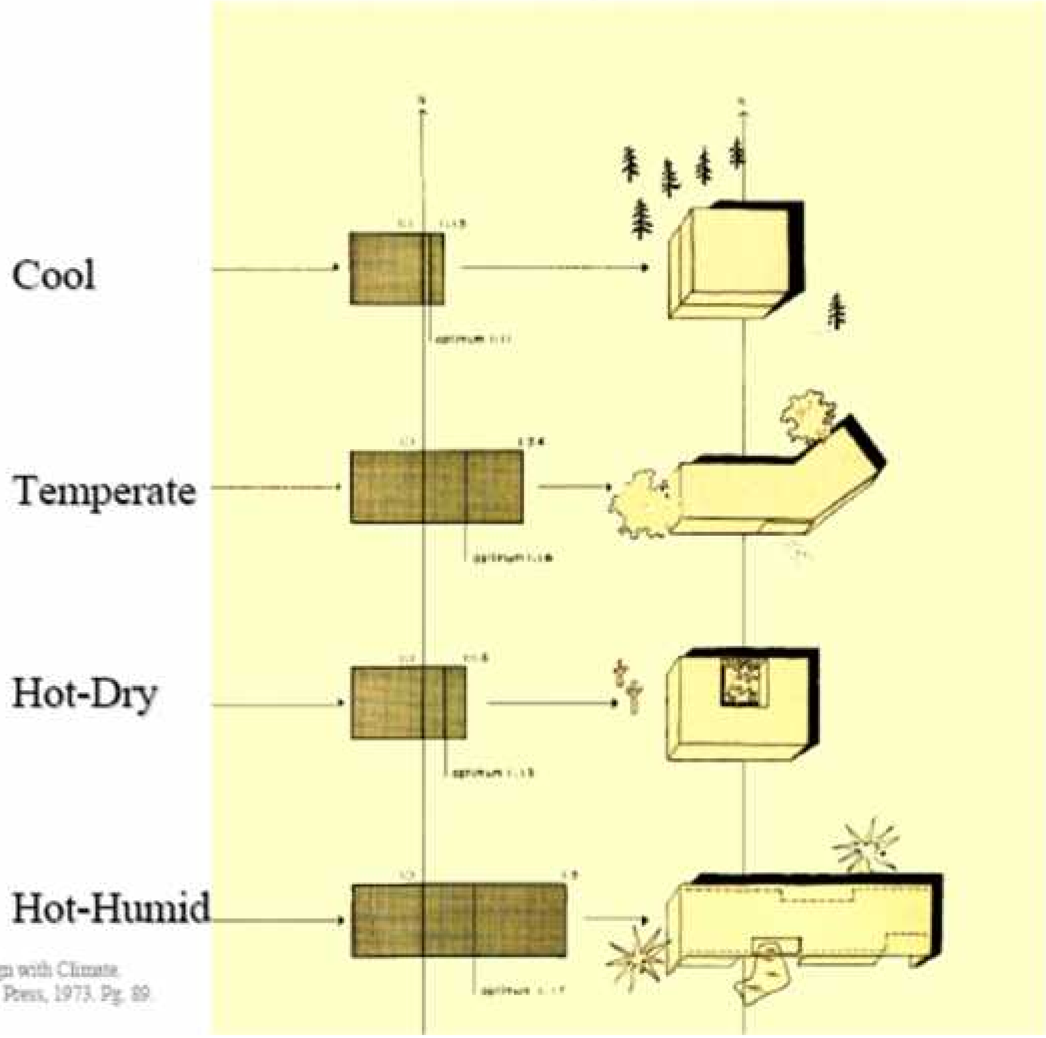




Terrestrial Perspective



Form, Massing and Orientation



Cool

Temperate

Hot-Dry

Hot-Humid

Minimal surface area

Building extruded in
East/West direction

gyay. Design with Climate.
University Press, 1973. Pg. 89.

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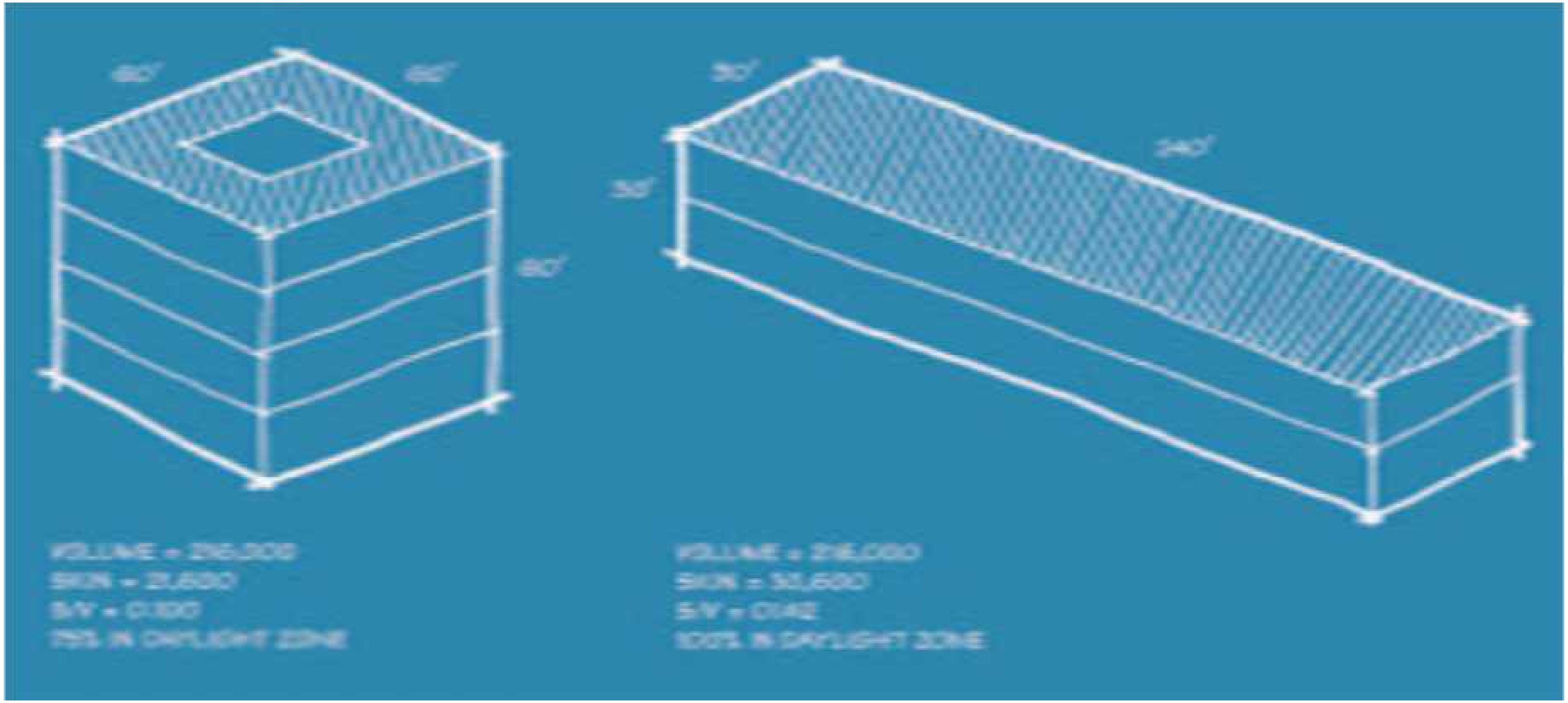
Building Massing and Orientation

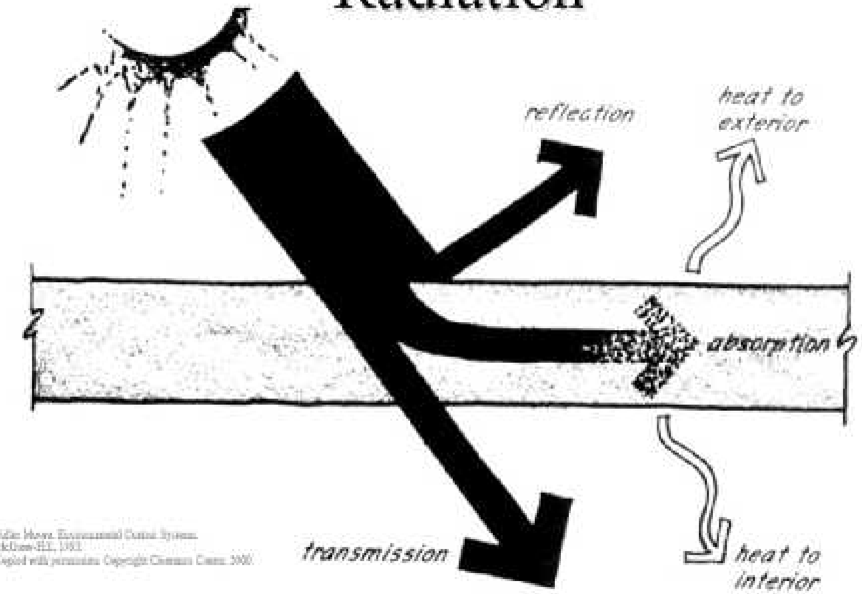
There is a trade-off between a compact form that minimizes conductive heat transfer through the envelope and a form that facilitates day lighting, solar gain, and natural ventilation. **The most compact building would appropriable in the shape of a cube and would have the least losses and gains through the building skin.** However, except in very small buildings, much of the floor area in stages a square building is far from the perimeter day lighting. A building that optimizes day lighting and natural ventilation would be shaped so that more of the floor area is close to the perimeter. While a narrow shape may appear to compromise the thermal performance of the building, the electrical load and cooling load savings achieved by a well-designed day lighting system will more than compensate for the increased skin losses. Effective day lighting depends on apertures of appropriate size and orientation, with interior or exterior shading devices to control unwanted direct sunlight.-



Volume	216000	216000
Skin	21800	30600
S/V	0.1	0.148
70% daylight zone		100% DAYLIGHT ZONE

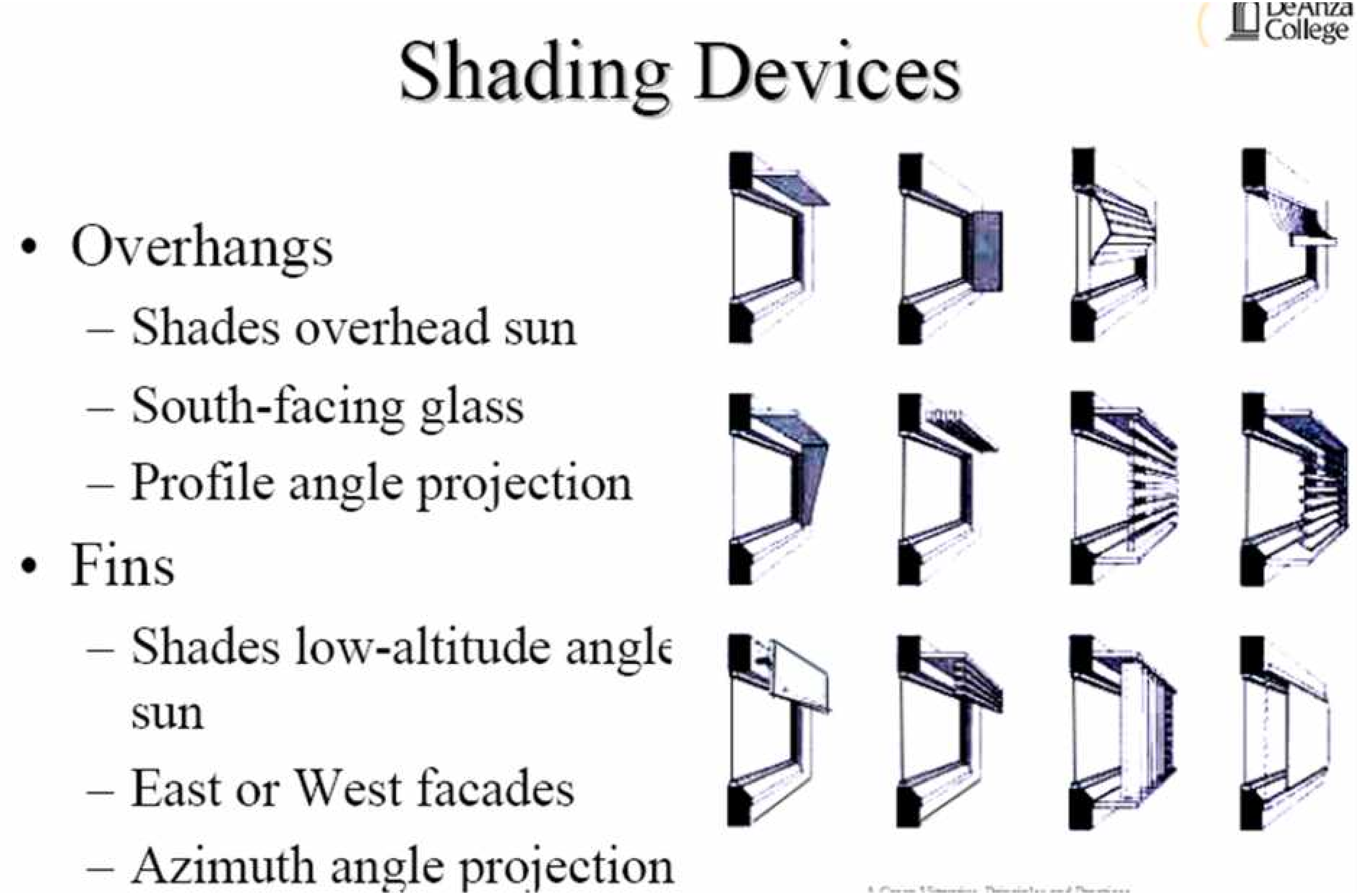
The skin-to-volume ratio is the exposed surface area compared to the building volume.

Radiation



Color and Radiation

- Reflectance/Absorbtance of Solar Radiation
- Reflectance/Emissivity of Long-Wave IR Radiation



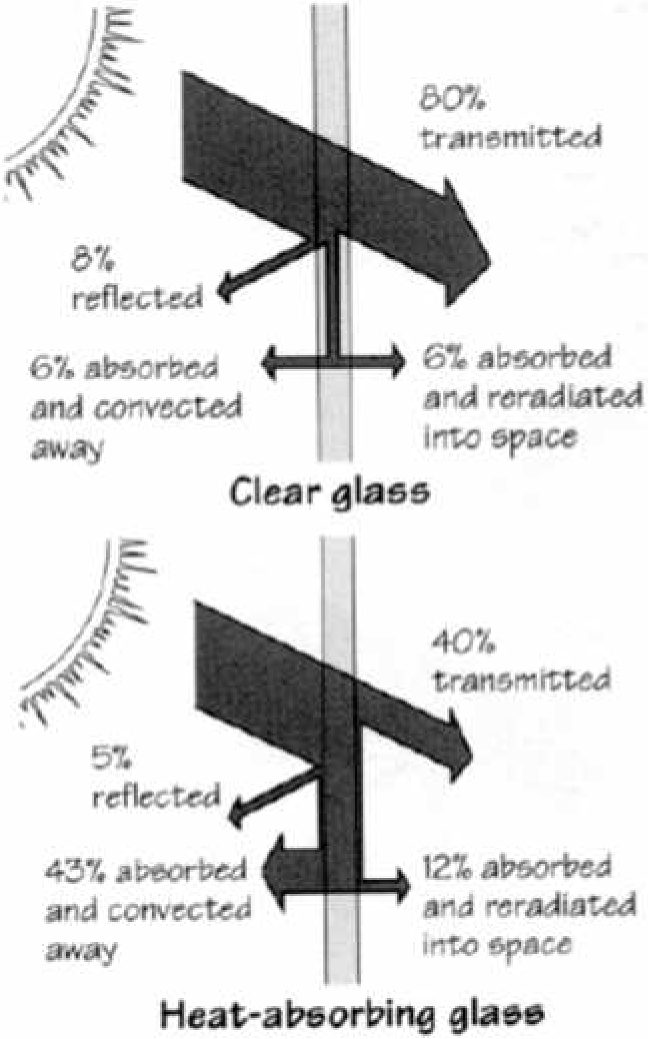
DeAnza College

Shading Devices

- Overhangs
  - Shades overhead sun
  - South-facing glass
  - Profile angle projection
- Fins
  - Shades low-altitude angle sun
  - East or West facades
  - Azimuth angle projection

Solar Wavelengths Striking Glass Are:

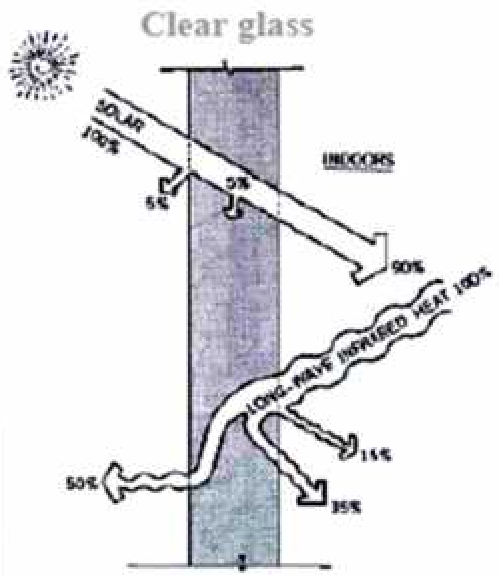
- Transmitted
- Absorbed
- Reflected

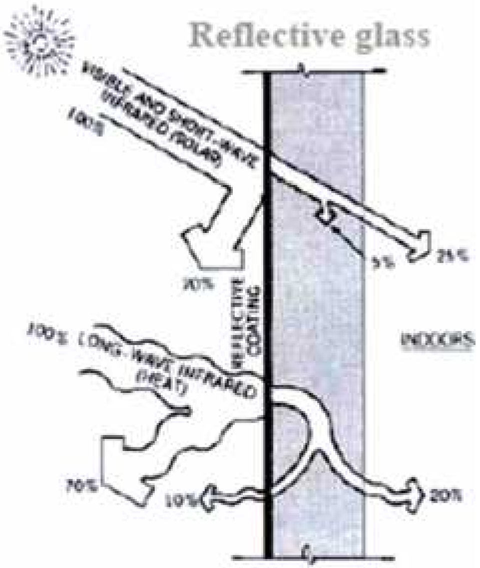


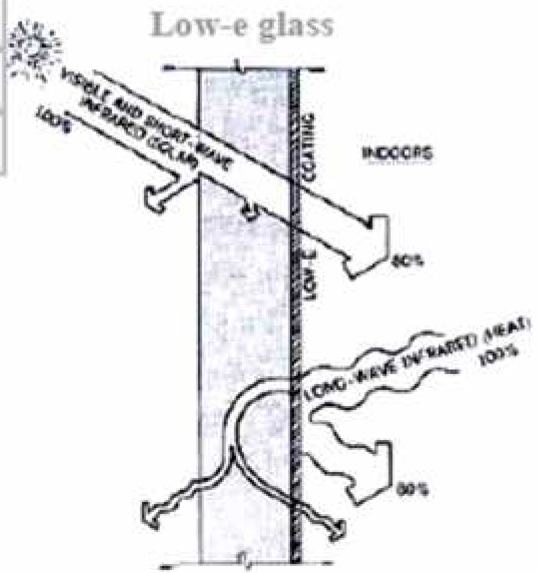
Glass Transmission

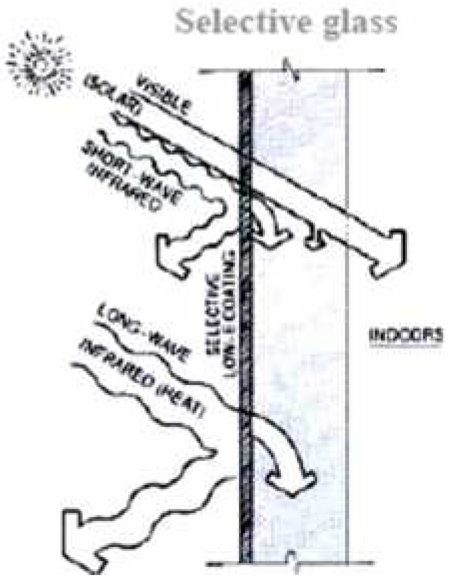
Transmits	UV	Visible light	Short wave IR (solar)	Long wave IR (earth)
Clear glass	X	X	X	X*
Reflective glass				
Low-e glass	X	X	X	
Selective glass		X		

*Absorbs and re-radiates long-wave


Clear glass


Reflective glass


Low-e glass


Selective glass

Norbert Lechner. Heating, Cooling, Lighting: Design Methods for Architects.
John Wiley& Sons, 1991. Pg. 361,362.

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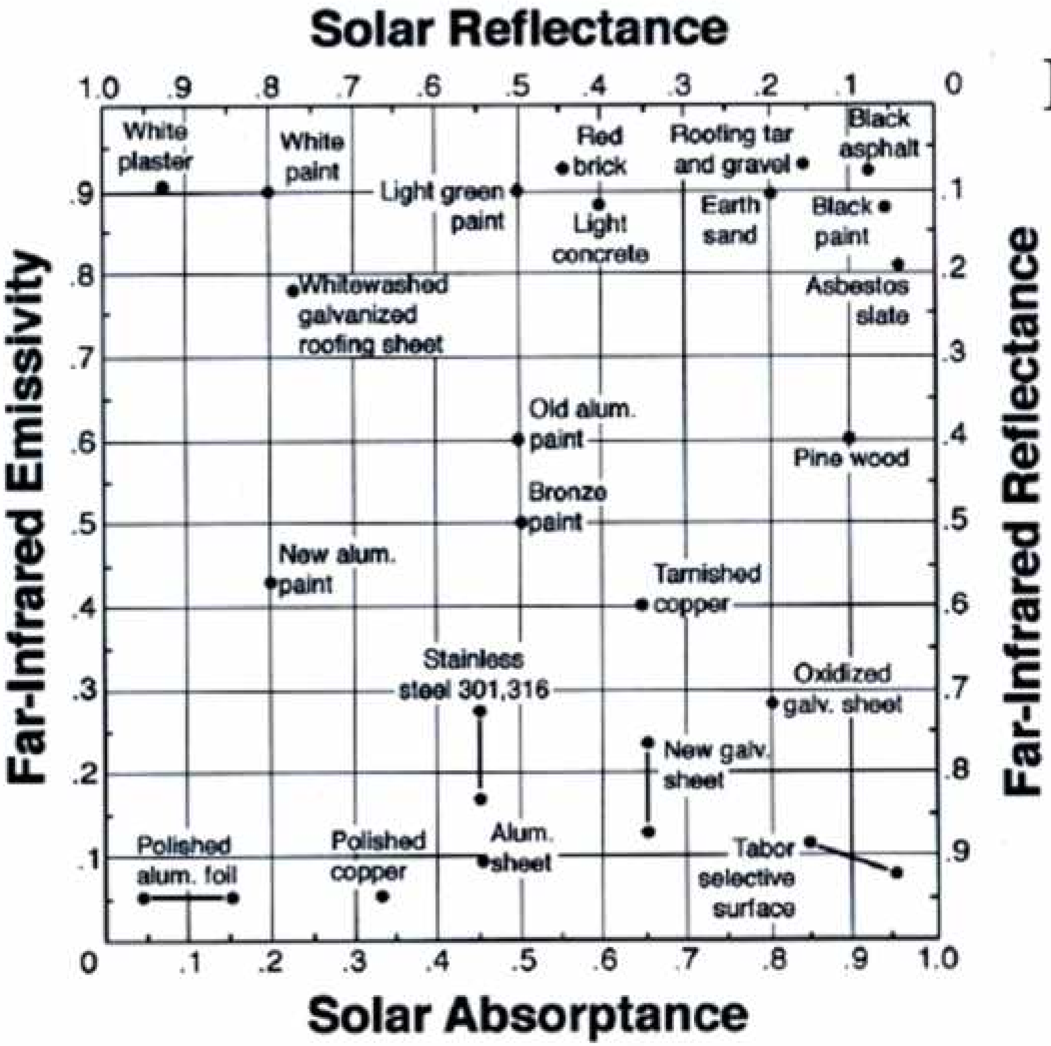
Roof/Wall Color



Desired attributes

- High solar reflectance
- High far IR emissivity

Donald watson - editor. Time-saver standards for Architectural Design Data.

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Thermal comfort

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation(ANSI/ASHRAE Standard 55[1]).

Maintaining this standard of thermal comfort for occupants of buildings or other enclosures is one of the important goals of HVAC (heating, ventilation, and air conditioning) design engineers.

Thermal comfort is affected by heat conduction, convection, radiation, and evaporative heat loss. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. It has been long recognized that the sensation of feeling hot or cold is not just dependent on air temperature alone.

Effects of thermal discomfort

Thermal discomfort has been known to lead to sick building syndrome symptoms.[3][4] The combination of high temperature and high relative humidity serves to reduce thermal comfort and indoor air quality.[3] The occurrence of symptoms increased much more with raised indoor temperatures in the winter than in the summer due to the larger difference created between indoor and outdoor temperatures.

Factors determining thermal comfort

Metabolism Physiological factors such as age, activity, sex and health.

Clothing insulation The type of clothing has strong influence on the rate of heat transfer from the human body.

Relative humidity

Draft , air motion

Radiant Temperature Asymmetry dry bulb temperature

Floor Surface Temperature surrounding surface temperature.

Vertical Air Temperature Difference

Effects of natural ventilation on thermal comfort

Operative temperature This is the average of the air dry-bulb temperature and of the mean radiant temperature at the given place in a room.

Architectural programming involves an analysis of the required spaces to meet the functional and operational needs of the facility. With an eye toward sustainability and energy-efficiency targets, the individual spaces should be clearly described in terms of their:

- **Primary functions**
- **Occupancy and time of use**
- **Daylight potential and electric light requirements**
- **Indoor environmental quality standards**
- **Equipment and plug loads**
- **Acoustic quality**

Daylighting Benefits

- Enhances the quality of luminous environment.
- Reduces energy use from lighting and can save money.
- Reduces peak demand & associated charges.
- Can reduce cooling loads.
- Connects users to natural environment and characteristics of a given place
- Potential benefits in productivity

HUMAN THERMOREGULATION

The metabolic activities of the body result almost completely in heat that must be continuously dissipated and regulated to prevent abnormal body temperatures.

Insufficient heat loss leads to overheating also called hyperthermia, and excessive heat loss results in body cooling also called hypothermia. Skin temperatures greater than 45°C or less than 18°C cause pain (Hardy 1952). Skin temperatures associated with comfort at sedentary activities are 33 to 34°C and decrease with increasing activity (Fanger 1968). In contrast internal temperatures rise with activity. The temperature regulatory center in the brain is about 36.8°C at rest in comfort and increases to about 37.4°C when walking and 37.9°C when jogging. An internal temperature less than about 28°C can lead to serious cardiac arrhythmia and death and temperatures greater than 46°C can cause irreversible brain damage. Therefore, the careful regulation of body temperature is critical to comfort and health.

Inside design conditions for Winter:

T^{op} between 20.0 to 23.5^{o}C at a RH of 60%
T^{op} between 20.5 to 24.5^{o}C at a DPT of 2^{o}C

Inside design conditions for Summer:

T^{op} between 22.5 to 26.0^{o}C at a RH of 60%
T^{op} between 23.5 to 27.0^{o}C at a DPT of 2^{o}C

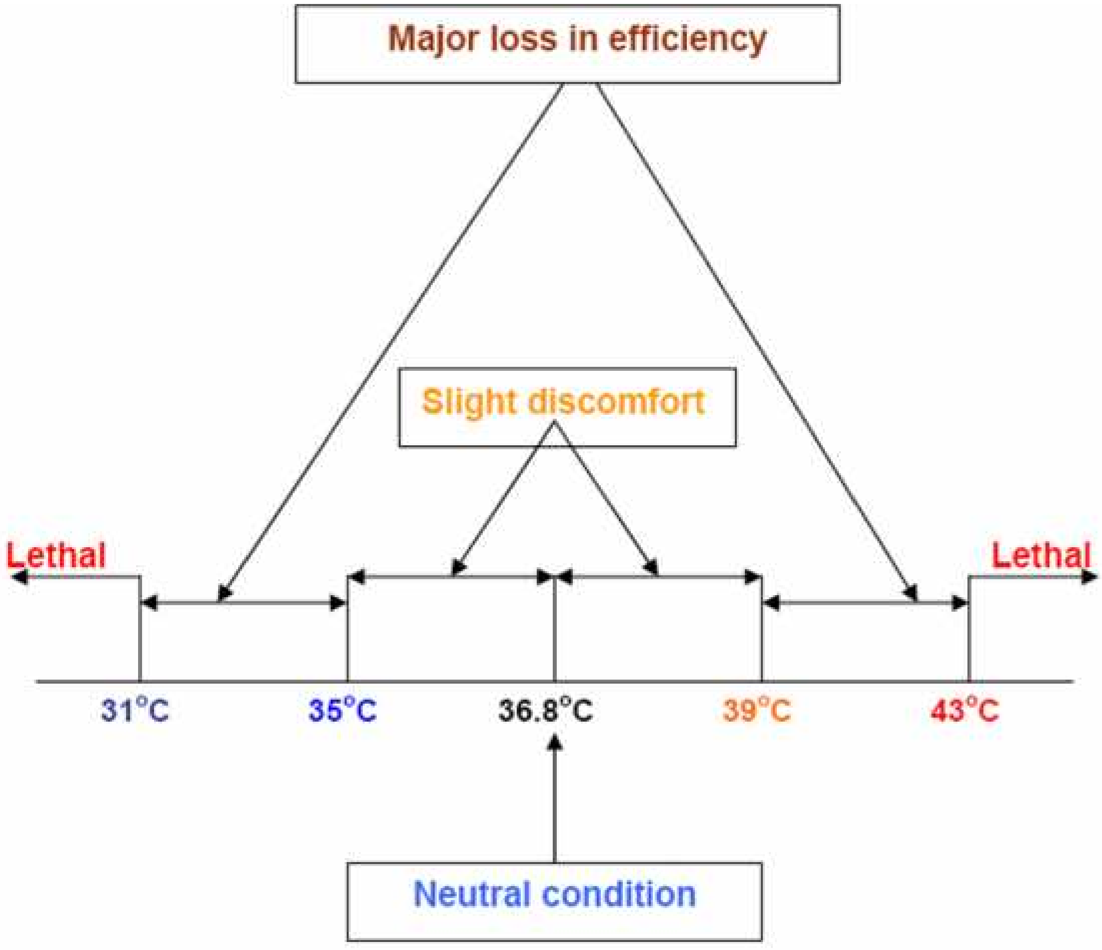


Fig.29.2: *Affect of the variation of core temperature on a human being*

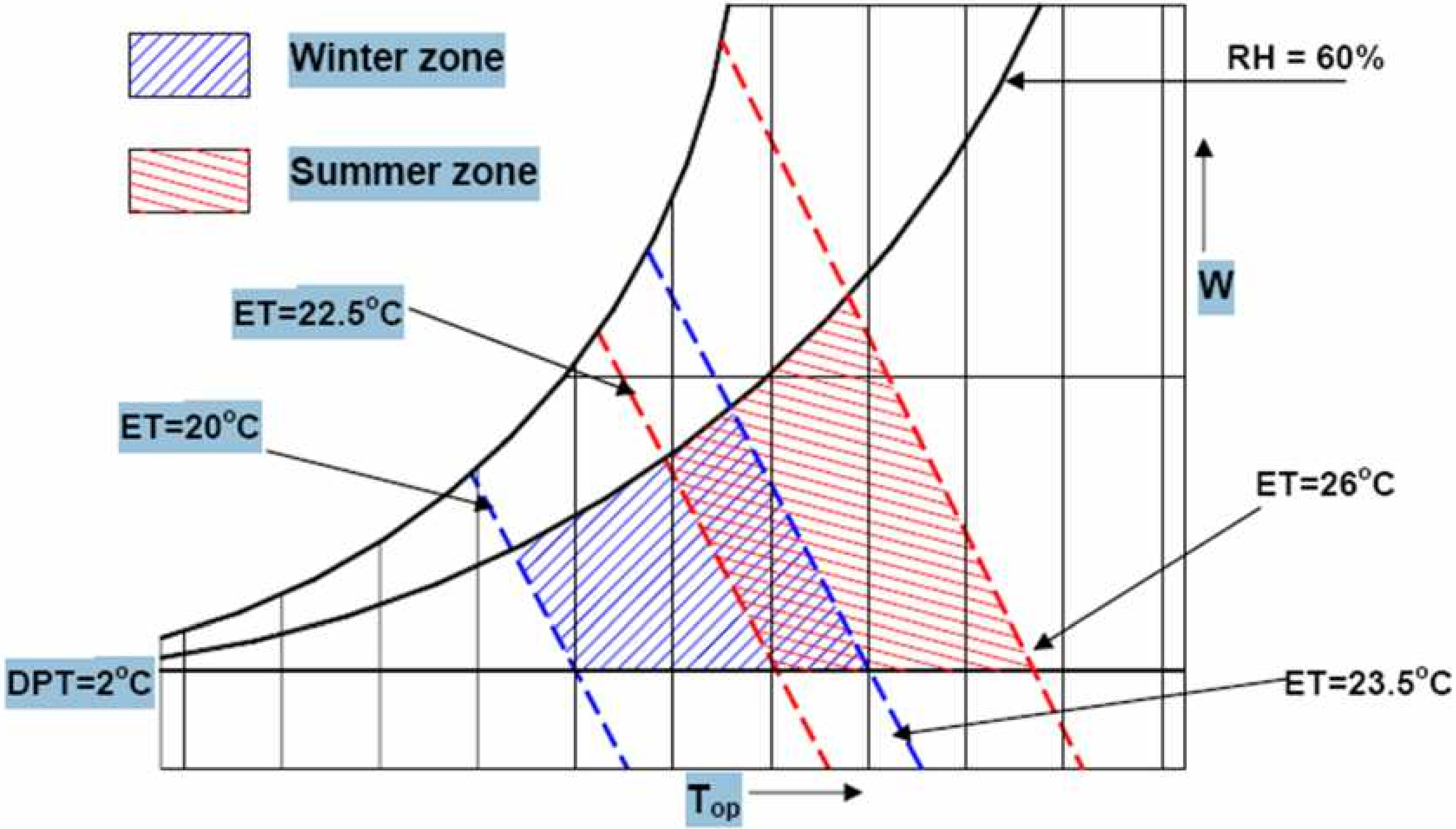
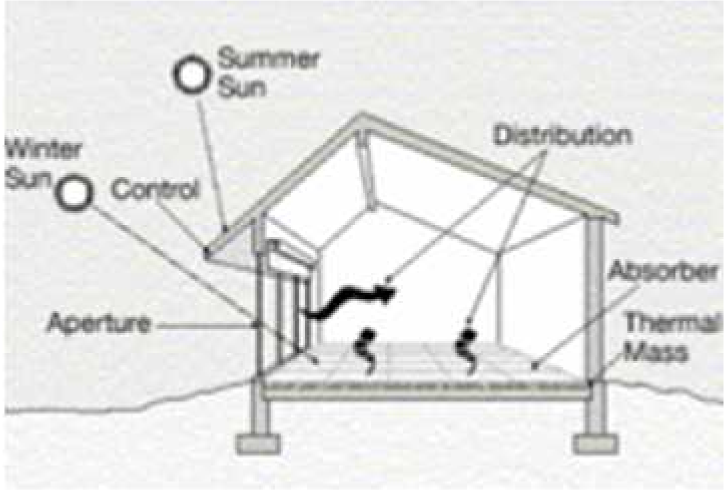


Fig.29.3: ASHRAE comfort chart for a sedentary person (activity ≈ 1.2 met)

Building design

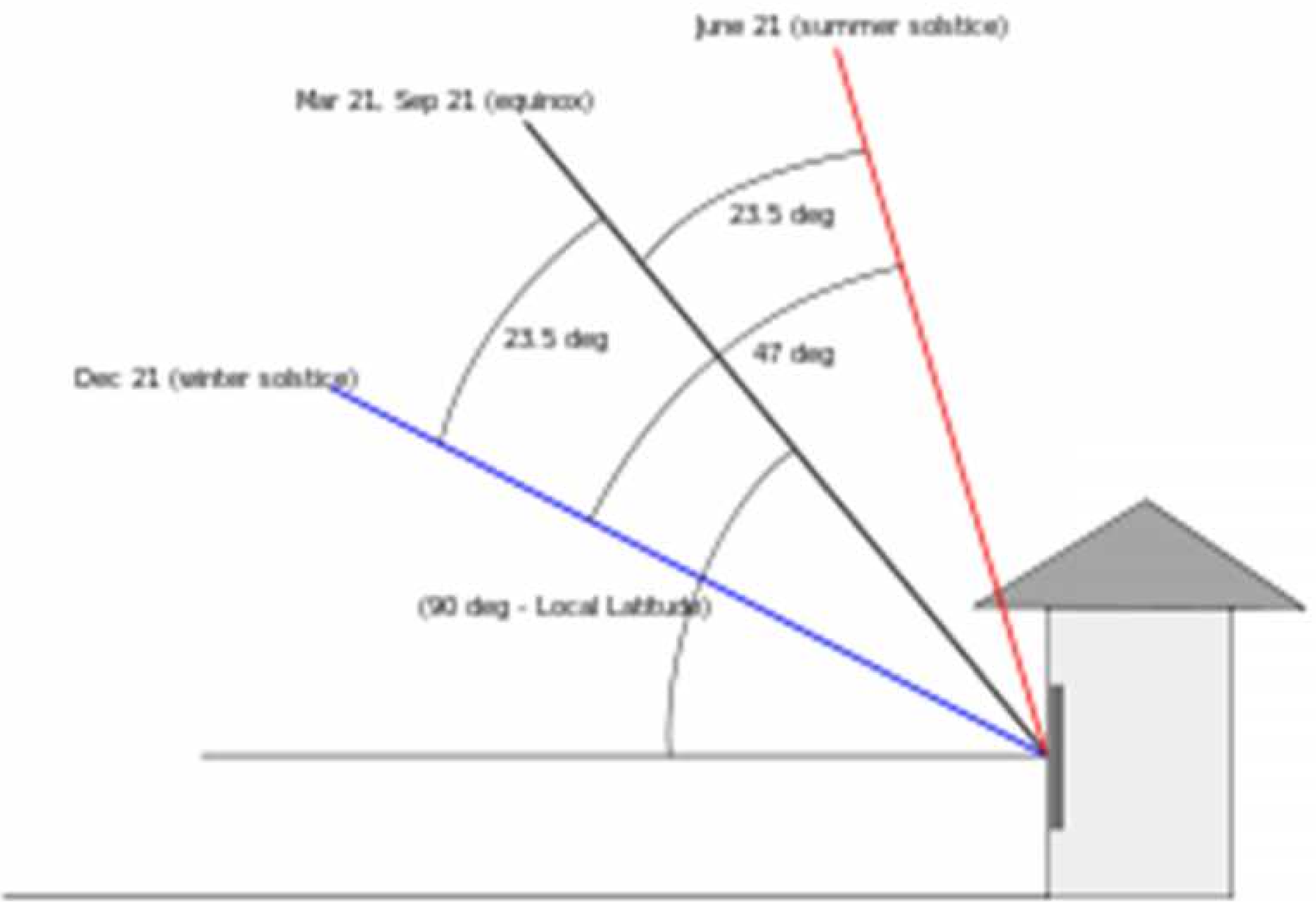


Elements of passive solar design, shown in a direct gain application

In passive solar building design, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design because, unlike active solar heating systems, it doesn't involve the use of mechanical and electrical devices.

The key to designing a passive solar building is to best take advantage of the local climate. Elements to be considered include window placement and glazing type, thermal insulation, thermal mass, and shading. Passive solar design techniques can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted".

The solar path in passive design



Q10) Draw the view of earth from sun for months December., March, June and September.

Q11) What is the meaning of Building Form, Massing and Orientation .

Q12) What are the percentages of Solar wavelength striking a glass window?

Q13) What is the meaning of thermal comfort? What is their effects?

Q14) What are the Factors determining thermal comfort?

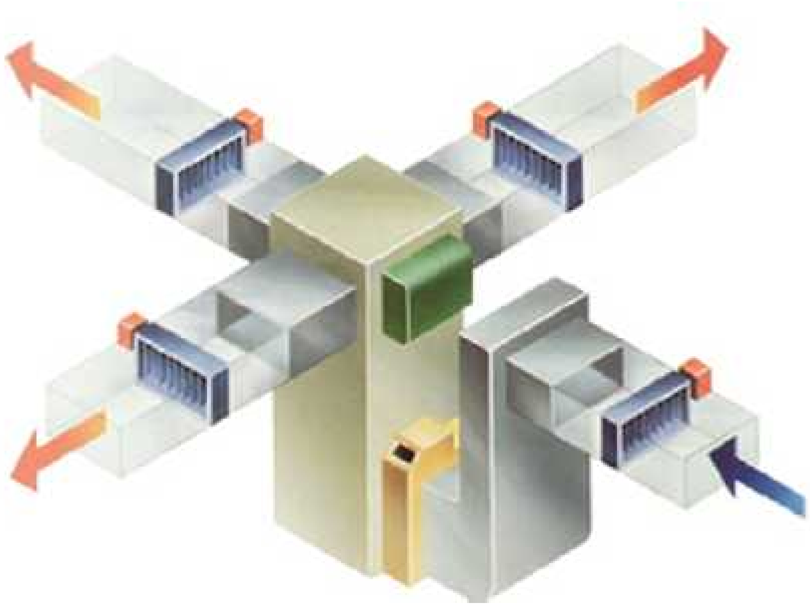
Q15) What is Architectural programming concerning thermal comfort?

Q16) What is Day lighting Benefits?

Q17) What is meant by HUMAN THERMOREGULATION? Draw the affect of the variation of core temperature on a human being.

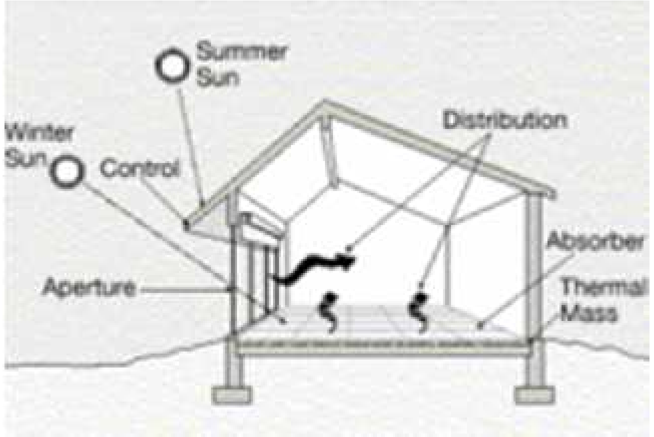
Q18) Show the factors effecting building design.

Energy conservation



Lecture Four

Environment control system



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Environment control system

Basic function of control systems

For the operation of air-conditioning systems a wide verity of automatic controls are available .

They could be grouped into three major function :

1. **Control which govern the air within the space**. The controls are sensing and actuating devices (Thermostats, humidistat, dampers, valves and switches) connected electrically or pneumatically into control system to keep environment at design conditions.
2. **Controls which function as protective devices** These controls acts as a safety device to protect the machines from damage and as a guard against high temperatures, low temperatures (like pressure controls, antifreeze devices, motor overloads, safety valves .. etc.
3. **Controls whose primary purpose to produce economy of operation** these devices reduce the amount of power, water, fuel consumed by the air-conditioning system(like water-control valve, autounloader on compressors, step controllers on heaters and compressors).

Type of control systems and their advantages in energy conservation are:

- **zone control**
- **seasonal control,**
- **operational control**
- **starting control**

zone control

Zoning is a method of heating, cooling and ventilating your home by utilizing multiple thermostats and motorized air volume dampers connected to a single central forced air duct system and allowing you to set different temperatures in different areas of your home. They sense temperature, pressure and humidity and function to maintain the condition space within the design limits. These controls are sensing and actuating devices (like Thermostats, humidistat, dampers, valves and switches).

Zoning is simply a way of dividing your home into areas with similar heating and cooling requirements. Every home has at least two zones; the living area and sleeping area, which are seldom used at the same time. Others are typically divided between upstairs and downstairs, master and kids bedrooms, formal living room, dining room, family room and kitchen. Each area is often occupied at different times and has different heating and cooling loads.

Zoning is accomplished by using automatic dampers in the ducts in each zone. Each zone is controlled by a thermostat that controls it's damper, and the heating/cooling unit provides conditioned air only to those required zones. The dampers to the zones that are satisfied will close, saving energy. Automatic setback thermostats allow you to program each thermostat to reach different temperatures during various times of the day. This truly provides:

The temperature you want.
Where you want it.
When you want it!

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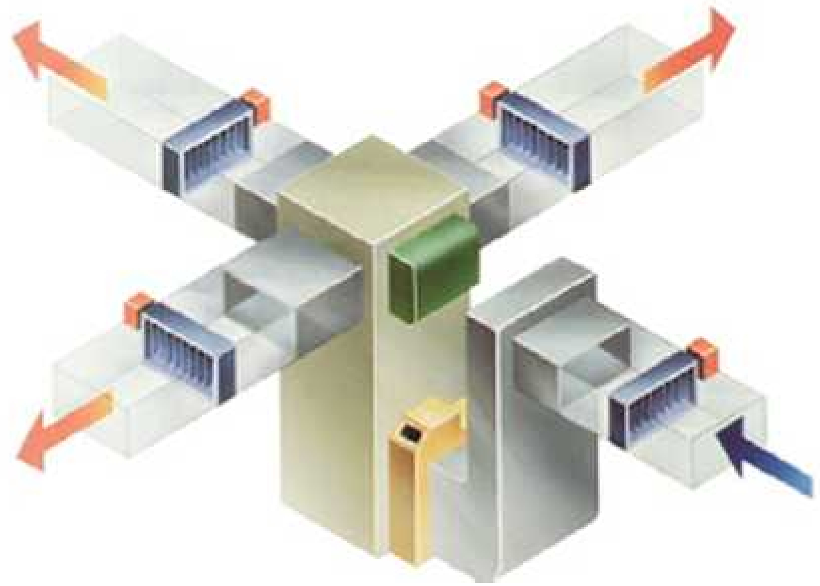
Zoning divides the house into areas with similar heating and cooling requirements with each zone being controlled by its own thermostat. The result is total comfort, no matter where you are inside your home, heating or cooling only the rooms that are needed, and wasting less energy.



By heating or cooling only those rooms you'll be using, Zoning allows you to conserve energy. Consider the alternative in most homes, whereby one thermostat controls the temperature of the entire house; rooms not in use are needlessly being heated or cooled, wasting energy and costing you money. An old wise tale says to leave your thermostat set and maintain a constant temperature continually, which is untrue. It cost much less to heat up a cold house where the thermostat has been off than to leave the setting the same all the time. This also goes for cooling. Always shut off the heating or cooling in areas not in use to maximize energy savings.

seasonal control

The process of air-conditioning may be inactive all the time. Residential and some commercial building have inactive cooling and dehumidification sections during winter months and inactive heating and humidification sections during summer . In large commercial installations it is not uncommon to have all the functions under simultaneous control for the entire year. It required elaborate controls and sensing devises. The heating, cooling humidification and dehumidification may be not necessary at all time . But cleaning and air motion are necessary except when the space is not occupied.

Operational control

controls may act as a safety device to protect machinery from damage by guarding against excessive heat or pressures or as capacity control for operation (like time delay relays, low pressure controls, temperature limit control …etc.) . They could provide economy of operation as well.

Starting control

Singly or sequentially start electric motors which drives compressors , fans, and pumps and also starts burners on boilers.

The control device can be positioned only to a maximum or minimum state (e.g., on or off). Because two-position control is simple and inexpensive, it is used extensively for both industrial and commercial control. A typical home thermostat that starts and stops a furnace or air-condition is an example of two-position action.

Environmental Control

Environmental Control allows people with disabilities to control functions in their own living space. This could include opening doors and windows for instance, or functions such as controlling a door intercom system, lights, a telephone, bed functions, TV, DVD player, cable TV boxes, the stereo and air-conditioning system control.

Transmitters operate using infrared light (IR) to control functions wirelessly. This is a safe, powerful, and user-friendly system which provides the user with complete independence.

Q19) What are the Basic function of control systems?

Q20) What are the Type of control systems and their advantages in energy conservation?

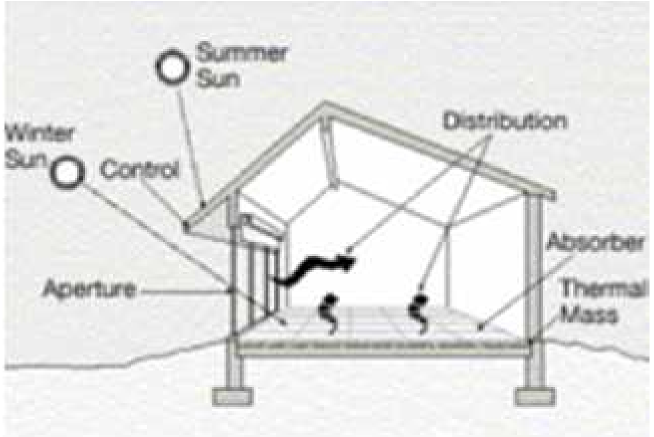
- **zone control**
- **seasonal control,**
- **operational control**
- **starting control**

Q21) What are the type of controls used to ease people life?

Energy conservation

Lecture Five and six

Estimating annual thermal load



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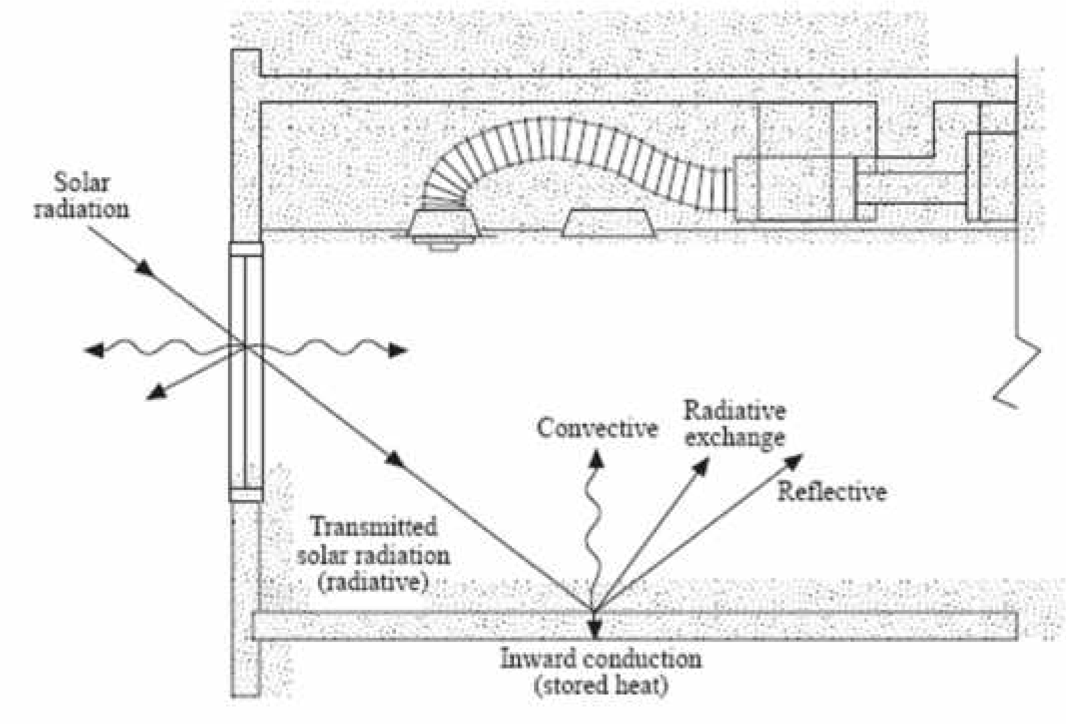
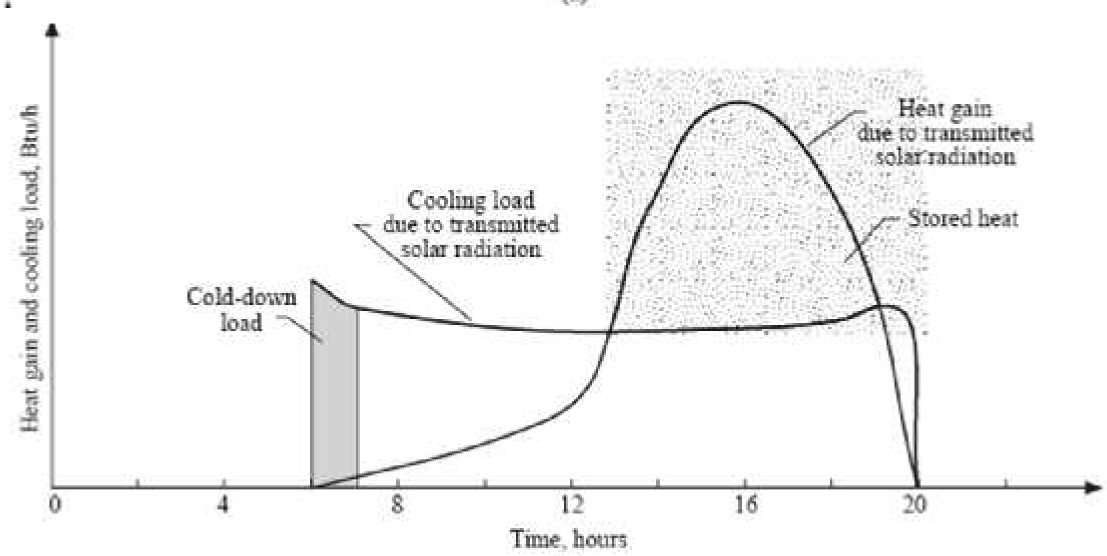
Convective Heat and Radiative Heat

Heat enters a space and transfer to the space air from either an external source or an internal source is mainly in the form of *convective heat and radiative heat transfer.* Consider radiative heat transfer, such as solar radiation striking the outer surface of a concrete slab as shown in Figure 9.6.1(a) and (b). **Most of the radiative heat is absorbed by the slab. Only a small fraction is reflected. After the heat is absorbed, the outer surface temperature of the slab rises.** If the slab and space air are in thermal equilibrium before the absorption of radiative heat, heat is convected from the outer surface of the slab to the space air as well as radiated to other surfaces. At the same time, heat is conducted from the outer surface to the inner part of the slab and stored there when the temperature of the inner part of the slab is lower than that of its outer surface. Heat convected from the outer surface of the concrete slab to the space air within a time interval forms the sensible cooling load.

The sensible heat gain entering the conditioned space does not equal the sensible cooling load during the same time interval because of the stored heat in the building envelope. Only the convective heat becomes cooling load instantaneously. The sum of the convective heats from the outer surfaces, including the outer surfaces of the internal heat gains in a conditioned space, becomes cooling load. This phenomenon results in a smaller cooling load than heat gain, as shown in Figure 9.6.1(a) and (b).


Solar radiation
Convective
Radiative exchange
Reflective
Transmitted solar radiation (radiative)
Inward conduction (stored heat)

(a)


Heat gain and cooling load, Btu/h
Heat gain due to transmitted solar radiation
Cooling load due to transmitted solar radiation
Stored heat
Cold-down load
0
4
8
12
16
20
Time, hours

(b)

- **The use of degree day method (DD)**

- A **degree day** is a measure of heating or cooling. Weekly or monthly degree-day figures may also be used within an energy monitoring and targeting scheme to monitor the heating and cooling costs of climate controlled buildings, while annual figures can be used for estimating future costs. A degree day is computed as the integral of a function of time that generally varies with temperature. The function is truncated to upper and lower limits that vary by organism, or to limits that are appropriate for climate control. The function can be estimated or measured by one of the following methods, in each case by reference to a chosen **base temperature**:

- **Variable base degree Day approach (VBDD) in applying the energy conservation means**

- frequent measurements and continuously integrating the temperature deficit or excess;
- Treating each day's temperature profile as a sine wave with amplitude equal to the day's temperature variation, measured from max and min, and totaling the daily results;
- As above, but calculating the daily difference between mean temperature and base temperature;
- As previous, but with modified formulae on days when the max and min straddle the base temperature.

A zero degree-day in energy monitoring and targeting is when either heating or cooling consumption is at a minimum, which is useful with power utility companies in predicting seasonal low points in energy demand.

So what are degree days?

Degree days are essentially a simplified representation of outside air-temperature data. They are widely used in the energy industry for calculations relating to the effect of outside air temperature on building energy consumption.

"*Heating degree days*", or "*HDD*", are a measure of how much (in degrees), and for how long (in days), outside air temperature was *lower* than a specific "*base temperature*" (or "*balance point*"). They are used for calculations relating to the energy consumption required to *heat* buildings.

A degree day is the difference between a base temperature and the mean daily outdoor air temperature $T_{o.m}$ for any one day, in °F. The total numbers of heating degree days HDD65 and cooling degree days CDD65 referring to a base temperature of 65°F per annum are

$$\mathrm{HDD65} = \sum_{n=1} \left(65 - T_{\mathrm{o.m}}\right)$$

$$\mathrm{CDD65} = \sum_{m=1} \left(T_{\mathrm{o.m}} - 65\right)$$

where n = number of days for which $T_{o.m} < 65$°F
m = number of days for which $T_{o.m} > 65$°F

How To Calculate Buildings Base Temperature?

The base temperature of a building determines the temperature below which the building needs heating. Assuming the inside temperature of a building is always higher than the outside due to heat gain. If it is 8 degrees for example, it will need to be heated to a level where human beings can comfortably stay in the building for example 21 degrees. Thus, the base temperature is equal to 21 – 8 = 13°C. This means that whenever the temperature outside the building falls below 15C, there will be a need for heating.

"*Cooling degree days*", or "*CDD*", are a measure of how much (in degrees), and for how long (in days), outside air temperature was *higher* than a specific base temperature. They are used for calculations relating to the energy consumption required to *cool* buildings.

Degree days also have applications relating to plant growth ("*growing degree days*"). However, our focus is on making software for energy saving, so our expertise are in the energy-saving applications of heating and cooling degree days.

Degree Days

Understanding Heating and Cooling Degree Days

Degree days are a specialist type of weather data, calculated from readings of outside air temperature. Heating degree days and cooling degree days are used extensively in calculations relating to building energy consumption, but the data is frequently used by those who don't understand what it really represents... This article aims to set that straight!

Contents

Heating degree days

In a nutshell(briefly): heating degree days are a measure of how much (in degrees), and for how long (in days), the outside air temperature was below a certain level. They are commonly used in calculations relating to the energy consumption required to heat buildings.

Why are heating degree days useful?

The energy consumption of building heating systems is more complicated than the energy consumption of TVs, kettles, or computers. You can't just plug a heating system into a Kill-A-Watt meter to find out how much energy it uses each hour, because the energy usage of a heating system varies with the weather.

Essentially, the colder the outside air temperature, the more energy it takes to heat a building.

If you live in the Caribbean, it's probably warm enough that you won't need heating at all; if you live in New York, you'll probably only need heating in the winter; if you live at the North Pole... you'll probably want your heating on all year round.

But the outside temperature doesn't just vary from one location to another - it varies all the time, wherever you happen to be. It's usually colder at night than it is in the day, and any single day/week/month/year is usually at least a little bit warmer or colder than the day/week/month/year before it.

If, like most people, you use your heating system to keep your building at a roughly constant temperature, the amount of energy that your heating system uses will vary from one day/week/month/year to the next, just like the outside air temperature does.

The idea is that the amount of energy needed to heat a building in any day/week/month/year is directly proportional to the number of heating degree days in that day/week/month/year.

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- **So how are heating degree days calculated?**
- *An example of heating degree days in action*

Let me introduce you to a man called Dan. Dan is the facilities manager of an office building, and he's under big pressure to reduce the building's energy consumption. The company CEO, Jock, has noticed the rising cost of energy, and he's decided that the business could, and should, save some money by becoming more energy efficient. Jock hasn't given much thought to how they're going to become more energy efficient, but he's certainly putting a lot of pressure on Dan to make it happen...

So, in January 2007, Dan spent a big chunk of his budget on improving the building's insulation. At the time, he was confident that this would seriously reduce the energy it took to heat the building, and that the savings in the energy bill would very quickly pay for the rather hefty capital cost.

Roll forward to January 2008, a year after Dan's big insulation spending spree, and Dan has a decidedly stressed look on his face... Jock, who's a "numbers guy", wants to see some "solid evidence" that Dan didn't "squander the company's hard-earned cash lining the pockets of some fly-by-night jokers". (No offence intended to the insulation industry - Jock just tends to be a little quick to point the finger...)

Anyway, Dan is sweating, and it's not because the building's temperature control is playing up (the well-insulated building is actually helping to keep things at a steady, comfortable temperature). Dan has just added up the heating energy consumption for 2007, and he's somewhat concerned by what he sees:

Heating energy consumption in 2006: 452,976 kWh
Heating energy consumption in 2007: 445,241 kWh

It's not that there hasn't been an improvement in the heating energy consumption (there has), it's just that Dan was rather hoping for more of an improvement... After spending a small fortune on insulation, he was actually rather hoping for significantly more of an improvement...

Now, it just so happens that, in Dan's neck of the woods, 2007 was quite a lot colder than 2006. Dan is aware of this, and, reluctant to admit that he might have overestimated the energy-saving power of his insulation idea, he is pinning his hopes on being able to prove that 2007's cold weather was to blame for the disappointing energy savings. Dan tried explaining this theory of his to Jock, but he was met with a rather blunt "Don't you try fobbing me off with any of your hand-waving nonsense!"

Shame on you, Dan, for forgetting that Jock is a numbers guy...

Fortunately all is not lost, as a colleague has tipped Dan off to these things called heating degree days. They're basically a measure of how cold the temperature was, but they're specifically for heating - if you've got 10% more degree days in any day/week/month/year you should expect 10% more heating energy consumption in that day/week/month/year, all other things being equal.

So, Dan hunted the web until he found Degree Days.net, a site that generates degree days for locations around the world. He found a weather station near the office building, and downloaded a few years' worth of heating degree days for that location. He quickly assembled the following figures:

Heating degree days in 2006: 3,320 (I'll explain what this number really *means* shortly)
Heating degree days in 2007: 4,092

Applying some simple arithmetic:

kWh per degree day in 2006 = 452,976 / 3,320 = 136
kWh per degree day in 2007 = 445,241 / 4,083 = 109

Comparing these two figures, Dan concluded that *the heating energy efficiency in 2007 was around 20% better than that in 2006*. Well done Dan: your insulation plan was a good one, and the company should make good savings from it for many years to come. In fact, it was such a good idea, Jock has convinced himself that it was his idea all along... So, Dan, it's looking unlikely that your insulation success will help your bonus, but at least you can stop sweating - your job security is no longer in immediate danger.

So how are heating degree days calculated?
Well, there's *one correct way* to calculate heating degree days (which requires vast quantities of temperature data - infinite quantities to be precise), and numerous different ways to approximate the same result using less temperature data.

Nonetheless, irrespective of the exact calculation method, **it always starts with a <u>base temperature.</u>**

The base temperature of a building

With regard to heating degree days, the *base temperature* of a building is the temperature below which that building needs heating.
Let's consider a regular office building. In fact, seeing how I put all that effort into the Dan story, let's consider the office building that Dan the facilities manager is in control of.

Dan tries to keep the office building heated to around 20C (about 68F) - after many years on the job he has determined that this is the temperature at which he gets the least number of people complaining that it's too hot or too cold.

On a summer day, when the outside temperature is 20C or above (about 68F), as you can probably guess, Dan switches the heating off - there's no point in heating a building when it's already warmer than the temperature you want it.

In fact, Dan has figured out that he can switch the heating off when the *outside* temperature reaches 17C (62.6F) - a few degrees below the desired *inside* temperature. The office has a lot of warm people in it and a lot of warm office equipment too - this essentially provides a few degrees of *free heating*. In technical terms, this would be described as an *average internal heat gain* of 3C, or 5.4F.

So, when the outside temperature is below 17C (62.6F), the heating needs to be on, and when the outside temperature is above 17C (62.6F), Dan can switch the heating off without incurring any more complaints than usual about it being too cold. Of course more people might complain that it's too *hot*, but that's a different story.

What this means is that the *base temperature* of Dan's building is 17C, or 62.6F.

All buildings have a base temperature - it varies from building to building, but you can think of it as **depending on two things**:

1. **What temperature is the building heated to? (e.g. Dan's building is heated to 20C or 68F.)**
2. **How much free heating comes from the people and equipment inside the building? In other words, what's the average internal heat gain?**

-

The base temperature of your building will determine the base temperature of the heating degree days that you should use to do your calculations.

Anyway, that explains the base temperature... But what do the heating-degree-day numbers actually mean? To understand this, you need to have a rough idea of how the figures are calculated.

Turning temperature readings into heating degree days

With the appropriate use of big, scary-looking formulae, it's quite possible to make it look as though degree-day-data calculation is something that's best left to the experts. **But it's actually very straightforward to turn temperature readings into degree days.** I'm going to use a few example calculations to explain how the process works for heating degree days.

Let's say that we're dealing with a **building with a base temperature** of around **17C** It's the start of July - Anyway, consider a single day, let's say July 1st, when the outside air temperature was 16C throughout the entire day. A constant temperature throughout an entire day is rather unlikely, I know, but degree days would be a lot easier to understand if the outside air temperature stayed the same... So, throughout the entire day on July 1st, the outside air temperature (16C) was consistently 1 degree below the base temperature of the building (17C), and we can work out the heating degree days on that day like so:

1 degree * 1 day = 1 heating degree day on July 1st

If, on July 2nd, the outside temperature was 2 degrees below the base temperature, we'd have:

2 degrees * 1 day = 2 heating degree days on July 2nd

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Let's look at July 3rd - this was a hotter day, and the outside air temperature was 17C, the same as the base temperature (i.e. 0 degrees below the base temperature). This gives:

0 degrees * 1 day = 0 heating degree days on July 3nd

On July 4th it was warmer again: 19C. Again, the number of degrees below the base temperature was zero, giving:

0 degrees * 1 day = 0 heating degree days on July 4th

You might have guessed: *when the outside air temperature goes over the base temperature, you don't get any heating degree days*. This makes sense, because you wouldn't need any heating either.

Right, now let's make it a *little* more realistic. July 5th had a temperature of 15C from 00:00 to 12:00, and 16C from 12:00 to 24:00. So for that day we have:

(2 degrees * 0.5 days) + (1 degree * 0.5 days) = 1.5 heating degree days on July 5th

(The 2 degrees is because 15C is 2 degrees below the base temperature of 17C, and the 0.5 days are because 00:00 to 12:00 is half a day. We calculate the heating degree days for each period in the day, and then add them together to get the total for that day: 1.5.)

On July 6th, colder weather started moving in: the temperature was 16C from 00:00 to 06:00, 15C from 06:00 to 12:00, 14C from 12:00 to 18:00, and 13C from 18:00 to 24:00. This gives the following:

(1 degree * 0.25 days) + (2 degrees * 0.25 days) + (3 degrees * 0.25 days) + (4 degrees * 0.25 days)

= 2.5 heating degree days on July 6th

Now, on July 7th, the temperature just kept changing... like it might on a real day... Between 00:00 and 00:30 it was 14C, between 00:30 and 01:00 it was 13.9C, between 01:00 and 01:30 it was 13.9C, between 01:30 and 02:00 it was 13.8C... it started getting warmer around 05:00, peaking at 17C between 14:00 and 14:30, and dropping again until it reached about 13.7C between 23:30 and 24:00. Complicated!

A proper calculation would not make for particularly interesting reading, so I'll leave most of it out. But essentially you just have to add up the figures for each of the half-hour periods in the day (one half-hour period is 1/48 days):(

3 degrees * 1/48 days) + (3.1 degrees * 1/48 days) + ... etc.

= 1.9 heating degree days on July 7th

Hopefully by now you're getting the idea!

So, from the examples above we've got:

- July 1st: 1 heating degree day
- July 2nd: 2 heating degree days
- July 3rd: 0 heating degree days
- July 4th: 0 heating degree days
- July 5th: 1.5 heating degree days
- July 6th: 2.5 heating degree days
- July 7th: 1.9 heating degree days

We'd expect the heating energy consumption on each of those days to vary with the heating degree days. So, the heating on July 2nd would use twice as much energy as the heating on July 1st, and, on July 3rd and July 4th, the heating wouldn't use any energy at all (zero degree days on those days would mean it would be warm enough for the heating to be switched off).

One of the best things about degree days is that you can add them together. Adding together the readings above gives a total of 8.9 heating degree days for the week beginning on July 1st and ending on July 7th. So we'd expect that the heating system would have used 8.9 times more energy in that whole week than it used on July 1st alone.

If you've got daily heating-degree-day values for each day in a month, you can add them up to get the total heating degree days for that month. And if you've got the heating-degree-day values for each month in a year, you can add them up to get the total heating degree days in the whole year.

And therein lies what I consider to be the beauty of degree days: you can add them up to get totals for long periods of time, and they still represent all the relevant variations in temperature over that whole time period. (Contrast that with an annual average temperature, which would tell you *nothing* about how much the temperature varied *within* that year.)

Real-world calculation methods

The calculation method that I explained above is essentially the *correct* one for calculating heating degree days: for each period over which the outside air temperature was constant, you multiply the degrees below the base temperature by the number of days that the temperature was fixed for (usually small fractions of days), and then you sum all the values together to get the total heating degree days for the period in question.

The problem with that approach is that, in the real world, outside air temperature doesn't remain constant - in fact it changes pretty much all the time. Mathematically speaking you'd need an *infinite* number of temperature readings to calculate degree days properly.

Fortunately, "mathematically speaking" doesn't really matter too much in this instance, and half-hourly or hourly temperature readings are plenty good enough to calculate degree days accurately using the method described above.

However, reliable half-hourly and hourly temperature readings are rarely readily available, so there are a number of other approximation methods that are used to calculate degree days from more commonly available measurements of outside air temperature. These methods typically use either the daily maximum and minimum temperatures, or the daily average temperatures

Energy Calculation Methods

- Degree-day method
  - A degree-day is the sum of the number of degrees that the average daily temperature (technically the average of the daily maximum and minimum) is above (for cooling) or below (for heating) a base temperature times the duration in days
    - Heating degree-days (HDD)
    - Cooling degree-days (CDD)
  - Summed over a period or a year for indicating climate severity (effect of outdoor air on a building)

Heating degree-day:

$$DD_h(t_{bal}) = (1\ \mathrm{day}) \sum_{\mathrm{days}} (t_{bal} - t_o)^+$$

Cooling degree-day:

$$DD_c(t_{bal}) = (1\ \mathrm{day}) \sum_{\mathrm{days}} (t_o - t_{bal})^+$$

t_{bal} = base temperature (or balance point temperature)
(e.g. 18.3 ^oC or 65 ^oF); $Q_{load} = Q_{gain} + Q_{loss} = 0$
t_o = outdoor temperature (e.g. average daily max./min.)

* Degree-hours if summing over 24-hourly intervals
Degree-day = $\Sigma(\text{degree-hours})^+ / 24$

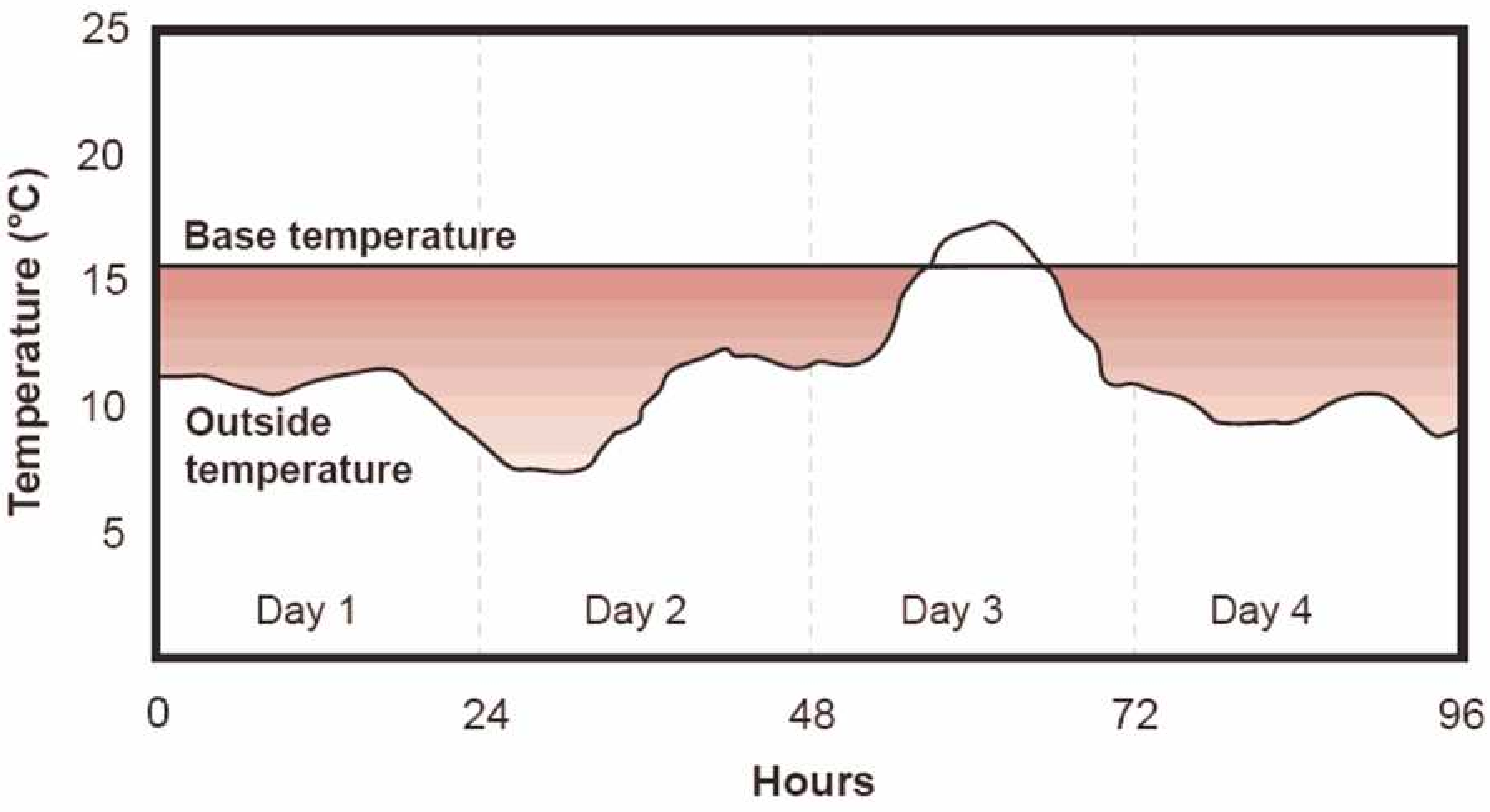
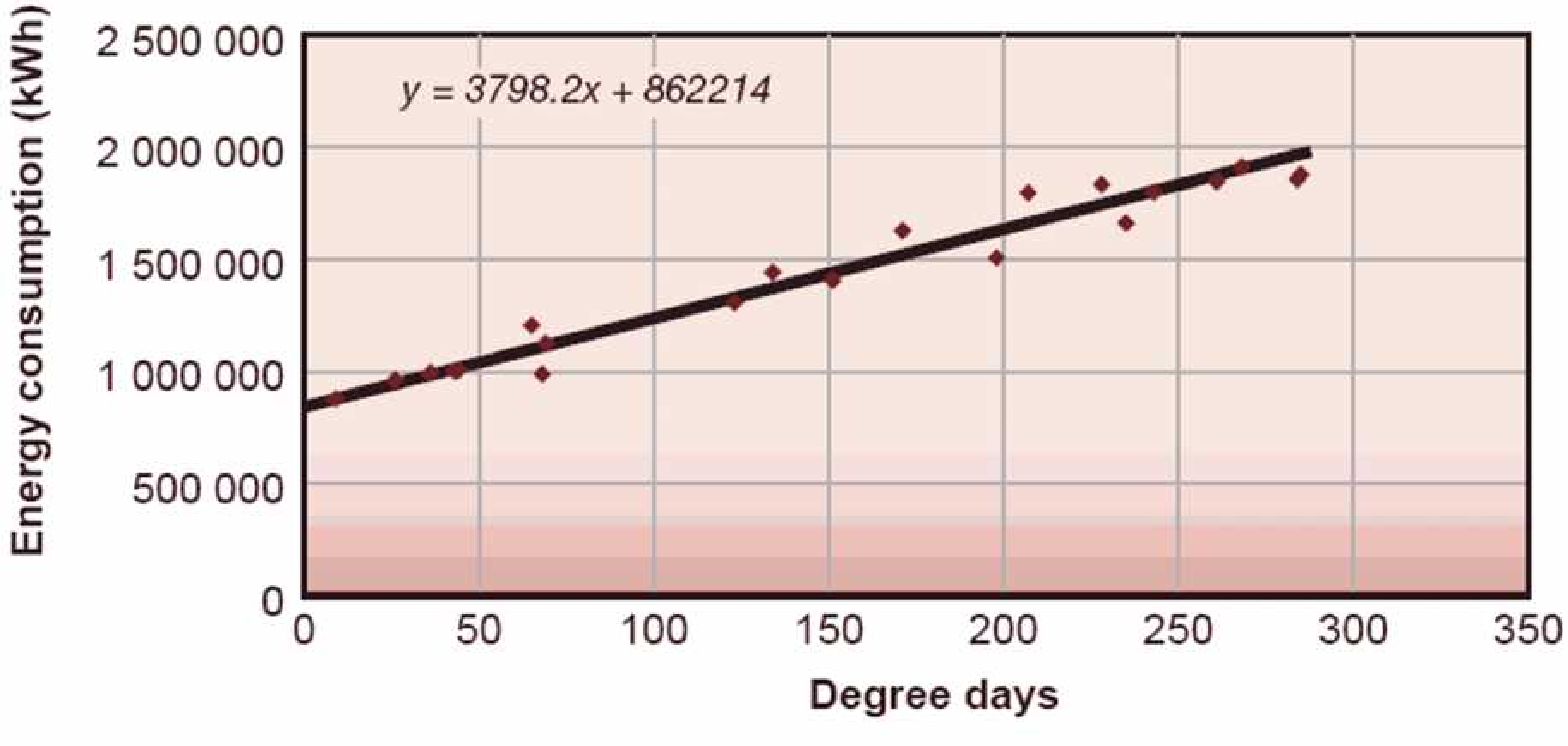


Figure 1 The shaded area is the degree-day value for the period



Correlation between energy consumption and degree days

Cooling degree days

Cooling degree days are a measure of how much (in degrees), and for how long (in days), the outside air temperature was *above* a certain level. They are commonly used in calculations relating to the energy consumption required to *cool* buildings.

I think of them as heating degree days in reverse: whilst heating degree days start adding up when the outside air temperature drops *below* the base temperature, cooling degree days start adding up when the outside air temperature rises *above* the base temperature. So the base temperature of cooling degree days is just the temperature *above* which the building needs *cooling*. Pretty straightforward, right?

Degree days

A1.1 Heating degree days

The concept of *degree days was first developed about 100 years ago for use in horticulture [1].* Nowadays, however, degree days are generally used to predict heating energy consumption in buildings. They provide building designers with a useful measure of the variation in outside temperature, which enables energy consumption to be related to prevailing weather conditions. It is not difficult to appreciate that in a cold month such as January, a given building will consume more heating energy than in a warmer month such as March. This is because:

- the outside air temperature is likely to be colder during January than in March; and
- lower air temperatures are likely to persist for longer in January compared with March.

From this it can be seen that heat energy consumption relates both to the degree of coldness and the duration of that coldness. The degree day method allows for both these factors by setting a base outside air temperature, above which most domestic and commercial buildings do not require any heating. In the UK this base temperature is generally taken to be 15.5 ° C. If the average outside air temperature on any given day is below the base temperature, then heating will be required.

However, the heat energy consumption in any given period is dependent not only on the magnitude of the temperature differential but also on its duration. For example, if an outside air temperature of 14.5 °C prevails for 24 hours, then a deficit of 1 °C will have been maintained for 1 day and 1 degree day will have been accrued. If the outside temperature remains at 14.5 °C for each day of a week, then a total of 7 degree days will be accumulated. Similarly, if an outside air temperature of 10.5 °C is maintained for 1 week then 35 degree days will be accumulated. By summating the daily temperature deficits over any given month it is possible to calculate cumulative degree days for that particular month. Therefore, by monitoring daily outside air temperature, it is possible to produce tables of monthly heating degree days for various locations, which can be used by building designers and operators to estimate heating loads. For example, if a particular building experiences 346 heating degree days in January and only 286 in March, it is reasonable to assume that heating fuel consumption in January should be 1.21 times that for March. Monthly and annual degree day figures are published in many sources. Table A1.1 shows 20-year average heating degree day data for the various geographical regions of the UK.

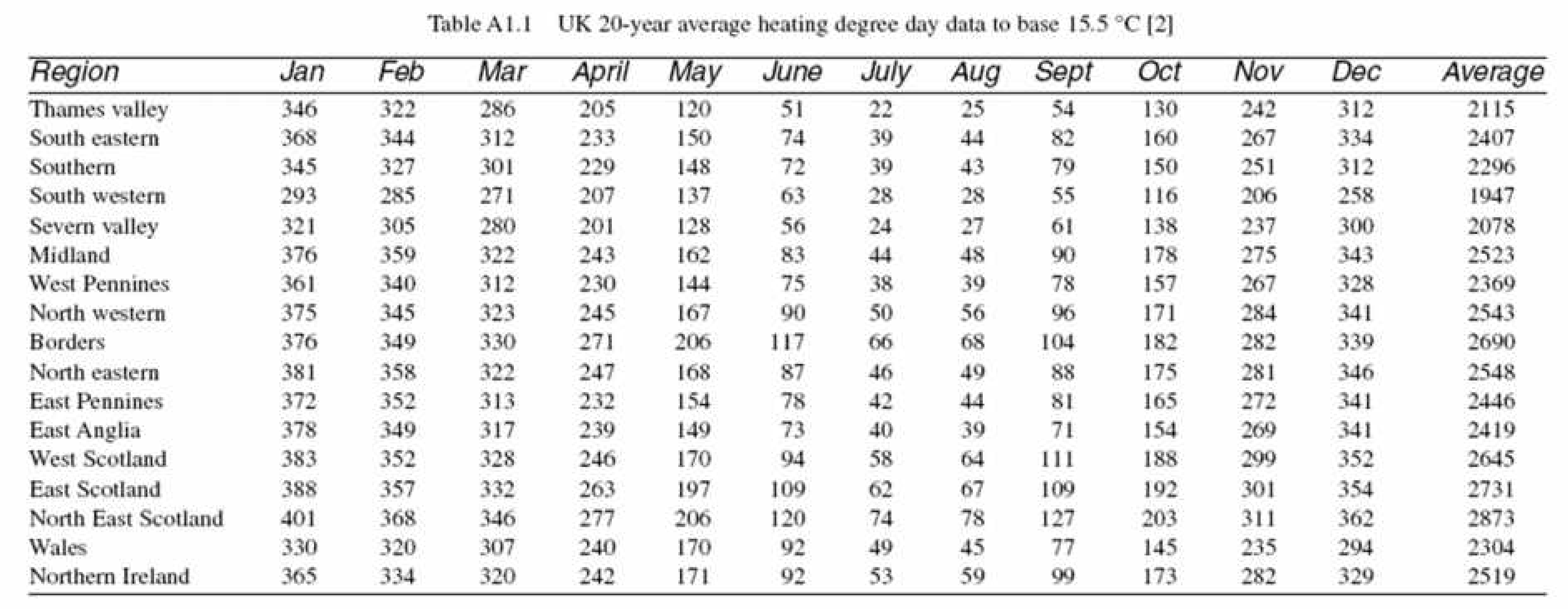


Table A1.1 UK 20-year average heating degree day data to base 15.5 °C [2]

Region	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
Thames valley	346	322	286	205	120	51	22	25	54	130	242	312	2115
South eastern	368	344	312	233	150	74	39	44	82	160	267	334	2407
Southern	345	327	301	229	148	72	39	43	79	150	251	312	2296
South western	293	285	271	207	137	63	28	28	55	116	206	258	1947
Severn valley	321	305	280	201	128	56	24	27	61	138	237	300	2078
Midland	376	359	322	243	162	83	44	48	90	178	275	343	2523
West Pennines	361	340	312	230	144	75	38	39	78	157	267	328	2369
North western	375	345	323	245	167	90	50	56	96	171	284	341	2543
Borders	376	349	330	271	206	117	66	68	104	182	282	339	2690
North eastern	381	358	322	247	168	87	46	49	88	175	281	346	2548
East Pennines	372	352	313	232	154	78	42	44	81	165	272	341	2446
East Anglia	378	349	317	239	149	73	40	39	71	154	269	341	2419
West Scotland	383	352	328	246	170	94	58	64	111	188	299	352	2645
East Scotland	388	357	332	263	197	109	62	67	109	192	301	354	2731
North East Scotland	401	368	346	277	206	120	74	78	127	203	311	362	2873
Wales	330	320	307	240	170	92	49	45	77	145	235	294	2304
Northern Ireland	365	334	320	242	171	92	53	59	99	173	282	329	2519

A1.2 Changing the base temperature

In the UK, degree day data are generally produced for a base temperature of 15.5 °C. However, other countries may use different base temperatures. Indeed, in the UK the National Health Service uses an alternative base temperature of 18.5 °C. It may therefore be necessary to convert data quoted at 15.5 °C to another base temperature. This can be done with relative accuracy by using Hitchin’s formula [1] below:

$$\text{Average degree days per day} = \frac{(t_b - t_o)}{1 - e^{-k(t_b - t_o)}}$$

where t_b *is the base temperature (°C),* t_o *is the mean air temperature in the month (°C), and* k *is* the constant.

The value of ‘k’ varies slightly with location and must be determined from 20-year weather data. However, a general k value of 0.71 can be assumed for most locations in the UK [1].

A1.3 Cooling degree days

Heating degree days are of considerable use when estimating and monitoring the energy consumption of non-air conditioned buildings. However, for air conditioned buildings they are only of limited value. Consequently, the concept of the *cooling degree day was developed.* Cooling degree days are defined as ‘the mean number of degrees by which the outside temperature on a given day exceeds the base temperature, totaled for all the days in the period’ [1]. There is, however, no general consensus on the base temperature that should be used for calculating cooling degree days and many users still use a 15.5 °C base [1].

Variable Base Degree Day approach (VBDD)

in applying the energy conservation means

Energy Calculation Methods

- Variable base degree-day (VBDD) method
  - Degree-day with variable reference temperatures
    - To account for different building conditions and variation between daytime and nighttime
    - First calculate the balance point temperature of a building and then the heating and cooling degree hours at that base temperature
    - Require tedious calculations and detailed processing of hourly weather data at a complexity similar to hourly simulations. Therefore, does not seem warranted nowadays (why not just go for hourly simulation)

CALCULATION OF HEATING, COOLING DEGREE DAYS

CALCULATION OF HEATING DEGREE DAYS

Heating Degree Days (HDD) for a particular climate is obtained by subtracting each day's mean outdoor dry bulb temperature from the balance point temperature; this result is the number of HDDs for that day. For example, if the maximum and minimum outdoor dry bulb temperatures of a place were 80°F and 20°F respectively, and the balance point temperature were 65°F, then HDD of the place for that particular day would have been 65-[(80+20)/2] = 15. If the mean outdoor dry bulb temperature is equal to or higher than the balance point temperature, then the HDD would be equal to 0.

Degree Days and Annual Heating loss

A preliminary estimate of annual heating load, using degree day method, can be obtained by the following formula:

$$H = PHL \times 24 \times HDD / \blacktriangle T$$

Where

- **H = Annual heating load in Btu**
- **PHL = peak heating load (heat loss) in Btu/hr**
- **HDD = heating degree days**
- **▲T = temperature difference, °F**

CALCULATION OF COOLING DEGREE DAYS

Cooling Degree Days (CDD) for a particular climate is obtained by subtracting each day's mean outdoor dry bulb temperature from the balance point temperature; this result is the number of CDDs for that day. For example, if the maximum and minimum outdoor dry bulb temperatures of a place were 90°F and 60°F respectively, and the balance point temperature were 65°F, then CDD of the place for that particular day would have been [(90+60)/2]-65 = 10. If the mean outdoor dry bulb temperature is equal to or lower than the balance point temperature, then the CDD would be equal to 0.

Annual cooling load

A preliminary estimate of annual heating load, using degree day method, can be obtained by the following formula:
C = PCL x 24 x CDD / ▲T
Where

- **C = Annual cooling load in Btu**
- **PCL = peak cooling load (heat gain) in Btu/hr**
- **CDD = cooling degree days**
- **▲T = temperature difference, °F**

Degree-Day Calculation Methods

High / Low method

If you select the high/low method, the software uses the highest temperature and the lowest temperature for a given day to calculate the average temperature for that day. The difference between the average temperature and the base threshold are assumed to be the number of degree-days accumulated on that day. For example, if the average of the highest and lowest temperatures is 24º above the base threshold, the software assumes 24 degree–days for the entire day.

Note: Unless 15 hours worth of records exist in the database for that day (from midnight to 3pm, for example), the software will not calculate degree-days for that day.

Integration method

If you select the integration method, the software calculates degree–days using the average temperature for an interval and the interval time. For example, if the average temperature during a 15 minute interval was 24º above the base threshold, the software would calculate 0.25 degree-days during that interval (24 * 15 minutes in interval/1440 minutes per day). The number of degree-days during each interval are added together to arrive at a degree-day total. This method calculates degree-day totals more accurately than the high/low method.

Heating & Cooling Degree-Days

Although degree-days are most commonly used in agriculture, they are also useful in building design and construction, and in fuel use evaluation. The construction industry uses heating degree-days to calculate the amount of heat necessary to keep a building, be it a house or a skyscraper, comfortable for occupation. Likewise, cooling degree-days are used to estimate the amount of heat that must be removed (through air-conditioning) to keep a structure comfortable. Heating and cooling degree-days are based on departures from a base temperature, typically 65ºF (18ºC).

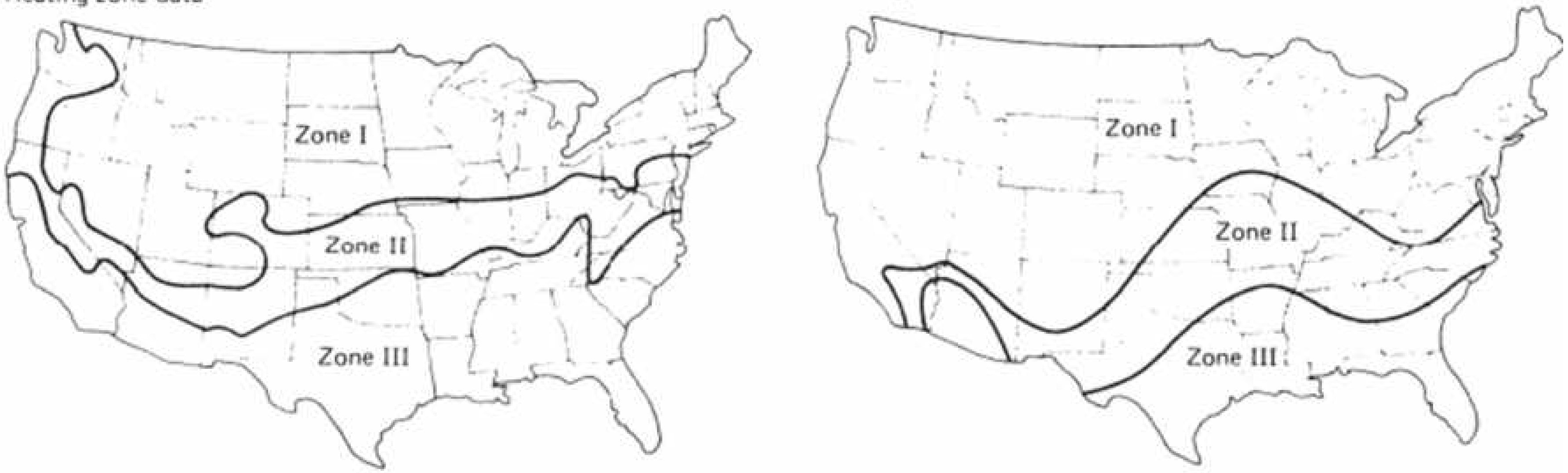
One heating degree–day is the amount of heat required to keep a structure at 65ºF when the outside temperature remains one degree **below** the 65ºF threshold for 24 hours. One heating degree–day is also the amount of heat required to keep that structure at 65ºF when the temperature remains 24ºF below that 65º threshold for 1 hour.

Likewise, one cooling degree–day is the amount of cooling required to keep a structure at 65ºF when the outside temperature remains one degree **above** the 65ºF threshold for 24 hours. One cooling degree–day is also the amount of cooling required to keep that structure at 65ºF when the temperature remains 24ºF above that 65º threshold for 1 hour.

Depending on the calculation method, both heating and cooling degree-days can accumulate in the same day. Also, note that there are no negative degree-days. If the temperature remains below the threshold, there is no degree-day accumulation.

Heating zone data

Cooling zone data



Heating zones Zone	Temp diff (TD)*	Degree days (DD)
I	80	8000
II	70	5500
III	50	3000

*Assume 70°F indoor temperature.

Cooling zones Zone	Cooling hours (hr)
I	500
II	1000
III	1500

Figure 3-9. Maps showing heating and cooling degree-day zones. (*Courtesy of Johns-Manville Sales Corp.*)

Q22) What are degree days? What is the Heating DD and cooling DD?

Q23) How To Calculate Buildings Base Temperature?

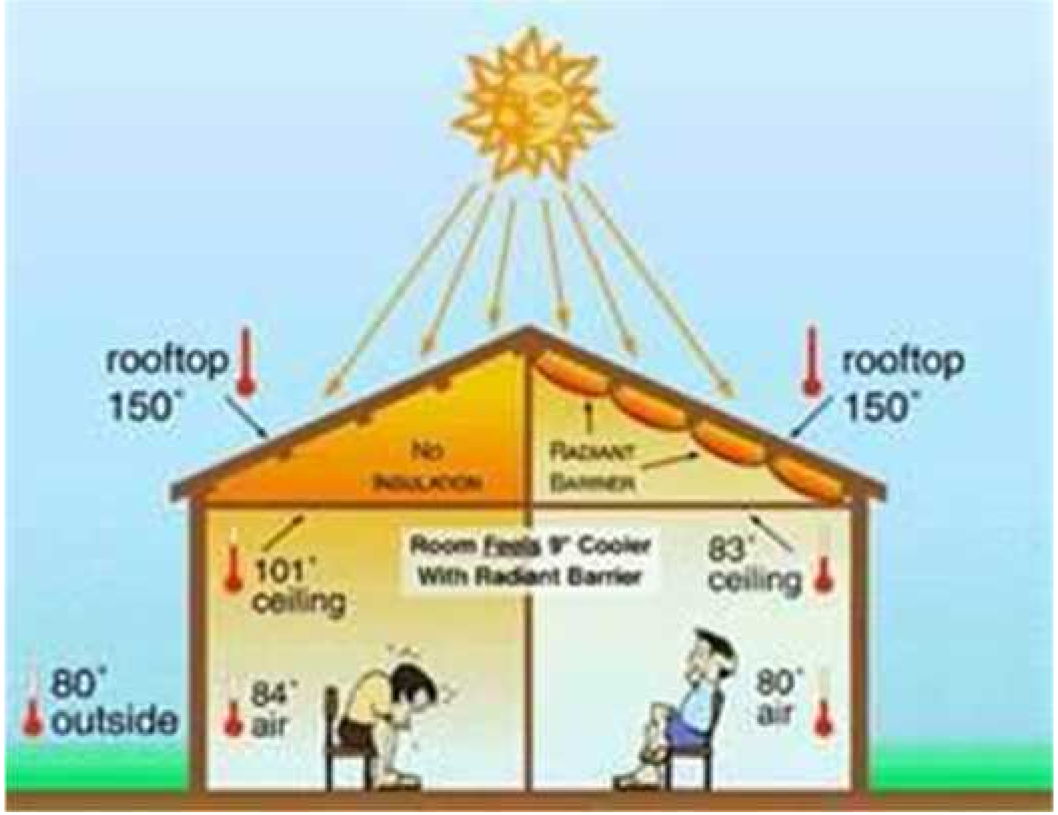
Q24) On the 1st January the temperature was 10°C for the day and night while on the 2nd from 12:00-3:00 was 9°C from 3:00 -4:30 was 8°C from 4:30 -8:30 was 7°C from 8:30 -12:30 was 8°C from 12:30 -18:30 was 9°C from 18:30 -22:30 was 6°C from 22:30 -24:00 was 6.5 °C . On the 3rd it was from 12:00-6:00 was 7°C from 6:00 -12:00 was 8°C from 12:00 -18:00 was 7°C from 18:00 -22:30 was 6°C from 22:30 -24:00 was 5°C. On the 4th it was from 12:00-6:00 was 5°C from 6:00 -12:00 was 7°C from 12:00 -18:00 was 8°C from 18:00 -22:30 was 7°C from 22:30 -24:00 was 6°C. On the 5th it was from 12:00-6:00 was 5°C from 6:00 -12:00 was 6°C from 12:00 -18:00 was 7°C from 18:00 -24:00 was 6°C. On the 6th it was from 12:00-6:00 was 6°C from 6:00 -12:00 was 7°C from 12:00 -18:00 was 8°C from 18:00 -22:30 was 9°C from 22:30 -24:00 was 7°C. On the 7th it was from 12:00-6:00 was 6°C from 6:00 -18:00 was 7°C from 18:00 -24:00 was 5°C. Find the heating degree days for this week of the year. If these temperatures occurred for 12 weeks what is the total HDD for this building?

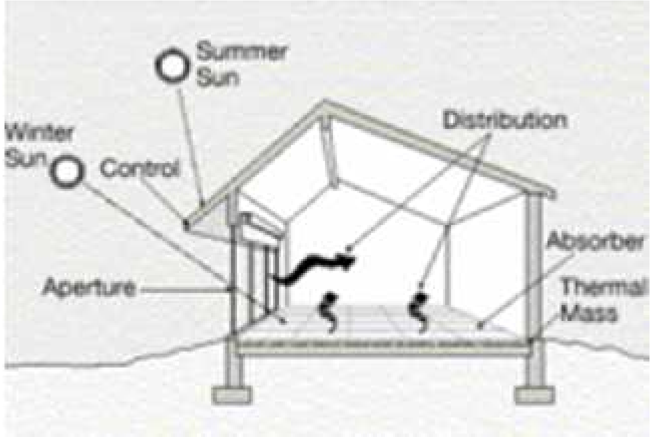
Q25)

Energy conservation

Lecture Seven and eight

Insulation types and properties





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Insulation types and properties

- Types of insulation are:

- foamed ,
- powdered,
- granular
- reflective,
- properties of insulate
- Variation of properties with temperature
- Selection of insulates using (λ\k) and critical thickness method
- Super insulation

Why insulate?

There are many reasons why professional engineers, architects and laymen use insulation, e.g.:

1. To comply with mandatory legislation (i.e. Building Regulations);
2. To reduce heat loss/heat gain;
3. To reduce running costs;
4. To control process temperatures;
5. To control surface temperatures;
6. To reduce the risk of freezing;
7. To provide condensation control;
8. To reduce heating plant capacity;

Other reasons why insulation is used are to provide:

9. Acoustic/correction and noise control;
10. Fire protection.

Thermal insulation

A thermal insulation material is one which frustrates the flow of heat. It will slow down the rate of heat loss from a hot surface and similarly reduce the rate of heat gain into a cold body.

CSR THERMAL AND ACOUSTIC INSULATION PRODUCTS

ROCKWOOL

GLASSWOOL

FLEXIBLE DUCT

CEILING BOARD

PRE-MOLDED PIPE INSULATION

Dr. K.J.Al-khishali

Insulation types

Insulation materials classification is to divide them into three groups - Organic 1, Organic 2 and Inorganic.

Organic Group 1 materials come from naturally occurring vegetation. Included in this group are cork, cellulose fiber, flax and sheep's wool. These materials are generally simple in their production techniques, environmentally benign, have a relatively low thermal performance.

Organic Group 2 materials come from fossilized vegetation: petroleum or coal. Included in this group are polystyrenes, polyurethanes, polyisocyanurates and phenolic foams. These materials generally have a high thermal performance, are combustible and are relatively impermeable.

Inorganic Group materials are silica or calcium based. Included in this group are mineral fibres, calcium silicate, cellular glass, vermiculite and perlite. These materials are generally incombustible, vermin and rot proof, they are relatively permeable and have a medium thermal performance.

Density effects

Most materials achieve their insulating properties by virtue of **the high void content** of their structure. The voids inhibit convective heat transfer because of their small size. A **reduction in void size reduces convection** but does **increase the volume of the material** needed to form the closer matrix, **thus resulting in an increase in product density**. Further **increases in density** continue to **inhibit convective** heat transfer, but ultimately the additional benefit is **offset by the increasing conductive** transfer through the matrix material and any **further increase in density causes a deterioration in thermal conductivity** (see Figure 30.1).

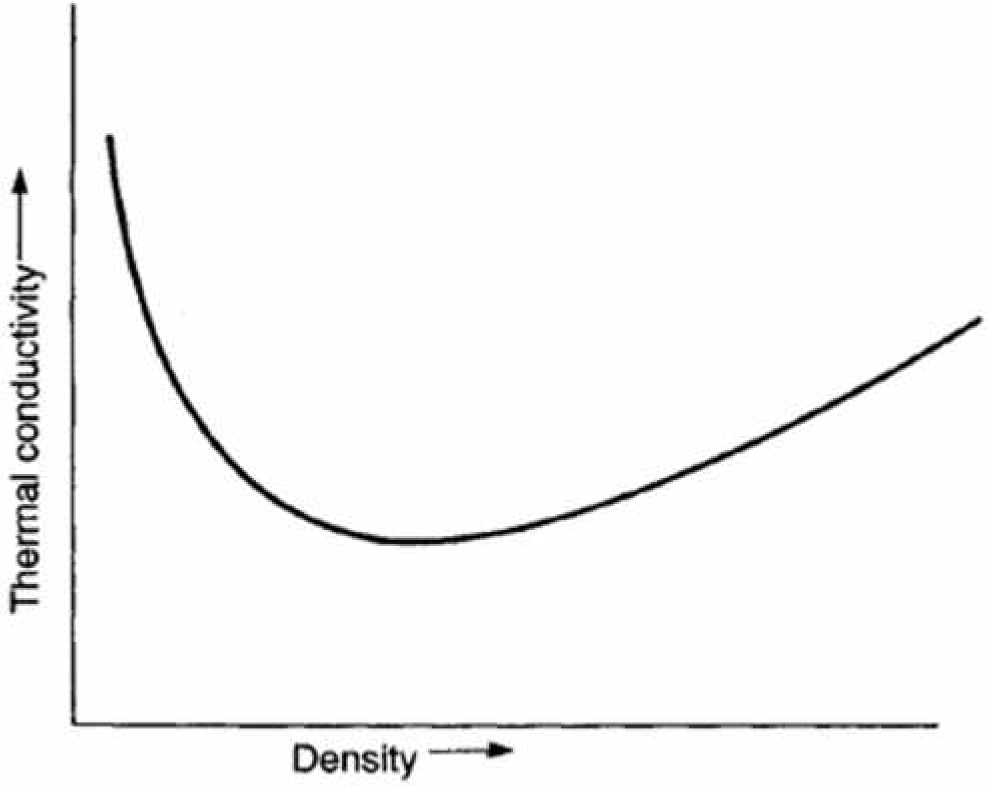


Figure 30.1 Typical relationship between thermal conductivity and density

Temperature effects

Thermal conductivity increases with temperature. The insulating medium (the **air or gas within the voids**)becomes more **excited as its temperature is raised**, and this **enhances convection within or between the voids**, thus increasing heat flow. This increase in thermal conductivity is generally continuous for air-filled products and can be mathematically modelled (see Figure 30.2). Those insulants which employ **'inert gases'** as their insulating medium **may show sharp changes in thermal conductivity, which may occur because of gas condensation**. However, this tends to take place at sub-zero temperatures.

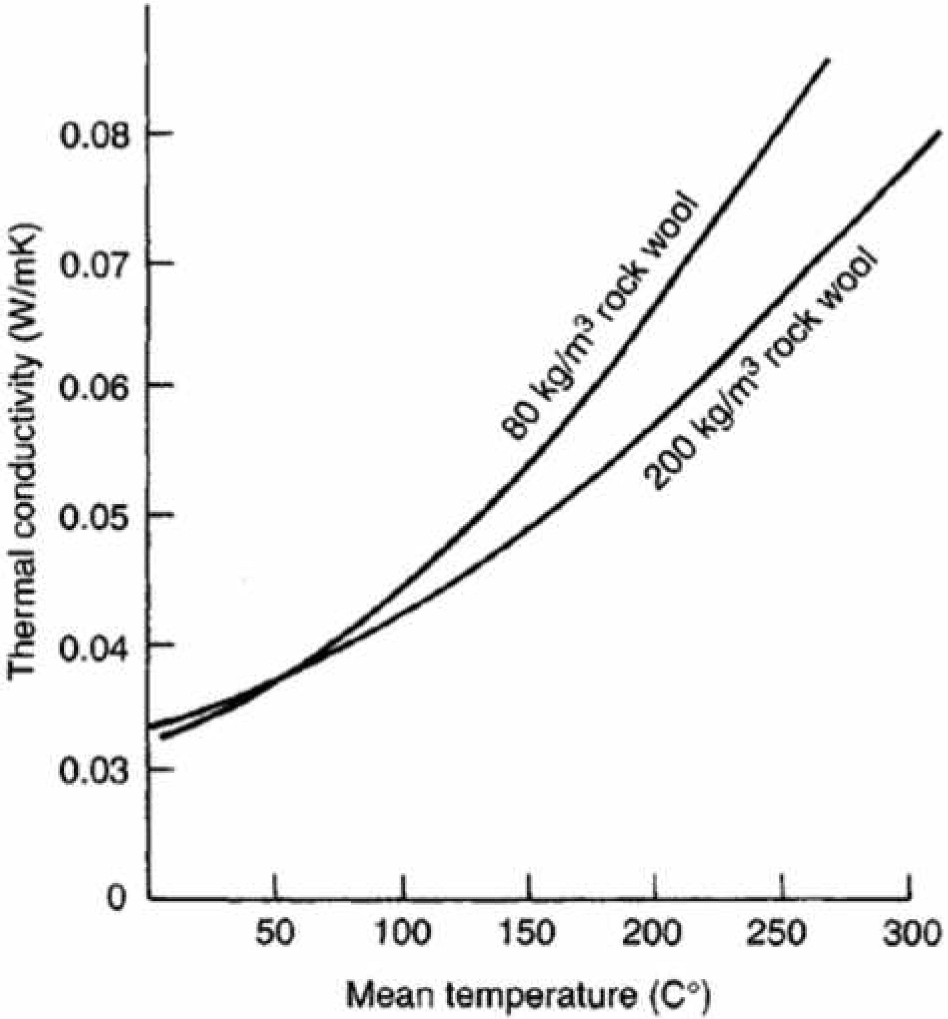
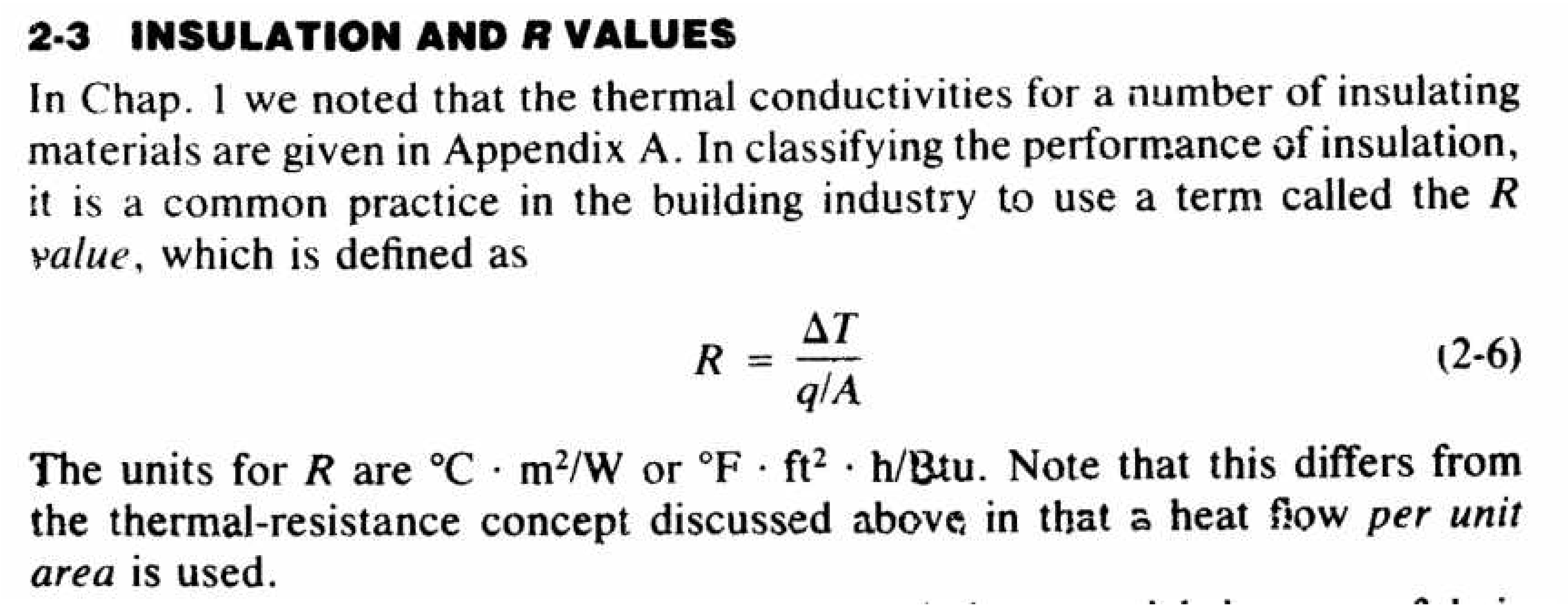


Figure 30.2 Typical relationship between thermal conductivity and mean temperature

- Selection of insulates using (λ\k) and critical thickness method



2-3 INSULATION AND *R* VALUES

In Chap. 1 we noted that the thermal conductivities for a number of insulating materials are given in Appendix A. In classifying the performance of insulation, it is a common practice in the building industry to use a term called the *R value*, which is defined as

$$R = \frac{\Delta T}{q/A} \tag{2-6}$$

The units for R are $^\circ\mathrm{C} \cdot \mathrm{m}^2/\mathrm{W}$ or $^\circ\mathrm{F} \cdot \mathrm{ft}^2 \cdot \mathrm{h}/\mathrm{Btu}$. Note that this differs from the thermal-resistance concept discussed above in that a heat flow *per unit area* is used.

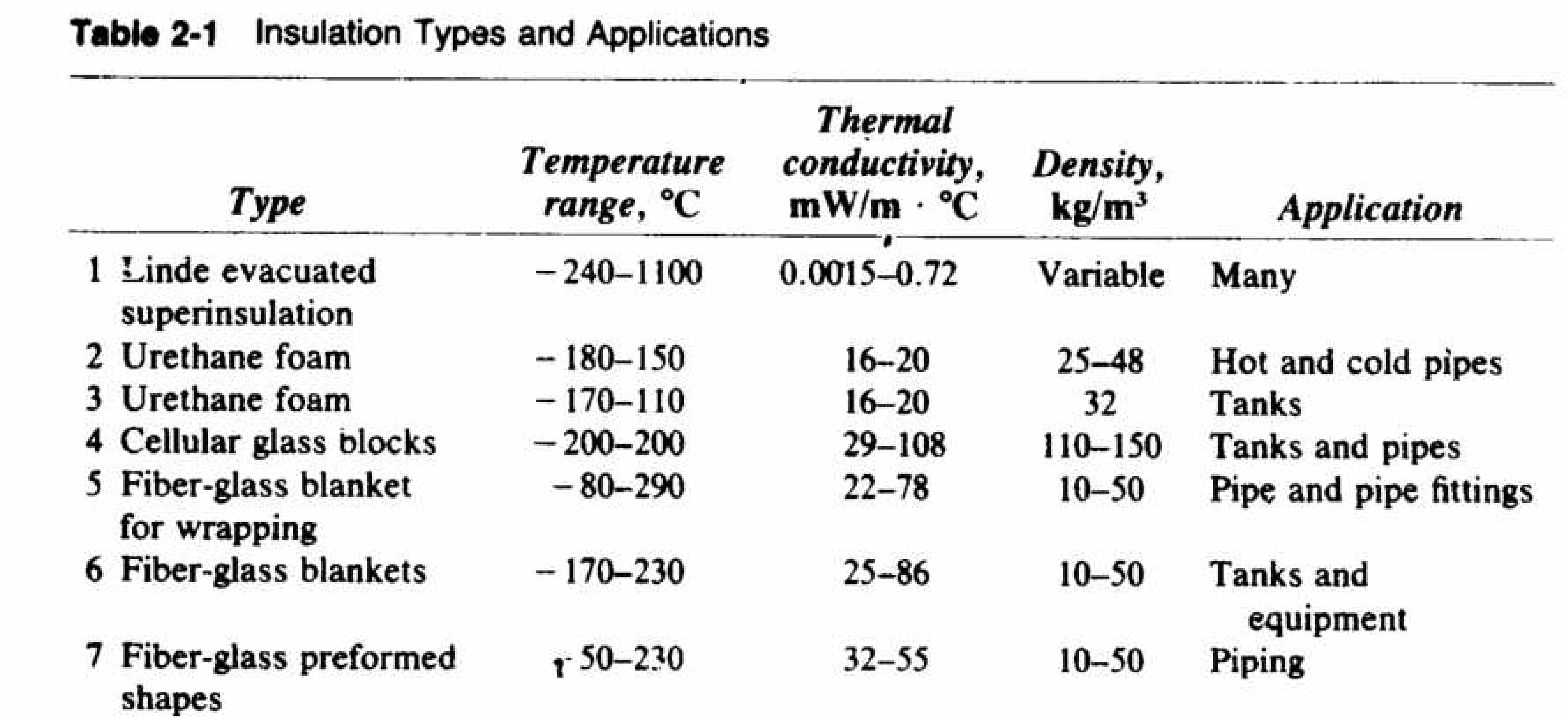


Table 2-1 Insulation Types and Applications

	Type	*Temperature range, °C*	*Thermal conductivity, mW/m · °C*	*Density, kg/m³*	*Application*
1	Linde evacuated superinsulation	−240–1100	0.0015–0.72	Variable	Many
2	Urethane foam	−180–150	16–20	25–48	Hot and cold pipes
3	Urethane foam	−170–110	16–20	32	Tanks
4	Cellular glass blocks	−200–200	29–108	110–150	Tanks and pipes
5	Fiber-glass blanket for wrapping	−80–290	22–78	10–50	Pipe and pipe fittings
6	Fiber-glass blankets	−170–230	25–86	10–50	Tanks and equipment
7	Fiber-glass preformed shapes	−50–230	32–55	10–50	Piping

2-6 CRITICAL THICKNESS OF INSULATION

Let us consider a layer of insulation which might be installed around a circular pipe, as shown in Fig. 2-7. The inner temperature of the insulation is fixed at T_i, and the outer surface is exposed to a convection environment at T_∞. From the thermal network the heat transfer is

$$q = \frac{2\pi L(T_i - T_\infty)}{\dfrac{\ln (r_o/r_i)}{k} + \dfrac{1}{r_o h}} \tag{2-17}$$

Now let us manipulate this expression to determine the outer radius of insulation r_o which will maximize the heat transfer. The maximization condition is

$$\frac{dq}{dr_o} = 0 = \frac{-2\pi L(T_i - T_\infty)\left(\dfrac{1}{kr_o} - \dfrac{1}{hr_o^2}\right)}{\left[\dfrac{\ln (r_o/r_i)}{k} + \dfrac{1}{r_o h}\right]^2}$$

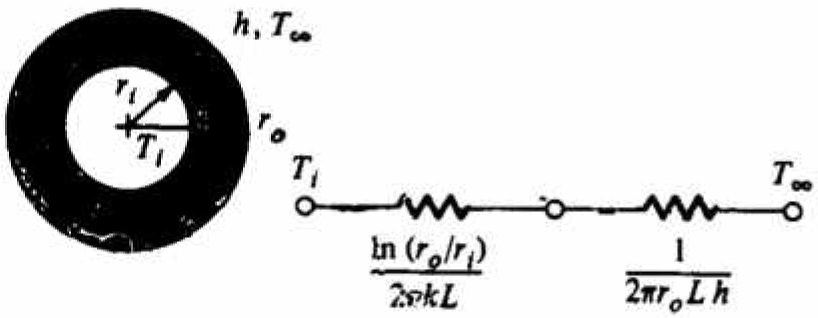


Fig. 2-7 Critical insulation thickness.

which gives the result

$$r_o = \frac{k}{h} \tag{2-18}$$

Equation (2-18) expresses the critical-radius-of-insulation concept. If the outer radius is less than the value given by this equation, then the heat transfer will be *increased* by adding more insulation. For outer radii greater than the critical value an increase in insulation thickness will cause a decrease in heat transfer. The central concept is that for sufficiently small values of h the convection heat loss may actually increase with the addition of insulation because of increased surface area.

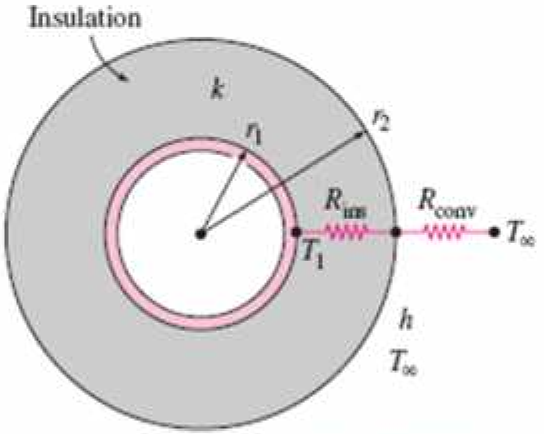
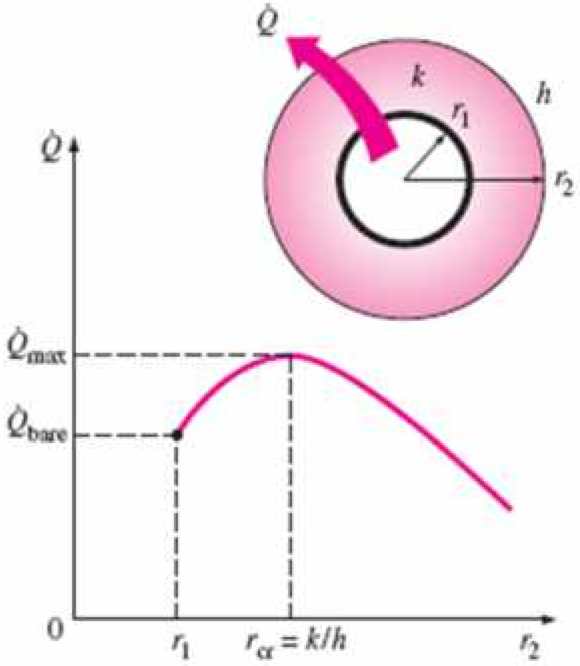


FIGURE 17–30

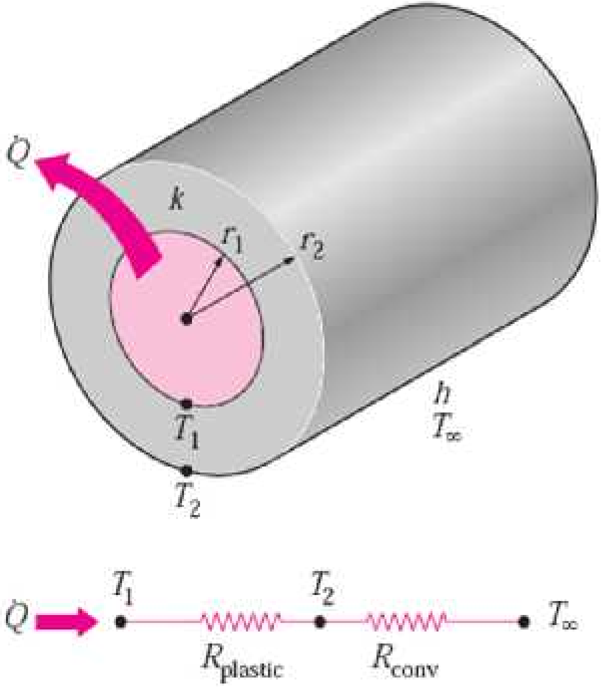
An insulated cylindrical pipe exposed to convection from the outer surface and the thermal resistance network associated with it.



Example:

Heat Loss from an Insulated Electric Wire

A 3-mm-diameter and 5-m-long electric wire is tightly wrapped with a 2-mm thick plastic cover whose thermal conductivity is *$k = 0.15$ W/m · °C. Electrical* measurements indicate that a current of 10 A passes through the wire and there is a voltage drop of 8 V along the wire. If the insulated wire is exposed to a medium at *$T = 30$°C with a heat transfer coefficient of $h = 12$ W/m2 · °C, determine* the temperature at the interface of the wire and the plastic cover in steady operation. Also determine whether doubling the thickness of the plastic cover will increase or decrease this interface temperature.



SOLUTION An electric wire is tightly wrapped with a plastic cover**.** The interface temperature and the effect of doubling the thickness of the plastic cover on the interface temperature are to be determined.

Assumptions 1 Heat transfer is steady since there is no indication of any change with time. **2 Heat transfer is one-dimensional since there is thermal** symmetry about the centerline and no variation in the axial direction. **3 Thermal** conductivities are constant. **4 The thermal contact resistance at the interface is** negligible. **5 Heat transfer coefficient incorporates the radiation effects, if any.**

Properties The thermal conductivity of plastic is given to be $k = 0.15$ *W/m · °C.*

Analysis Heat is generated in the wire and its temperature rises as a result of resistance heating. We assume heat is generated uniformly throughout the wire and is transferred to the surrounding medium in the radial direction. In steady operation, the rate of heat transfer becomes equal to the heat generated within the wire, which is determined to be

$$\dot{Q} = \dot{W}_e = VI = (8\text{ V})(10\text{ A}) = 80\text{ W}$$

The thermal resistance network for this problem involves a conduction resistance for the plastic cover and a convection resistance for the outer surface in series, as shown in Fig. 3–32. The values of these two resistances are determined to be

$$A_2 = (2\pi r_2)L = 2\pi(0.0035\text{ m})(5\text{ m}) = 0.110\text{ m}^2$$

$$R_{\text{conv}} = \frac{1}{hA_2} = \frac{1}{(12\text{ W/m}^2\cdot{}^\circ\text{C})(0.110\text{ m}^2)} = 0.76^\circ\text{C/W}$$

$$R_{\text{plastic}} = \frac{\ln(r_2/r_1)}{2\pi kL} = \frac{\ln(3.5/1.5)}{2\pi(0.15\text{ W/m}\cdot{}^\circ\text{C})(5\text{ m})} = 0.18^\circ\text{C/W}$$

and therefore

$$R_{\text{total}} = R_{\text{plastic}} + R_{\text{conv}} = 0.76 + 0.18 = 0.94^\circ\text{C/W}$$

Then the interface temperature can be determined from

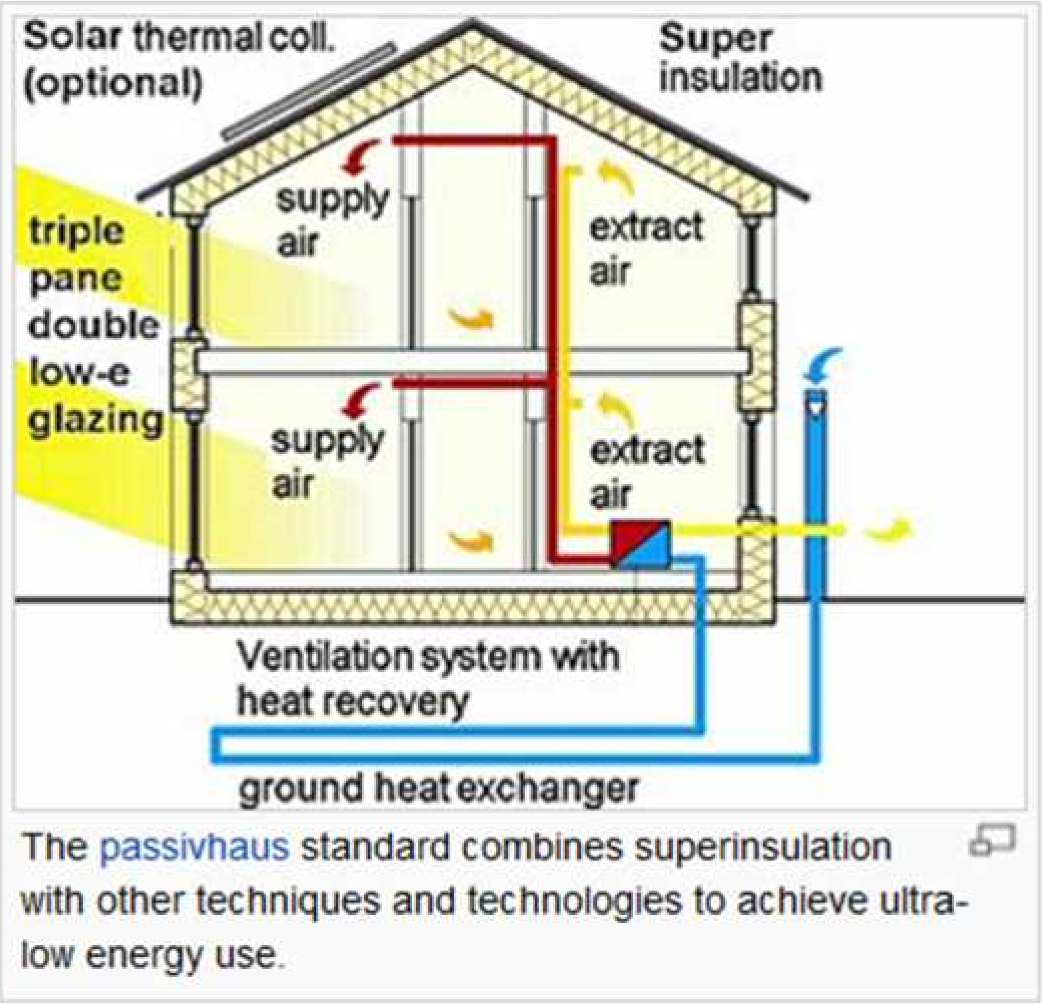
$$\dot{Q} = \frac{T_1 - T_\infty}{R_{\text{total}}} \longrightarrow T_1 = T_\infty + \dot{Q}R_{\text{total}}$$
$$= 30^\circ\text{C} + (80\text{ W})(0.94^\circ\text{C/W}) = 105^\circ\text{C}$$

To answer the second part of the question, we need to know the critical radius of insulation of the plastic cover. It is determined from Eq. 3–50 to be

$$r_{cr} = \frac{k}{h} = \frac{0.15\ \mathrm{W/m \cdot {}^\circ C}}{12\ \mathrm{W/m^2 \cdot {}^\circ C}} = 0.0125\ \mathrm{m} = 12.5\ \mathrm{mm}$$

which is larger than the radius of the plastic cover. Therefore, increasing the thickness of the plastic cover will *enhance heat transfer until the outer radius* of the cover reaches 12.5 mm. As a result, the rate of heat transfer *Q · will increase* when the interface temperature *T1 is held constant, or T1 will decrease* when *Q · is held constant, which is the case here.*

Super insulation is an approach to building design, construction, and retrofitting that dramatically reduces heat loss (and gain) by using much higher levels of insulation and air tightness than normal. Super insulation is one of the ancestors of the passive house approach.



The passivhaus standard combines superinsulation with other techniques and technologies to achieve ultra-low energy use.

Retrofits

There is no set definition of super insulation, but super insulated buildings typically include:
- Very high levels of insulation (typically $R_{ip}40$ walls and $R_{ip}60$ roof, corresponding to SI U-values of 0.15 and 0.1 W/(m²·K) respectively)
- Details to ensure insulation continuity where walls meet roofs, foundations, and other walls
- Airtight construction, especially around doors and windows
- a Heat recovery ventilation to provide fresh air
- No large windows facing any particular direction
- Much smaller than conventional heating system, sometimes just a small backup heater

It is possible, and increasingly desirable, to retrofit super insulation to an existing older house or building. The easiest way is often to add layers of continuous rigid exterior insulation,[4] and sometimes by building new exterior walls that allow more space for insulation.

An improved continuous air barrier is almost always worth adding, as older homes tend to be leaky, and such an air barrier can be important for energy savings and durability.

Interior retrofits are possible where the owner wants to preserve the old exterior siding, or where setback requirements don't leave space for an exterior retrofit.

Q25) What are the types of insulation material formation?

Q26) Why insulate? Give at least 5 reasoning for that.

Q27) Classify the insulation materials and name some of their products.

Q28) What is the density of insulation effect on its thermal conductivity ? Draw its relation.

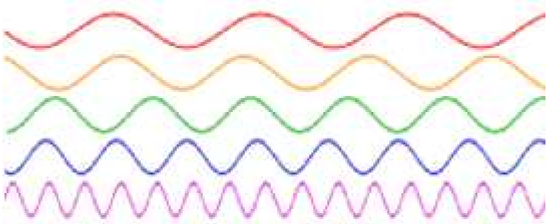
Q29) What is the Temperature of insulation effect on its thermal conductivity ? Draw its relation for different densities.

Q30) A 4-mm-diameter and 5-m-long electric wire is tightly wrapped with a 1-mm thick plastic cover whose thermal conductivity is k = 0.2 W/m · °C. Electrical measurements indicate that a current of 15 A passes through the wire and there is a voltage drop of 8 V along the wire. If the insulated wire is exposed to a medium at T 30°C with a heat transfer coefficient of h = 15 W/m2 · °C, determine the temperature at the interface of the wire and the plastic cover in steady operation. Also determine whether doubling the thickness of the plastic cover will increase or decrease this interface temperature..

Energy conservation

Lecture Nine

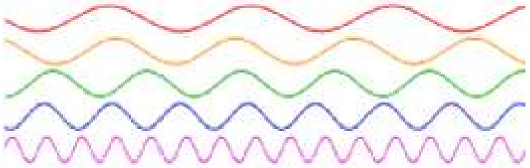
Acoustic insulation



Dr.K.Al-khishali

SOUND

Sound is a mechanical wave that is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing. Sound that is perceptible by humans has frequencies from about 20 Hz to 20,000 Hz. In air at standard temperature and pressure, the corresponding wavelengths of sound waves range from 17 m to 17 mm.. It is a traveling oscillation in a medium exhibiting the properties of both elasticity and inertia. In fluid media (air or water), the disturbance travels as a longitudinal compression wave. Sound is generated by a vibrating surface or a turbulent fluid stream. **In HVAC system design, both airborne and structure-borne sound propagation are of concern.**



Speed

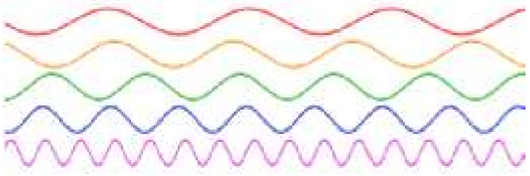
The speed of a longitudinal wave in a fluid medium is a function of the medium's density and modulus of elasticity. In air at room temperature, the speed of sound is about 340 m/s; in water, about 1500 m/s.

Speed of Sound=c= $(\gamma R T)^{0.5}$

$\gamma = 1.4$ **R = Gas constant T = Temperature**

Frequency

Frequency is the number of oscillations (or cycles) per unit time completed by a vibrating object. The international unit for frequency is cycles/s or hertz (Hz). Sinusoidal waves of various frequencies; the bottom waves have higher frequencies than those above. The horizontal axis represents time.



Wavelength

Wavelength is the distance between successive rarefactions or compressions of the propagation medium. Wavelength, speed, and frequency are interrelated by the following equation:

$$\lambda = c/f$$

where

λ = wavelength, m

c = speed of sound, m/s

f = frequency, Hz

Noise transmission,
noise level
noise control and
design techniques

Dr.K.Al-khishali

Noise transmission,

The behavior of sound propagation is generally affected by three things:

- A relationship between density and pressure. This relationship, affected by temperature, determines the speed of sound within the medium.
- The propagation is also affected by the motion of the medium itself. For example, sound moving through wind. Independent of the motion of sound through the medium, if the medium is moving, the sound is further transported.
- The viscosity of the medium also affects the motion of sound waves. It determines the rate at which sound is attenuated. For many media, such as air or water, attenuation due to viscosity is negligible.

When sound is moving through a medium that does not have constant physical properties, it may be refracted.

Sound cannot travel through a vacuum.

Acoustics

Acoustics is the interdisciplinary science that deals with the study of all mechanical waves in gases, liquids, and solids including vibration, sound, ultrasound and infrasound.

Noise

Noise Is a term often used to refer to an unwanted sound.

Sound pressure or **acoustic pressure** is the local pressure deviation from the ambient (average, or equilibrium) atmospheric pressure caused by a sound wave. Sound pressure in air can be measured using a microphone, and in water using a hydrophone. The SI unit for sound pressure p is the pascal (symbol: Pa).

Sound pressure level (SPL) or **sound level** is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level. The commonly used "zero" reference sound pressure in air or other gases is 20 µPa RMS, which is usually considered the threshold of human hearing (at 1 kHz).

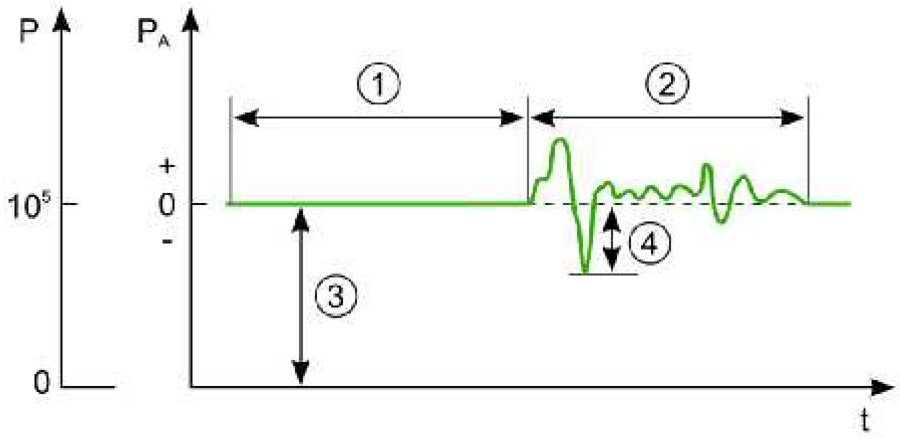
Sound pressure level

Sound pressure is the difference, in a given medium, between average local pressure and the pressure in the sound wave. A square of this difference (i.e., a square of the deviation from the equilibrium pressure) is usually averaged over time and/or space, and a square root of this average provides a root mean square(RMS) value. For example, 1 Pa RMS sound pressure (94 dBSPL) in atmospheric air implies that the actual pressure in the sound wave oscillates between (1 atm $-\sqrt{2}$ Pa) and (1 atm $+\sqrt{2}$ Pa), that is between 101323.6 and 101326.4 Pa. Such a tiny (relative to atmospheric) variation in air pressure at an audio frequency is perceived as a deafening sound, and can cause hearing damage, according to the table below.

As the human ear can detect sounds with a wide range of amplitudes, sound pressure is often measured as a level on a logarithmic decibel scale. The **sound pressure level** (SPL) or L_p is defined as

$$L_p = 10 \log_{10}\left(\frac{p^2}{{p_{ref}}^2}\right) = 20 \log_{10}\left(\frac{p}{p_{ref}}\right) \text{ dB}$$

where p is the root-mean-square sound pressure and ρ_{ref} is a reference sound pressure. Commonly used reference sound pressures, defined in the standard ANSI S1.1-1994, are 20 µPa in air and 1 µPa in water. Without a specified reference sound pressure, a value expressed in decibels cannot represent a sound pressure level. A-weighting attempts to match the response of the human ear to noise and A-weighted sound pressure levels are labeled dBA. C-weighting is used to measure peak levels.



Sound pressure diagram:
1. silence,
2. audible sound,
3. atmospheric pressure,
4. instantaneous sound pressure

Sound pressure or **acoustic pressure** is the local pressure deviation from the ambient (average, or equilibrium) atmospheric pressure caused by a sound wave

Sound pressure level (SPL) or **sound level** is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level. The commonly used "zero" reference sound pressure in air is 20 µPa RMS, which is usually considered the threshold of human hearing (at 1 kHz).

Instantaneous sound pressure

The instantaneous sound pressure is the deviation from the local ambient pressure caused by a sound wave at a given location and given instant in time. The effective sound pressure is the root mean square of the instantaneous sound pressure over a given interval of time (or space).

Total pressure p_{total} is given by:

$$p_{total} = p_0 + p_{osc}$$

where:

p_0 = local ambient atmospheric (air) pressure,

p_{osc} = sound pressure deviation

Distance law

When measuring the sound created by an object, it is important to measure the distance from the object as well, since the sound pressure decreases with distance from a point source with a $1/r$ relationship (and not $1/r^2$, like sound intensity).

The **distance law** for the sound pressure p in 3D is inverse-proportional to the distance r of a punctual sound source.

$$p \propto \frac{1}{r}$$

Symbol	SI Unit	Meaning
p	pascals	sound pressure
f	hertz	frequency
ρ	kg/m^3	density of medium
c	m/s	speed of sound
v	m/s	particle velocity
$= 2 \cdot \quad \cdot f$	radians/s	angular frequency
ξ	meters	particle displacement
$Z = c \bullet \rho$	N·s/m^3	acoustic impedance
a	m/s^2	particle acceleration
I	W/m^2	sound intensity
E	W·s/m^3	sound energy density
P_{ac}	watts	sound power or acoustic power
A	m^2	Area

Source of sound	Sound pressure	Sound pressure level
Sound in air	pascal RMS	dB re 20 μPa
Shockwave (distorted sound waves > 1 atm; waveform valleys are clipped at zero pressure)	>101,325 Pa	>194 dB
Theoretical limit for undistorted sound at 1 atmosphere environmental pressure	101,325 Pa	~194.094 dB
Stun grenades	6,000–20,000 Pa	170–180 dB
Rocket launch equipment acoustic tests	~4000 Pa	~165 dB

Simple open-ended thermoacoustic device[6]	12,619 Pa	176 dB
.30-06 rifle being fired 1 m to shooter's side	7,265 Pa	171 dB (peak)
M1 Garand rifle being fired at 1 m	5,023 Pa	168 dB
Jet engine at 30 m	632 Pa	150 dB
Threshold of pain	63.2 Pa	130 dB
Vuvuzela horn at 1 m	20 Pa	120 dB(A)[7]
Hearing damage (possible)	20 Pa	approx. 120 dB
Jet engine at 100 m	6.32 – 200 Pa	110 – 140 dB
Non-electric chainsaw at 1 m	6.3 Pa	110 dB[8]
Jack hammer at 1 m	2 Pa	approx. 100 dB

Traffic on a busy roadway at 10 m	$2\times10^{-1} – 6.32\times10^{-1}$ Pa	80 – 90 dB
Hearing damage (over long-term exposure, need not be continuous)	0.356 Pa	85 dB[9]
Passenger car at 10 m	$2\times10^{-2} – 2\times10^{-1}$ Pa	60 – 80 dB
EPA-identified maximum to protect against hearing loss and other disruptive effects from noise, such as sleep disturbance, stress, learning detriment, etc.		70 dB[10]
Handheld electric mixer		65 dB
TV (set at home level) at 1 m	2×10^{-2} Pa	approx. 60 dB
Washing machine, dishwasher		42-53 dB[11]
Normal conversation at 1 m	$2\times10^{-3} – 2\times10^{-2}$ Pa	40 – 60 dB
Very calm room	$2\times10^{-4} – 6.32\times10^{-4}$ Pa	20 – 30 dB
Light leaf rustling, calm breathing	6.32×10^{-5} Pa	10 dB
Auditory threshold at 1 kHz	2×10^{-5} Pa	0 dB[9]

Soundproofing or Noise Control

Soundproofing is any means of reducing the sound pressure with respect to a specified sound source and receptor. There are several basic approaches to reducing sound:

- •increasing the distance between source and receiver,
- •using noise barriers to reflect or absorb the energy of the sound waves,
- •using damping structures such assound baffles, or
- •using active antinoise sound generators.

Distance

The energy density of sound waves decreases as they spread out, so that increasing the distance between the receiver and source results in a progressively lesser intensity of sound at the receiver. In a normal three dimensional setting, with a point source and point receptor, the intensity of sound waves will be attenuated according to the inverse square of the distance from the source.

Damping

Damping means to reduce resonance in the room, by absorption or redirection (reflection or diffusion). Absorption will reduce the overall sound level,

Absorption

Absorbing sound spontaneously converts part of the sound energy to a very small amount of heat in the intervening object (the absorbing material), rather than sound being transmitted or reflected.

- **Porous absorbers**

Porous absorbers, typically open cell rubber foams or melamine sponges, absorb noise by friction within the cell structure. The exact absorption profile of a porous open cell foam will be determined by a number of factors including the following:

Cell size
Tortuosity
Porosity
Material thickness
Material density

- **Resonant absorbers**

Resonant panels, Helmholtz resonators and other resonant absorbers work by damping a sound wave as they reflect it.

- **Reflection**

In an outdoor environment such as highway engineering, embankments or panelling are often used to reflect sound upwards into the sky.

- **Diffusion**

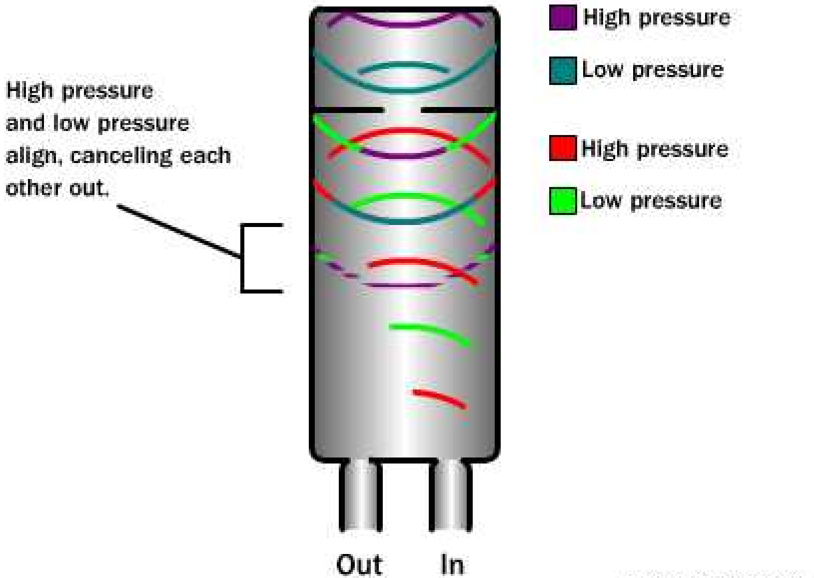
If a specular reflection from a hard flat surface is giving a problematic echo then an acoustic diffuser may be applied to the surface. It will scatter sound in all directions.

Residential soundproofing

Residential soundproofing aims to decrease or eliminate the effects of exterior noise. The main focus of residential soundproofing in existing structures is the windows. Curtains can be used to damp sound either through use of heavy materials or through the use of air chambers known as honeycombs. Single-, double- and triple-honeycomb designs achieve relatively greater degrees of sound damping. The primary soundproofing limit of curtains is the lack of a seal at the edge of the curtain. Double-pane windows achieve somewhat greater sound damping than single-pane windows. Significant noise reduction can be achieved by installing a second interior window. In this case the exterior window remains in place while a slider or hung window is installed within the same wall openings.

Noise barriers as exterior soundproofing

Noise barriers along major highways to protect adjacent residents from intruding roadway noise. The technology exists to predict accurately the optimum geometry for the noise barrier design. Noise barriers may be constructed of wood, masonry, earth or a combination thereof.



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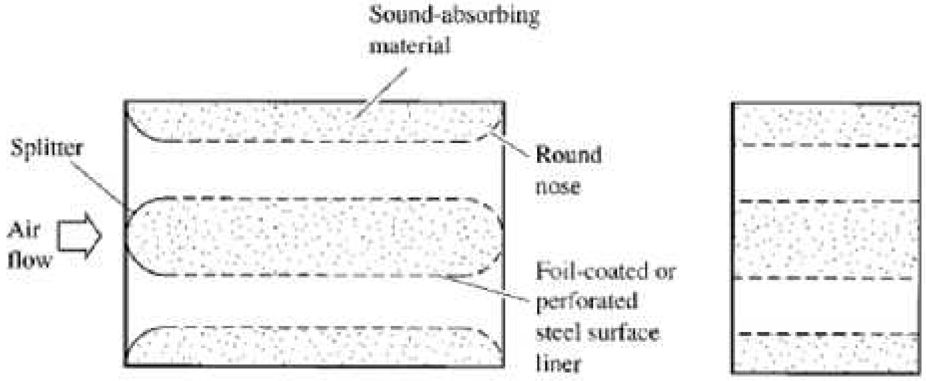


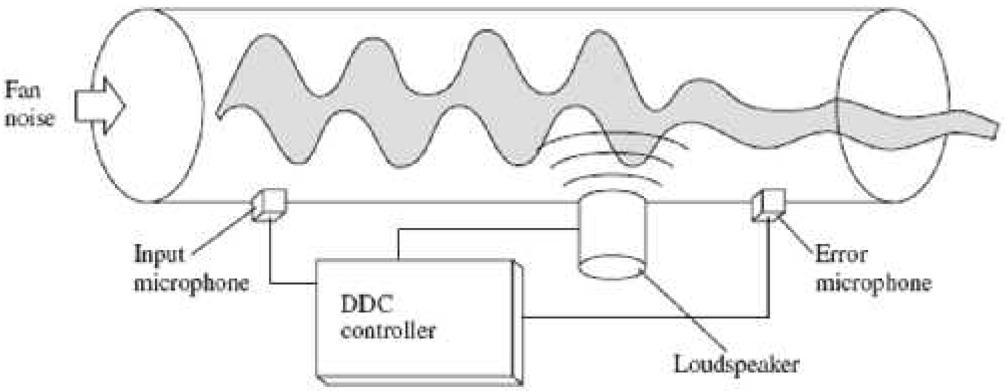


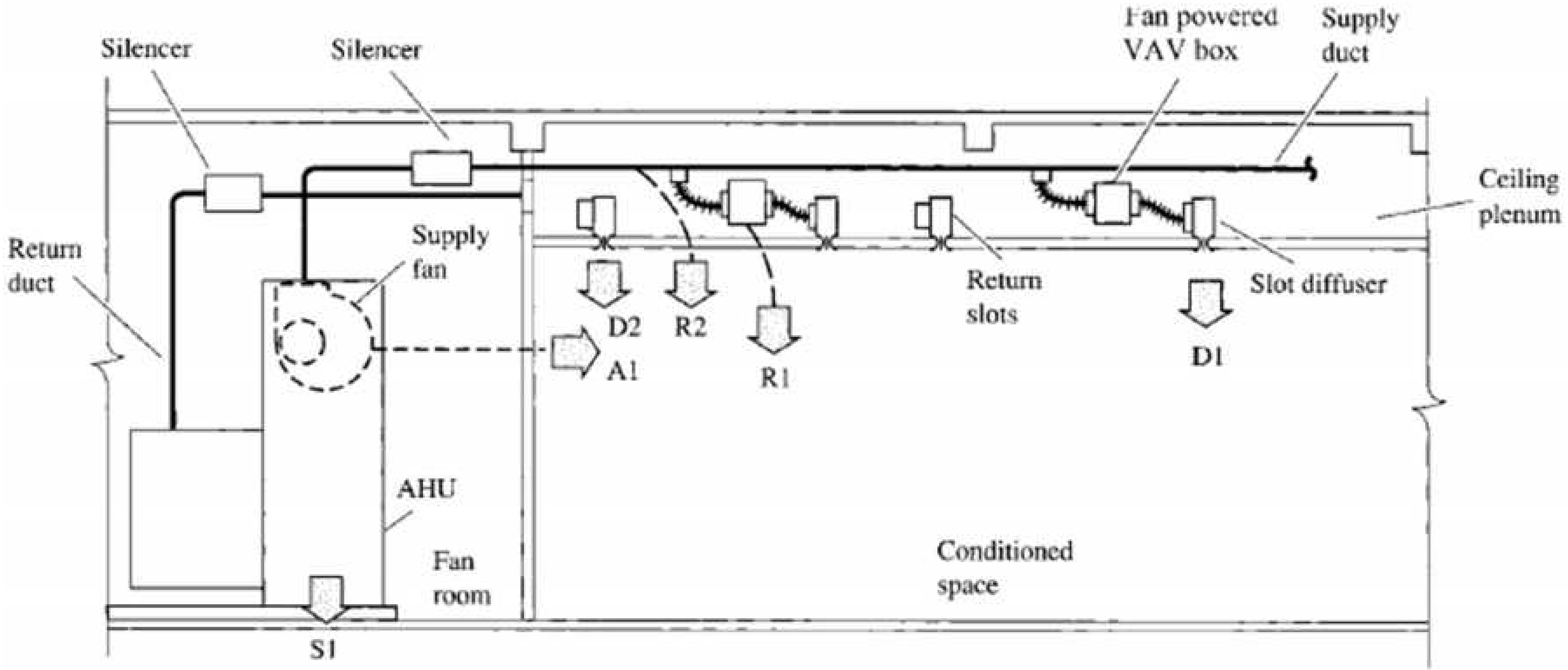
FIGURE 19.5 An active silencer.

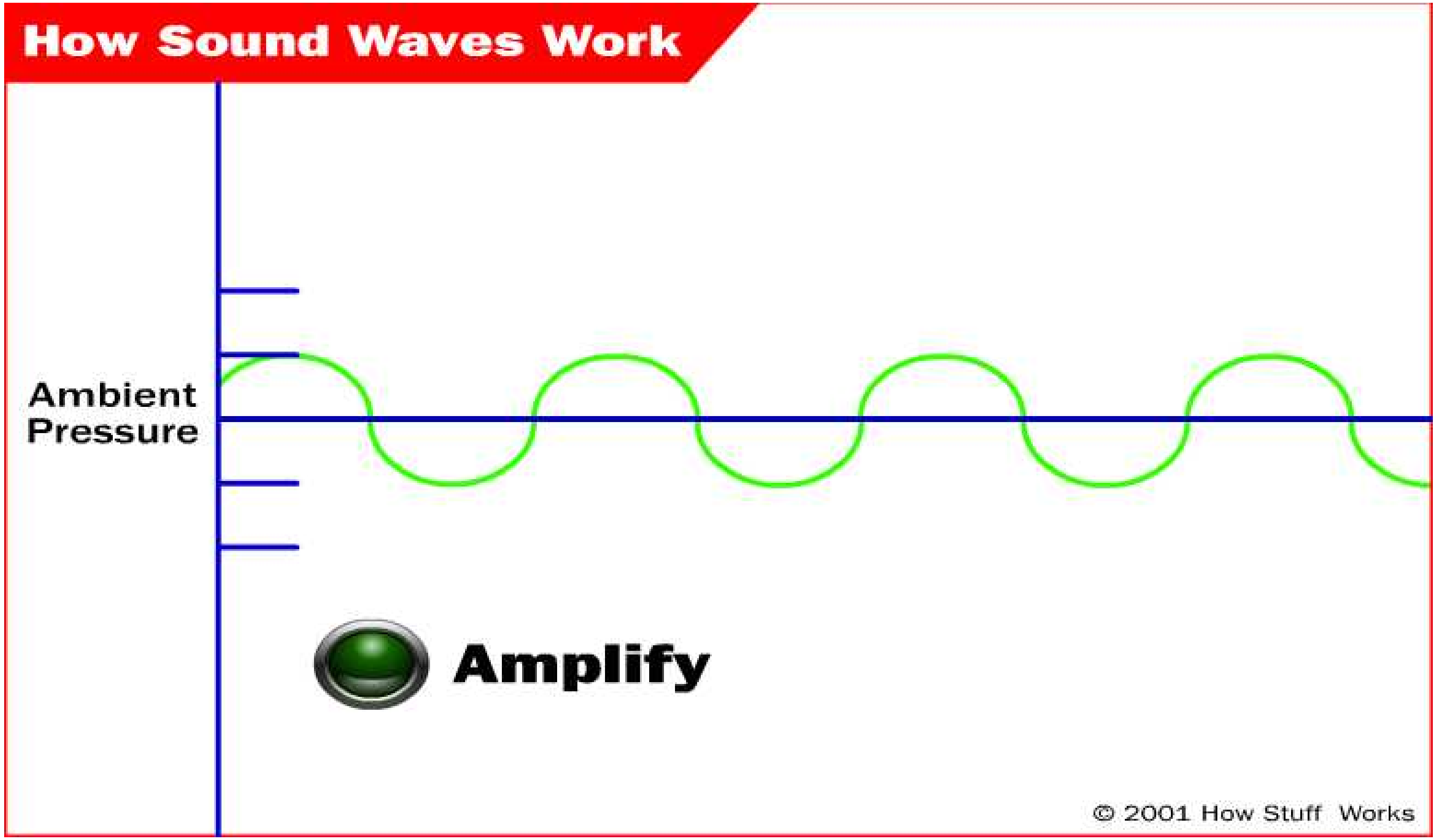
sound source

HVAC&R equipment that acts as noise generators includes fans, compressors, pumps, and dampers; this noise is in addition to other airflow noise in ducts.

Sound transmits from the source to the receiver via the following paths:

Duct-borne paths or (system noise)D1,D2 , Radiated sound path (Duct walls and casings)R1,R2 Airborne path (adjacent area by air) A1 and Structure-borne path (vibration by building structure) S1.




How Sound Waves Work
Ambient
Pressure
Amplify
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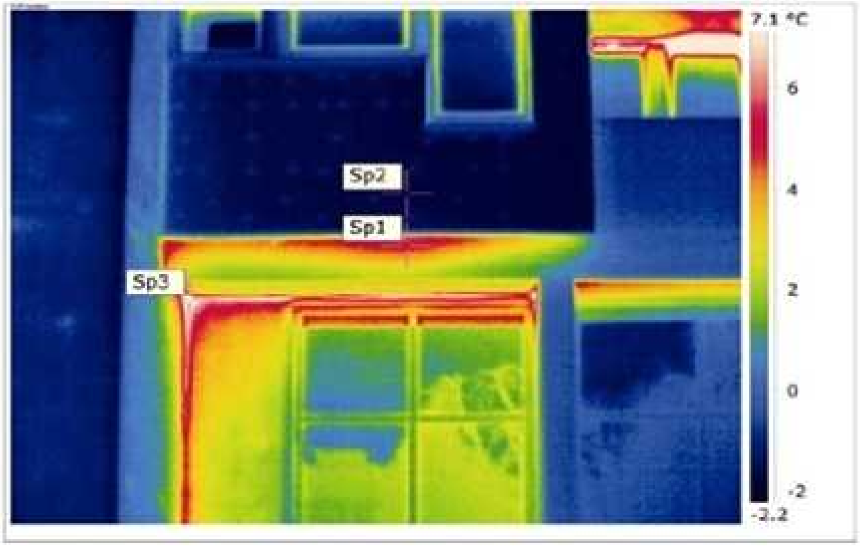
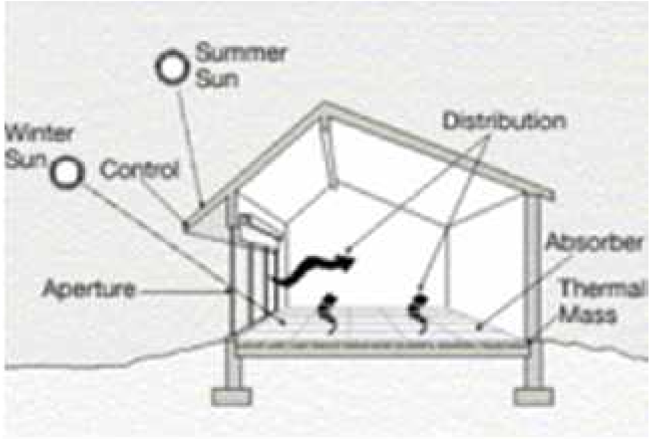
Energy conservation

Lecture Eleven

Minimizing heat and infiltration losses





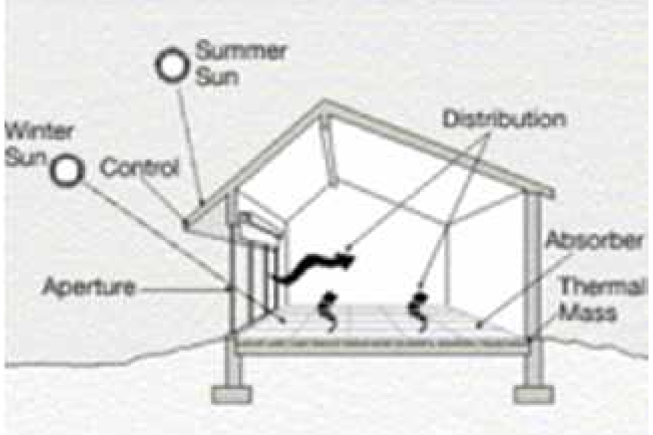
Dr.K.Al-khishali

Energy Conservation Guidebook
Second Edition
by
Dale R. Patrick
Stephen W. Fardo
Ray E. Richardson
Steven R. Patrick

Energy conservation

Lecture Eleven

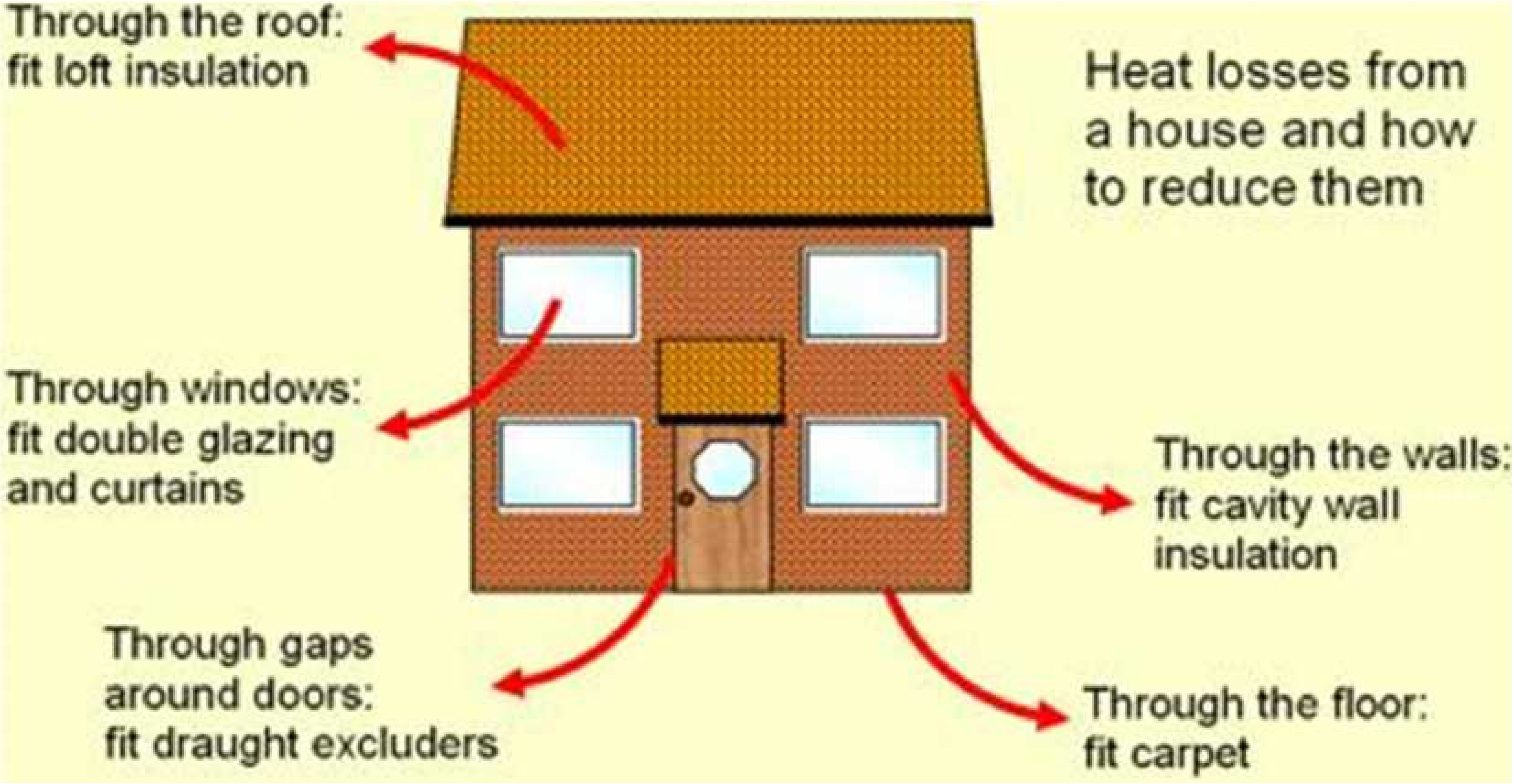
Minimizing heat and infiltration losses



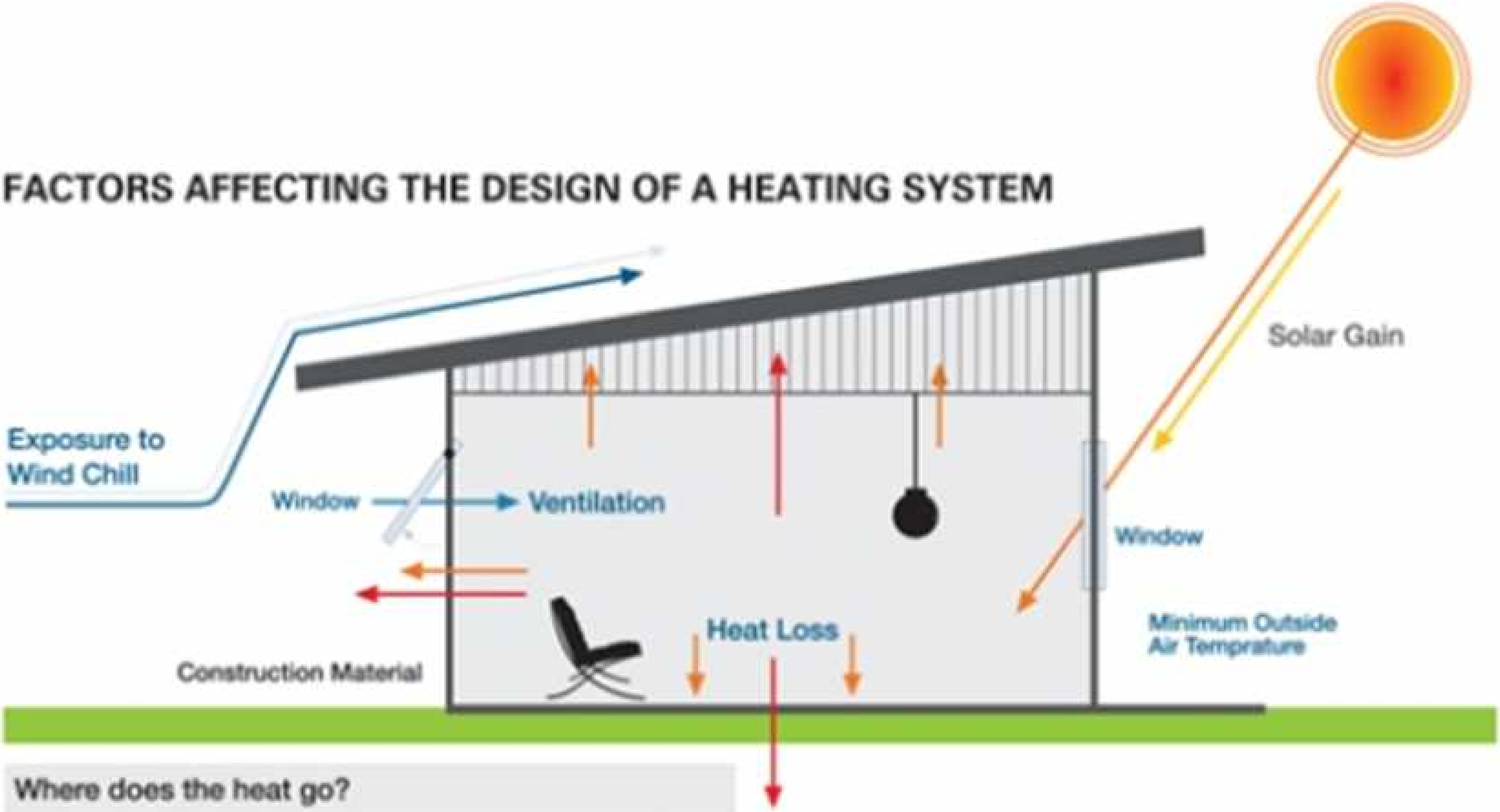
Dr.K.Al-khishali

Minimizing heat and infiltration losses

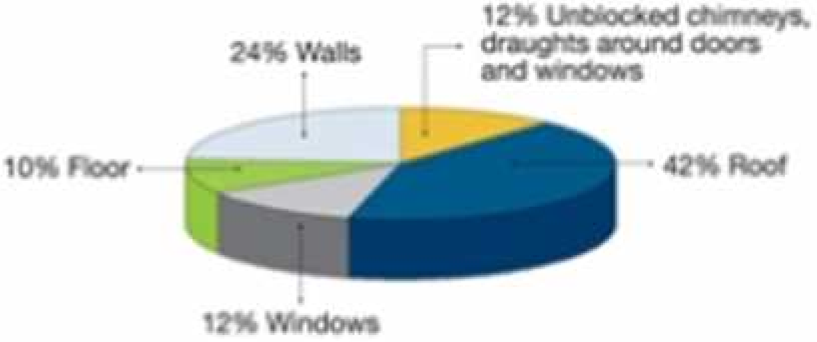
- The use of insulation , double glassing , shading , tight and weather stripped windows
- Reduce/ remove condensation in building especially cold stores



FACTORS AFFECTING THE DESIGN OF A HEATING SYSTEM



Where does the heat go?



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Minimizing heat losses

heat losses

Heat loss is a very important factor in the operation of a building. The amount of heat that is lost from a building into the outside air affects the amount of heating, cooling, and ventilation required in a building.

The building heat loss are:

1. The heat transmitted through the walls, ceiling, floor, glass or other kinds of heat loss.
2. The heat required to warm or cool the air entering the space.

Heat loss that occurs through walls, floors, and ceilings is referred to as *transmission heat loss.*

The sum of the heat losses is referred to as the heating or cooling loads.

A major part of building heat gain is due to solar radiation, hence an estimate of the amount of solar radiation the building is subjected to is essential for estimating the cooling and heating loads on the buildings.

By proper design and orientation of the building, selection of suitable materials and landscaping it is possible to harness solar energy beneficially. This can reduce the overall cost (initial and operating) of the air conditioning system considerably by reducing the required capacity of the cooling and heating equipment.

Solar radiation is an important variable to consider when calculating heat gain. Most solar radiation occurs through windows. There for **orientation of the window** (direction it faces), the **kind of glass** used, and **whether or not shade** trees or roof overhang are in front of the window affect solar radiation. The **amount of shaded area** of a **window varies** according to **orientation**, **amount of overhang** or permanently **shaded area**, and the **geographic latitude** of the building. Ordinarily, windows oriented toward the northeast or northwest cannot be protected by roof overhangs or shade trees. They are considered to be in maximum sunlight and minimum shade.

Heat-gain calculations for buildings **must also consider the heat given off by people and appliances.**

Insulating Glass Windows

A relatively new idea to help conserve energy in window areas is insulating glass. These windows are made with two or more panes separated by an air space or thermal break.

Window Shades and Blinds

Window shades and blinds, such as those shown in the Figure of shading devices in lecture Three, can provide energy savings in most climatic areas

Double-Glazed Window Panes

It is possible to reduce heat loss through double-glazed window panes without purchasing complete insulating glass units.

Insulated Drapes and Curtains

When drapes and curtains are needed to cover window and door areas, they can be replaced by insulated types. This is another method of reducing heat loss through window and door areas.

Insulated Shutters

Insulated shutters are now made to cover entire window openings. They can reduce heat loss by a substantial amount.

Insulation.

Check the amount of insulation in walls, ceilings, and floors. All areas between heated or cooled spaces and outside or unheated or uncooled spaces should have the proper amount of insulation. Areas to check also include storage areas, basements, and attics. Also check for water-damaged insulation. Assure that the vapor barrier faces the heated or cooled space and is properly installed.

Have the proper amount of insulation put into the under insulated areas. Wall insulation can be pumped to wall cavities and between studs. Solid walls can have insulation put on and then be covered. Some and minor patching and tacking may also be helpful.

Solar Window Film

Solar window film can help reduce energy use in buildings. This film is permanently bonded to the inside of the window glass during its installation. It is similar to tinted glass; however, it rejects more sunlight while saving room heat that escapes through windows during the winter season. Solar window film provides a reflective surface to control heat gain in summer and heat loss in winter. The film functions by reflecting sunlight, thus reducing glare inside. Essentially, solar window film can reduce the heat of sunlight passing into a building, reduce glare inside, and reduce heat loss through windows.

Minimizing infiltration losses

Infiltration

In all buildings, there is some cold air that comes inside. An equal amount of hot air goes outside. This process is called *infiltration heat loss.*

Most structures has some air leakage or infiltration from the cracks around doors , widows, lighting fixtures and joints between walls , roof and floors . This result a heat loss or gain as the out side air temperature and humidity are not as the inside designs value. Sensible heat will be increased as well as the latent heat. Methods used to estimate this loss is either by the crack method or the number of air change method. Infiltration is highly dependent on pressure difference between outside and inside, wind speeds, cracks location with respect to wind direction and stake effect. Also, on the type of building usage and occupants.

Heat loss may be greatly reduced just by sealing cracks between materials. Sealing cracks causes air infiltration to be reduced.

Air Doors or Curtains

Air doors or curtains are air circulation units mounted above open areas. They provide an air barrier to protect exterior or interior openings from heat transfer.

Infiltration

Infiltration is the uncontrolled inward flow of outdoor air through cracks and openings in the building envelope due to the pressure difference across the envelope. The pressure difference may be caused by any of the following:

1. Wind pressure

2. Stack effect due to the outdoor and indoor temperature difference

3. Mechanical ventilation air

infiltration technically, its unwanted, uncontrolled airflow through buildings, moving in or out of the structure. For example, in cold weather, the heated air inside the building flows out. Frigid outside air and moisture leak in – rooms feel drafty. Air infiltration is caused by leaks around windows and doors, and by the spaces, joints, voids and cracks hidden inside the structure.

In summer, for low-rise commercial buildings that have their exterior windows well sealed, and if a positive pressure is maintained in the conditioned space when the air system is operating, normally the infiltration can be considered zero.

For high-rise buildings, infiltration should be considered and calculated in both summer and winter. As soon as the volume flow rate of infiltrated air $\dot{V}_{inf}$, cfm (m^3 /min), is determined, the space sensible heat gain from infiltration q_{inf}, *Btu /h (W), can be calculated as*

$$q_{s,\mathrm{inf}} = 60\dot{V}_{\mathrm{inf}}\,\rho_o c_{pa}\,(T_o - T_r)$$

where ρ_o *density of outdoor air, lb/ ft3 (kg/m3). The space latent heat gain from infiltration* $q_{l,\ inf}$ Btu/h (W), can be calculated as

$$q_{l,\mathrm{inf}} = 60\dot{V}_{\mathrm{inf}}\rho_o\,(w_o - w_r)h_{fg,32}$$

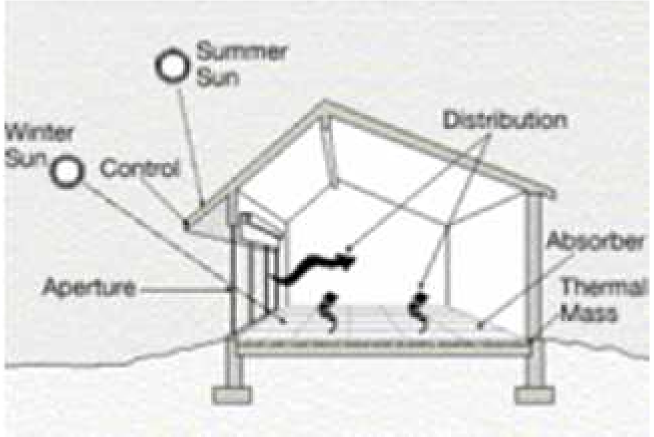
where w_o, w_r *= humidity ratio of outdoor and space air, respectively, lb/ lb (kg /kg)*
$h_{fg,\ 32}$ *= latent heat of vaporization at 32°F, Btu/ lb (J /kg).*

Energy conservation

Lecture Thirteen

Solar radiation passive and active

- Direct solar radiation
- Diffused solar radiation
- Reflective solar radiation
- Solar Angle.
- Heat gain by fenestration ie. Solar and fabric
- Estimating solar performance



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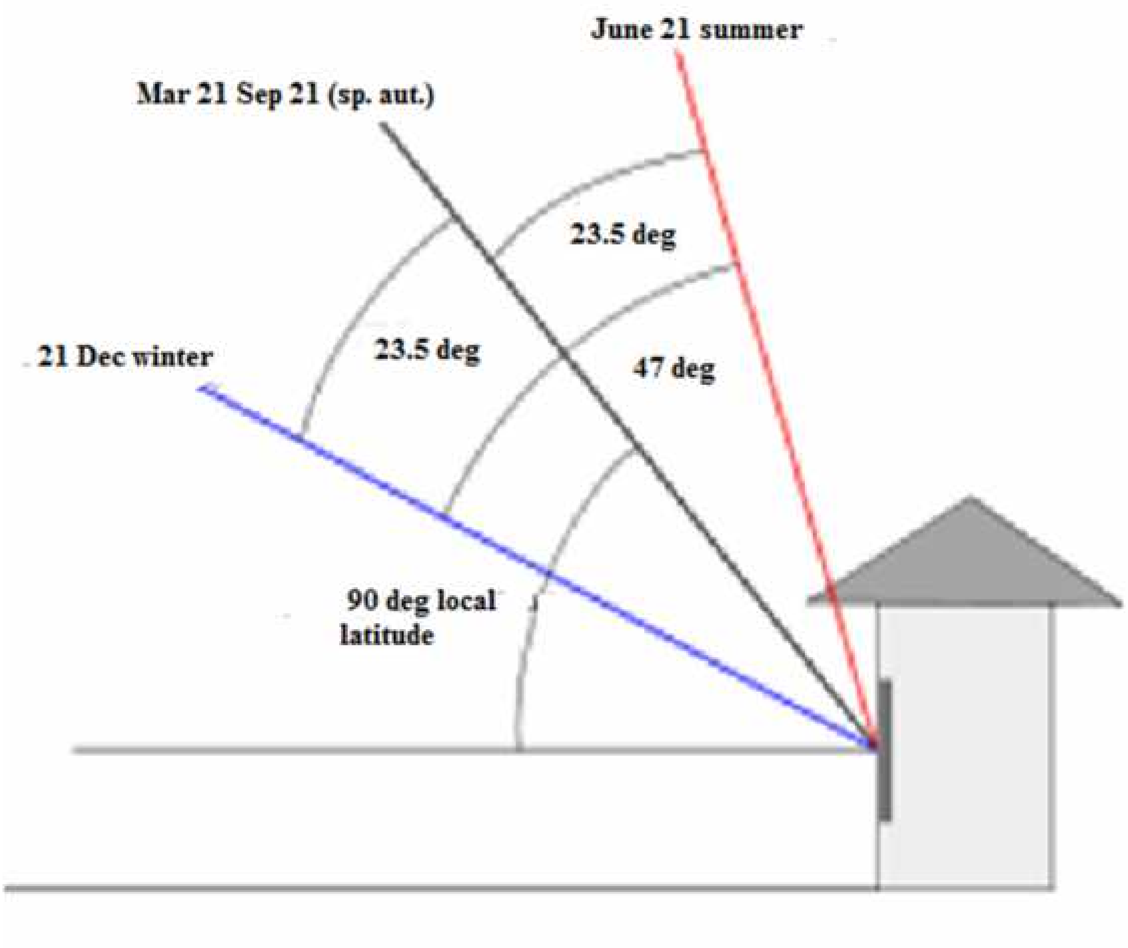
Direct solar radiation

In equatorial regions at less than 23.5 degrees, the position of the sun at solar noon will oscillate from north to south and back again during the year.

In regions closer than 23.5 degrees from either north-or-south pole, during summer the sun will trace a complete circle in the sky without setting whilst it will never appear above the horizon six months later, during the height of winter.



Direct solar gain

Direct gain attempts to control the amount of direct solar radiation reaching the living space. This direct solar gain is a critical part of passive solar house designation as it imparts (added value) to a direct gain.

The Earth receives 174 petawatts (PW)(Peta= 10^{15}) of incoming solar radiation (insolation) at the upper atmosphere.[2] Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet. Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature.

Insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time

References :R&AC%20Lecture%2032Cooling And Heating Load Calculations

32.2.4. Solar geometry: R&AC%20Lecture%2032loadcal

For calculation purposes, the sun may be treated as a radiant energy source with surface temperature that is approximately equal to that of a blackbody at 6000 K. The spectrum of wavelength of solar radiation stretches from 0.29 µm to about 4.75 µm. Table 32.1 shows spectral distribution of solar radiation with percentage distribution of total energy in various bandwidths.

Type of radiation	Wavelength band (µm)	% of total radiation
Invisible ultra-violet (UV)	0.29 to 0.40	7
Visible radiation	0.40 to 0.70	39
Near Infrared (IR)	0.70 to 3.50	52
Far infrared (FIR)	4.00 to 4.75	2

Table 32.1. Spectral distribution of solar radiation

Solar constant:

This is the flux of solar radiation on a surface normal to the sun's rays beyond the earth's atmosphere at the mean earth-sun distance. The currently accepted value of solar constant is 1370 W/m^2.

Depletion of solar radiation due to earth's atmosphere:

In passing through the earth's atmosphere, which consists of dust particles, various gas molecules and water vapour, the solar radiation gets depleted due to **reflection**, **scattering** and **absorption**.

The length of travel of sun’s rays through the atmosphere is expressed in terms of ‘**air mass, m**’ which is defined as the ratio of mass of atmosphere in the actual sun-earth path to that which would exist if the sun were directly overhead at sea level. As shown in Fig. 32.1, the air mass is given by:

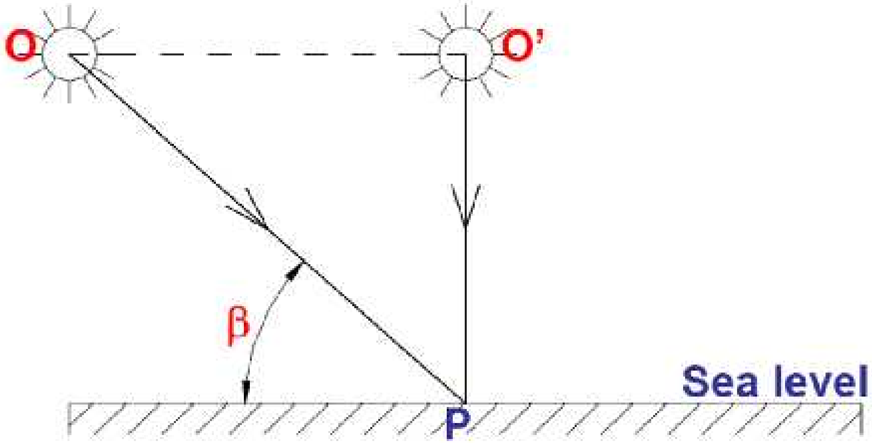


Fig.32.1: Depletion of solar radiation due to earth’s atmosphere

$$\text{air mass, m} = \frac{\text{length OP}}{\text{length O'P}} = \frac{\sin 90^{o}}{\sin \beta} = \frac{1}{\sin \beta}$$

where **β** is called as **altitude angle**, which **depends on** the **location**, **time of the day** and **day of the year**. Thus smaller the altitude angle, larger will be the depletion of radiation.

The rate at which solar radiation is striking a surface per unit area of the surface is called as the **total solar irradiation** on the surface. This is given by:

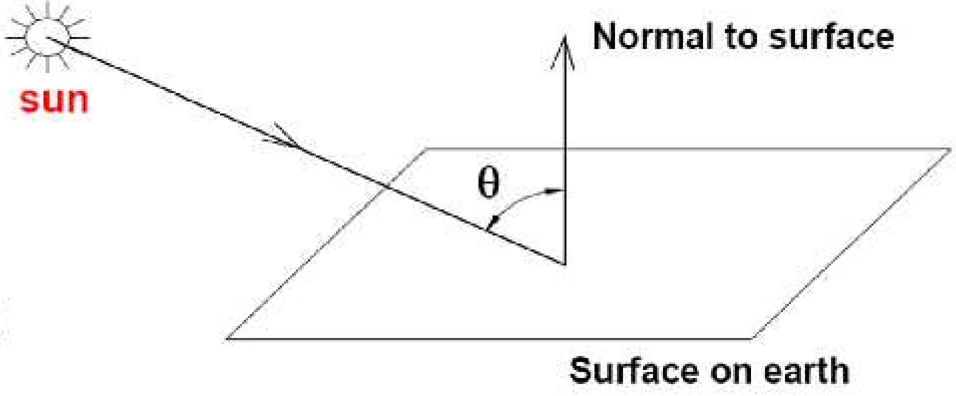


Fig. 32.2 Definition of angle of incidence

$$I_{i\theta} = I_{DN}\cos\theta + I_{d\theta} + I_{r\theta}$$

Where

$I_{i\theta}$ = Total solar irradiation of a surface, W/m

I_{DN} = Direct radiation from sun, W/m^2

$I_{d\theta}$ = Diffuse radiation from sky, W/m^2

$I_{r\theta}$ = Short wave radiation reflected from other surfaces, W/m^2

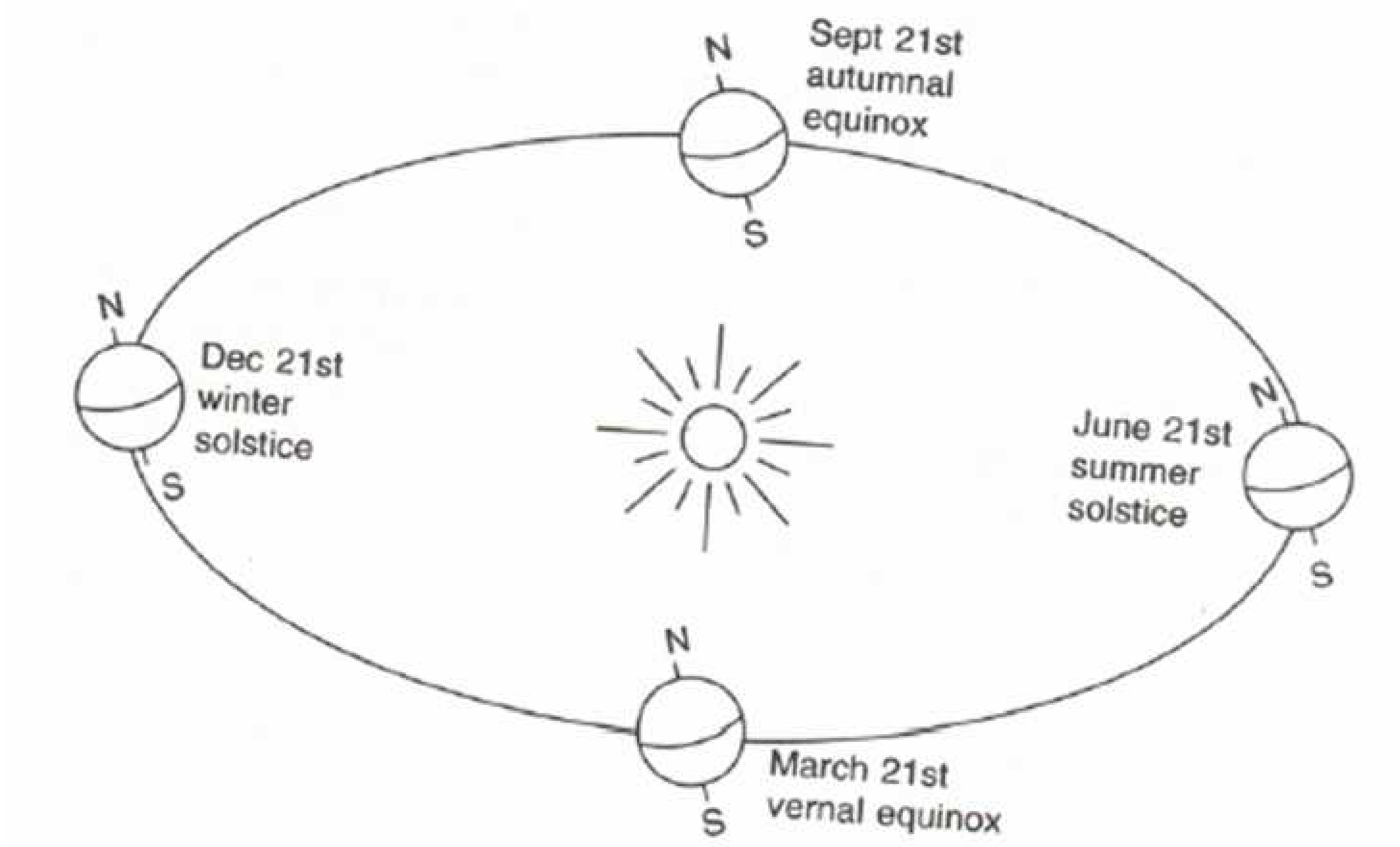
θ = Angle of incidence, degrees (Figure 32.2)

The angle of incidence θ depends upon

i. Location on earth
ii. Time of the day, and
iii. Day of the year

The above three parameters are defined in terms of **latitude, hour angle and declination**, respectively.

The planet earth makes one rotation about its axis every 24 hours and one revolution about the sun in a period of about 365 days. The earth's equatorial plane is tilted at an angle of about 23.5° with respect to its orbital plane. The earth's rotation is responsible for day and night, while its tilt is responsible for change of seasons.



The position of the earth at the start of each season as it revolves in its orbit around the sun. During summer solstice (June 21st) the sun’s rays strike the northern hemisphere more directly than they do the southern hemisphere. As a result, the northern hemisphere experiences summer while the southern hemisphere experiences winter during this time. The reverse happens during winter solstice (December 21st).

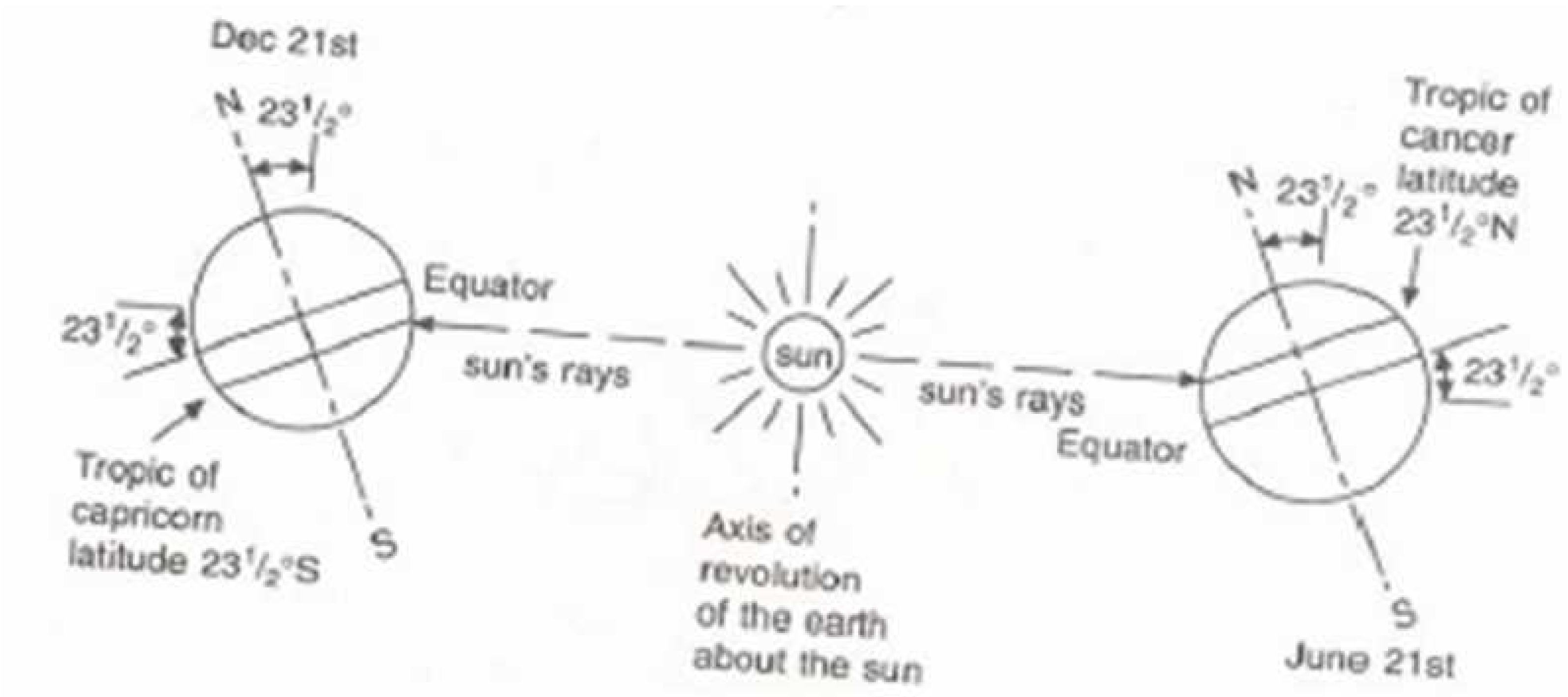


Figure.5 shows the position of a point P on the northern hemisphere of the earth, whose center is at point O. Since the distance between earth and sun is very large, for all practical purposes it can be considered that the sun’s rays are parallel to each other when they reach the earth.

Latitude, l: It is the angle between the lines joining O and P and the projection of OP on the equatorial plane. Shown in Fig.5.

$$\text{latitude}, l = \text{angle } \angle POA$$

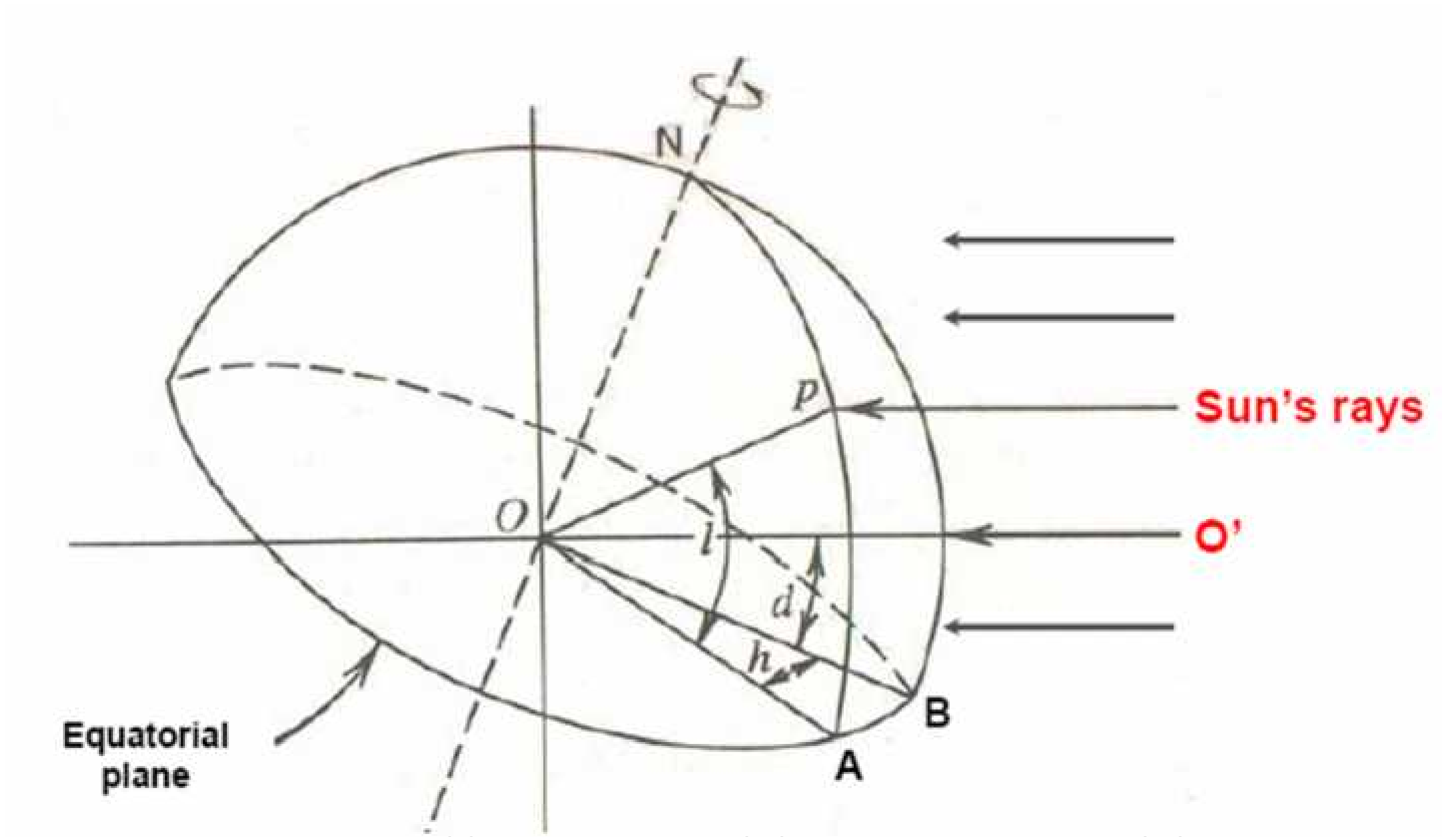


Fig..5: Definition of latitude (l), declination (d) and hour angles (h)

Hour angle, h: It is the angle between the projection of OP on the equatorial plane i.e., the line OA and the projection of the line joining the center of the earth to the center of the sun, i.e., the line OB. Therefore,

$$\text{hour angle}, h = \text{angle } \angle AOB$$

The hour angle is a measure of the time of the day with respect to solar noon. Solar noon occurs when the sun is at the highest point in the sky.

Declination, d: The declination is the declination angle between the line joining the center of the earth and sun and its projection on the equatorial plane , the angle between OO· And OB

Declination, d = angle □O· OB

For northern hemisphere, the declination varies from about + 23.5° on June the 21st (summer solstices) to – 23.5° on December 21st at equinoxes, i.e., on March 21st and September 21st the declination is 0° for northern hemisphere.

The declination varies approximately in a sinusoidal form, and on any particular day the declination can be calculated approximately using the equation:

$$\text{declination}, d = 23.47 \sin \frac{360(284+N)}{365}$$

where N is the day of the year numbered from January 1st. Thus on March 6th, N is 65 (65th day of the year) and from the above equation, declination on March 6th is equal to –6.4°.

Direct radiation from sun , (I_{DN}) : According to ASHREA model, the direct radiation is given by:

$$I_{DN} = A.\exp\left(-\frac{B}{\sin\beta}\right) \quad (W/m^2)$$

where A is the apparent solar irradiation which is taken as 1230 W/m^2 for the months of December and January and 1080 W/m^2 for mid-summer. Constant B is called atmospheric extinction coefficient which take a value of 0.14 in winter and 0.21 in summer.

Diffuse radiation from sky, I_d: According to ASHREA model, the direct radiation is given by:

$$I_d = C.I_{DN}.F_{WS} \quad (W/m^2)$$

The value of C is assumed to be constant for a cloudless sky for an average day of a month. Its average monthly values have been computed and are available in tabular form. The value of C can be taken as 0.135 for mid-summer and as 0.058 for winter. The factor FWS is called as view factor or configuration factor and is equal to the fraction of the diffuse radiation that is incident on the surface. For diffuse radiation, FWS is a function of the orientation of the surface only. It can be easily shown that this is equal to:

$$F_{WS} = \frac{(1+\cos\Sigma)}{2}$$

where Σ is the tilt angle. Obviously for horizontal surfaces ($\Sigma = 0^o$) the factor FWS is equal to 1, whereas it is equal to 0.5 for a vertical surface ($\Sigma = 90^o$).

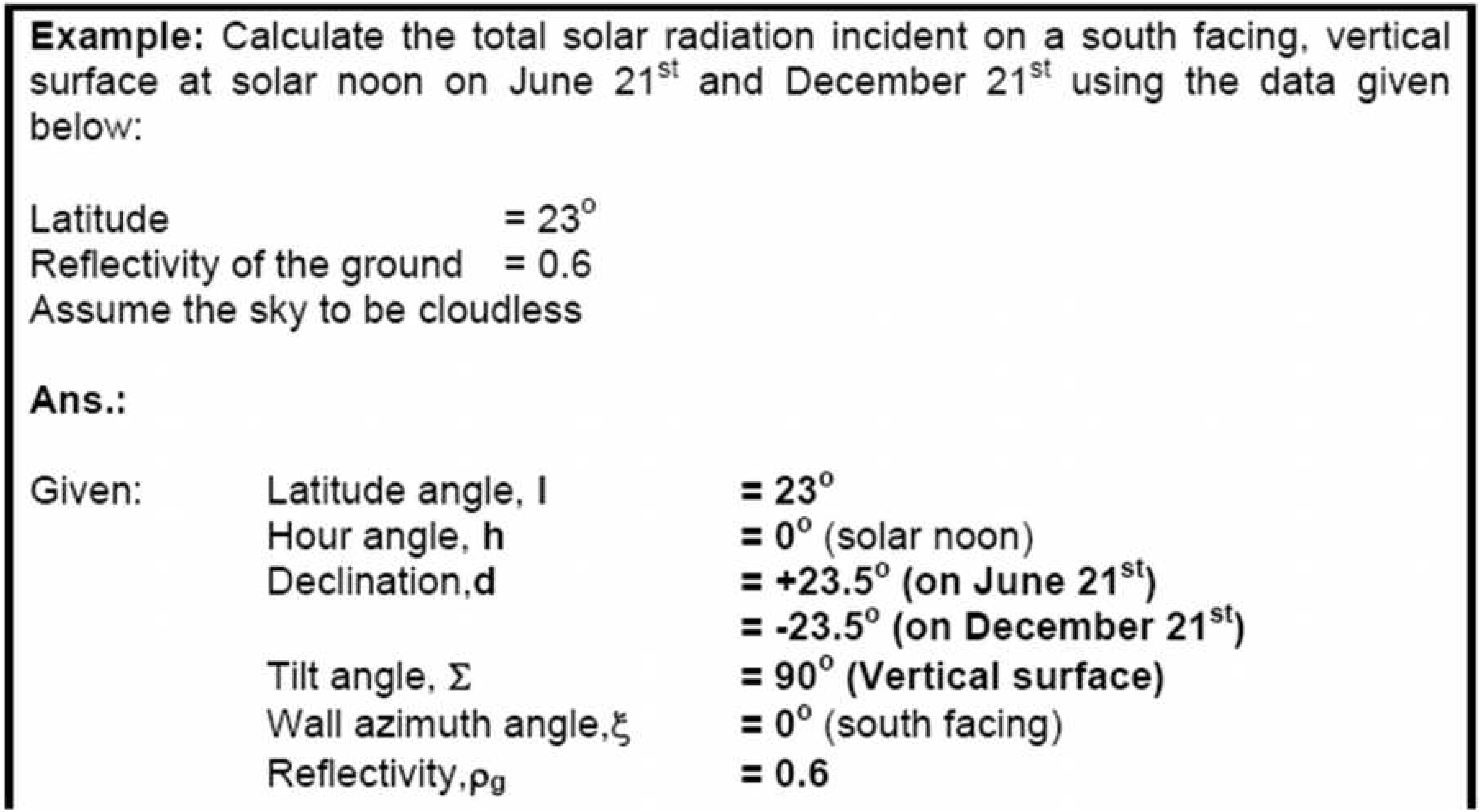
Reflected, short-wave (solar) radiation, I_r: The amount of solar radiation reflected from the ground onto a surface is given by:

$$I_r = (I_{DN} + I_d)\rho_g F_{WG}$$

where ρ_g is the reflectivity of the ground or a horizontal surface from where the solar radiation is reflected on to a given surface and F_{WG} is view factor from ground to the surface. The value of reflectivity obviously depends on the surface property of the ground. The value of the angle factor F_{WG} in the tilt angle is given by:

$$F_{WG} = \frac{(1 - \cos\Sigma)}{2}$$

Thus for horizontal surfaces ($\Sigma = 0^o$) the factor F_{WG} is equal to 0, whereas it is equal to 0.5 for a vertical surface ($\Sigma = 90^o$).



Example: Calculate the total solar radiation incident on a south facing, vertical surface at solar noon on June 21st and December 21st using the data given below:

Latitude = 23^o
Reflectivity of the ground = 0.6
Assume the sky to be cloudless

Ans.:

Given:
Latitude angle, **l** **= 23^o**
Hour angle, **h** **=** 0^o (solar noon)
Declination,**d** **= $+23.5^o$ (on June 21st)**
= -23.5^o (on December 21st)
Tilt angle, Σ **= 90^o (Vertical surface)**
Wall azimuth angle,ξ **=** 0^o (south facing)
Reflectivity,ρ_g **= 0.6**

June 21st :

Altitude angle β at solar noon $\beta_{max} = \frac{\pi}{2} - |(l - d)| = 89.53^o$

At solar noon, solar azimuth angle, $\gamma = 0^o$ as $l < d$

$\therefore$ wall solar azimuth angle, $\alpha = 180 - (\gamma + \xi) = 180^o$

Incidence angle $\theta_{ver} = \cos^{-1}(\cos\beta . \cos\alpha) = 89.53^o$

Direct radiation, I_{DN} Cos (θ):

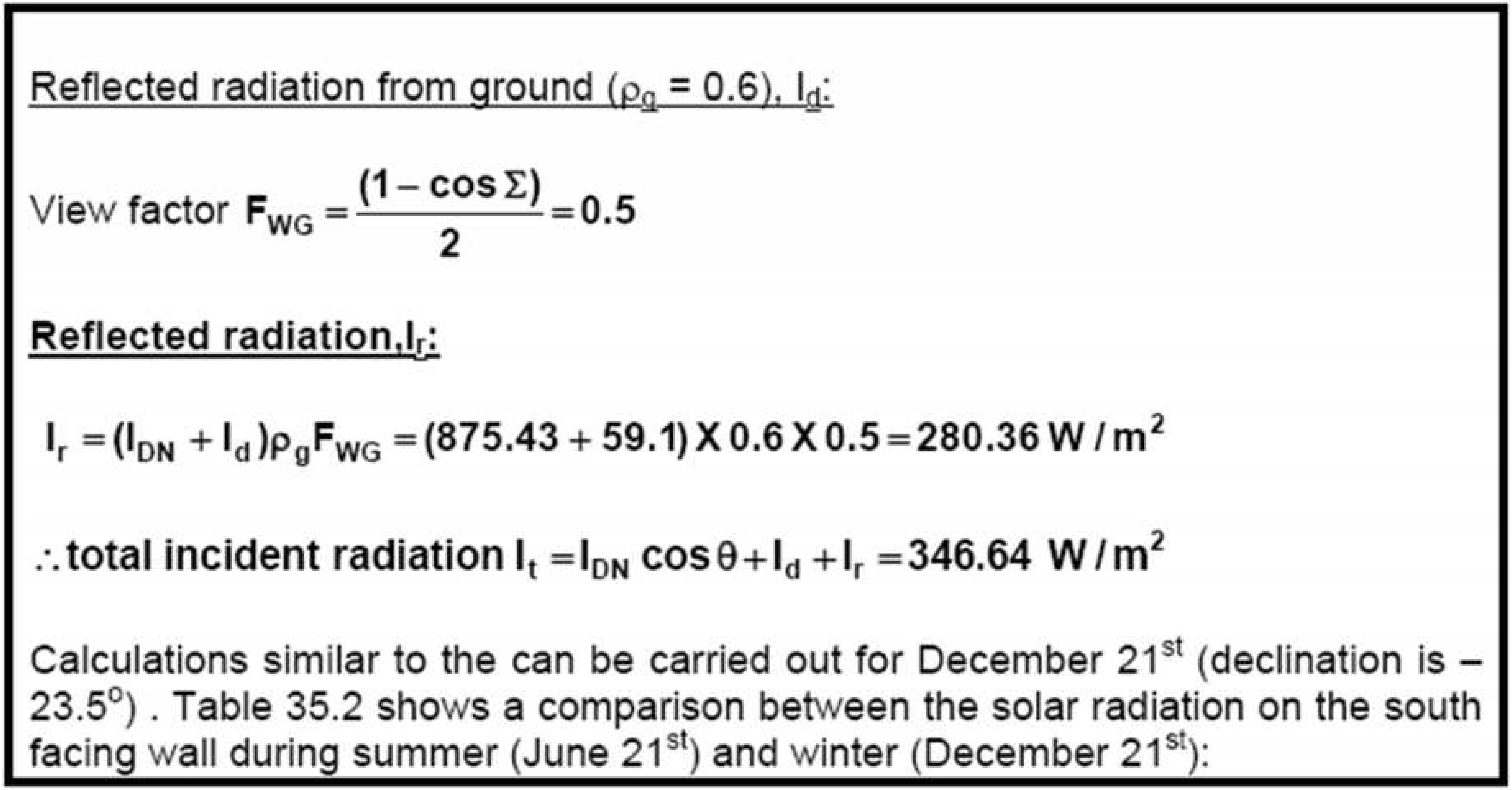
$$I_{DN} = A.\exp\left(-\frac{B}{\sin\beta}\right) = 1080.\exp\left(-\frac{0.21}{\sin 89.3}\right) = 875.4\ W/m^2$$

$$I_{DN}\cos\theta = 875.4 X \cos 89.53 = 7.18\ W/m^2$$

Diffuse radiation, I_d:

View factor $F_{WS} = \frac{(1 + \cos\Sigma)}{2} = 0.5$

Diffuse radiation $I_d = C.I_{DN}.F_{WS} = 0.135 X 875.4 X 0.5 = 59.1\ W/m^2$



Reflected radiation from ground ($\rho_g = 0.6$), I_d:

View factor $$F_{WG} = \frac{(1 - \cos\Sigma)}{2} = 0.5$$

Reflected radiation, I_r:

$$I_r = (I_{DN} + I_d)\rho_g F_{WG} = (875.43 + 59.1)\,X\,0.6\,X\,0.5 = 280.36\ W/m^2$$

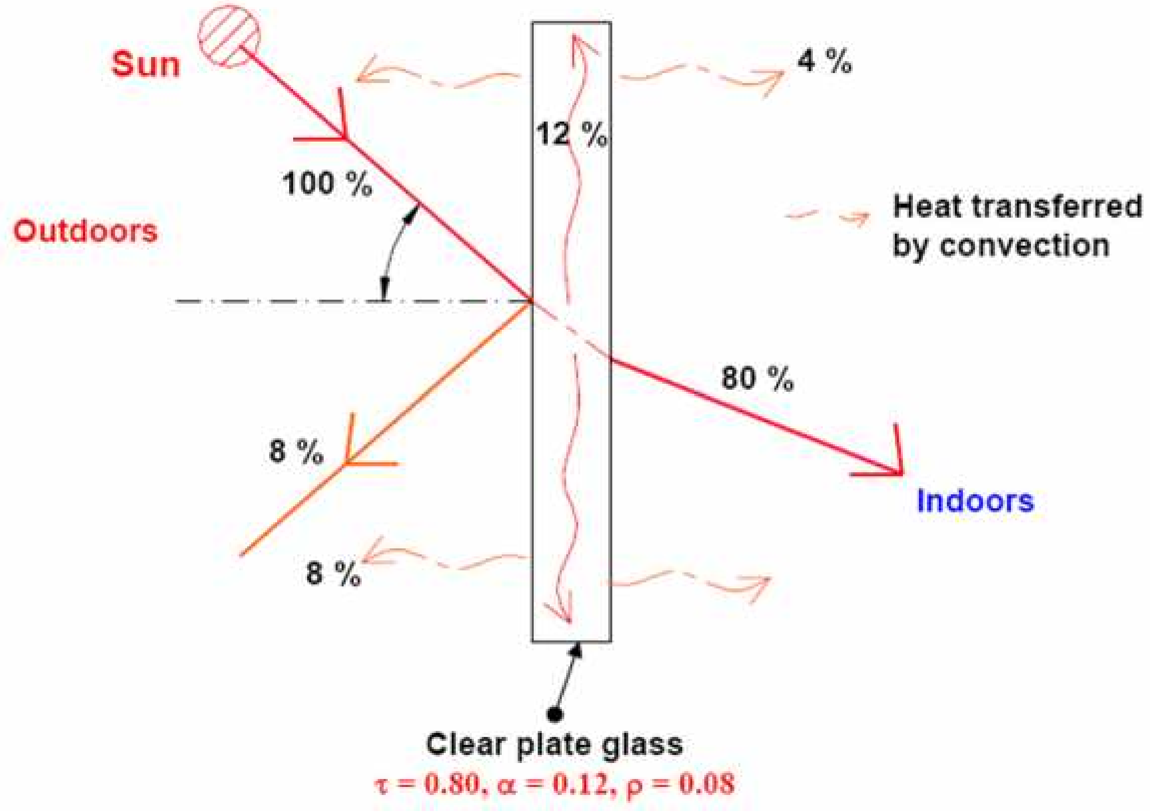
$$\therefore \textbf{total incident radiation } I_t = I_{DN}\cos\theta + I_d + I_r = 346.64\ W/m^2$$

Calculations similar to the can be carried out for December 21st (declination is – 23.5°) . Table 35.2 shows a comparison between the solar radiation on the south facing wall during summer (June 21st) and winter (December 21st):

Assuming the transmittivity and absorptivity of the surface same for direct, diffuse and reflected components of solar radiation, the amount of solar radiation passing through a transparent surface can be written as:

$$Q_{sg} = A\,(T.I_t + N.\alpha.I_t)$$

A = Area of the surface exposed to radiation
I_t = Total radiation incident on the surface
τ = Transmittivity of glass for direct, diffuse and reflected radiations
α = Absorptivity of glass for direct, diffuse and reflected radiations
N = Fraction of absorbed radiation transferred to the indoors by conduction and convection



In the above equation, the total incident radiation consists of direct, diffuse and reflected radiation, and it is assumed that the values of transmittivity and absorptivity are same for all the three types of radiation. Under steady state conditions it can be shown that the fraction of absorbed radiation transferred to the indoors, i.e., N is equal to:

$$N = \frac{U}{h_o}$$

where U is the overall heat transfer coefficient, which takes into account the external heat transfer coefficient, the conduction resistance offered by the glass and the internal heat transfer coefficient, and h^o is the external heat transfer coefficient

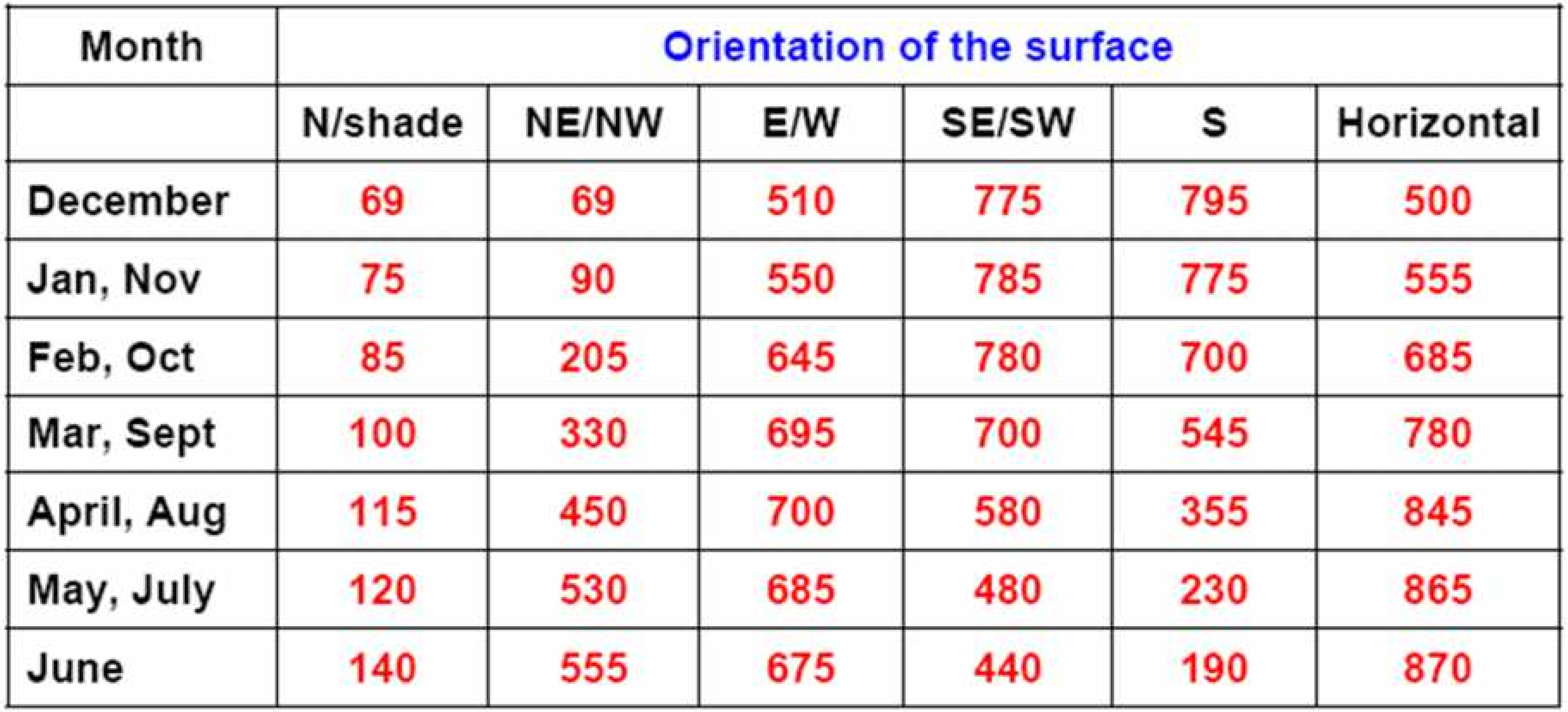
From the above two equations, we can write:

$$Q_{sg} = A\left[I_t\left(\tau + \frac{\alpha U}{h_o}\right)\right]$$

The term in square brackets for a single sheet, clear window glass (reference) is called as **Solar Heat Gain Factor (SHGF)**

The maximum SHGF values for different latitudes, months and orientations have been obtained and are available in the form of Tables in ASHRAE handbooks.

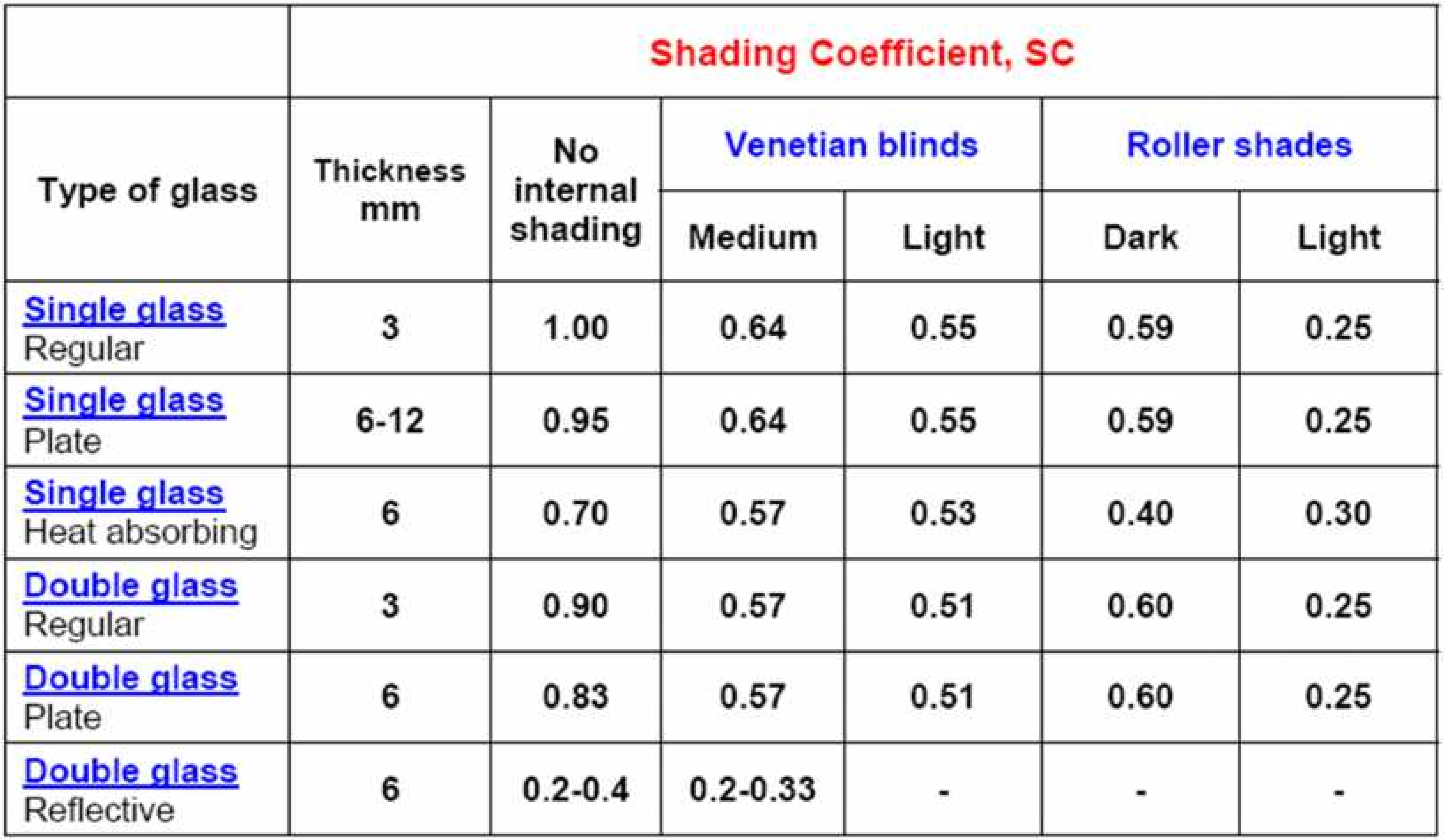
R&AC%20Lecture%2033-Solar Radiation Through Fenestration the maximum SHGF values in W/m^2 for 32^o N latitude for different months and orientations (direction a glass is facing).



Month	Orientation of the surface					
	N/shade	NE/NW	E/W	SE/SW	S	Horizontal
December	69	69	510	775	795	500
Jan, Nov	75	90	550	785	775	555
Feb, Oct	85	205	645	780	700	685
Mar, Sept	100	330	695	700	545	780
April, Aug	115	450	700	580	355	845
May, July	120	530	685	480	230	865
June	140	555	675	440	190	870

a **Shading Coefficient (SC)** is defined such that the heat transfer due to solar radiation is given by: $Q_{sg} = A.(SHGF_{max}).(SC)$

The shading coefficient depends upon the type of the glass and the type of internal shading devices. Typical values of SC for different types of glass with different types of internal shading devices have been measured and are tabulated in ASHRAE Handbooks.



	Shading Coefficient, SC					
Type of glass	Thickness mm	No internal shading	Venetian blinds		Roller shades	
			Medium	Light	Dark	Light
Single glass Regular	3	1.00	0.64	0.55	0.59	0.25
Single glass Plate	6-12	0.95	0.64	0.55	0.59	0.25
Single glass Heat absorbing	6	0.70	0.57	0.53	0.40	0.30
Double glass Regular	3	0.90	0.57	0.51	0.60	0.25
Double glass Plate	6	0.83	0.57	0.51	0.60	0.25
Double glass Reflective	6	0.2-0.4	0.2-0.33	-	-	-

It can be inferred from the above table that the heat transferred through the glass due to solar radiation can be reduced considerably using suitable internal shadings, however, this will also reduce the amount of sunlight entering into the interior space.

Effect of external shading:

The solar radiation incident on a glazed window can be reduced considerably by using external shadings. The external shading reduces the area of the window exposed to solar radiation, and thereby reduces the heat transmission into the building. A very common method of providing external shading is to use overhangs.

Figure 33.2 shows an inset window of height H, width W and depth of the inset d. Without overhang, the area exposed to solar radiation is H X W, however, with overhang the area exposed is only x X y. The hatched portion in the figure shows the area that is under shade, and hence is not experiencing any direct solar radiation. Thus the solar radiation transmitted into the building with overhang is given by:

$$Q_{sg} = A_{unshaded}.(SHGF_{max}).(SC) = (x.y).(SHGF_{max}).SC$$

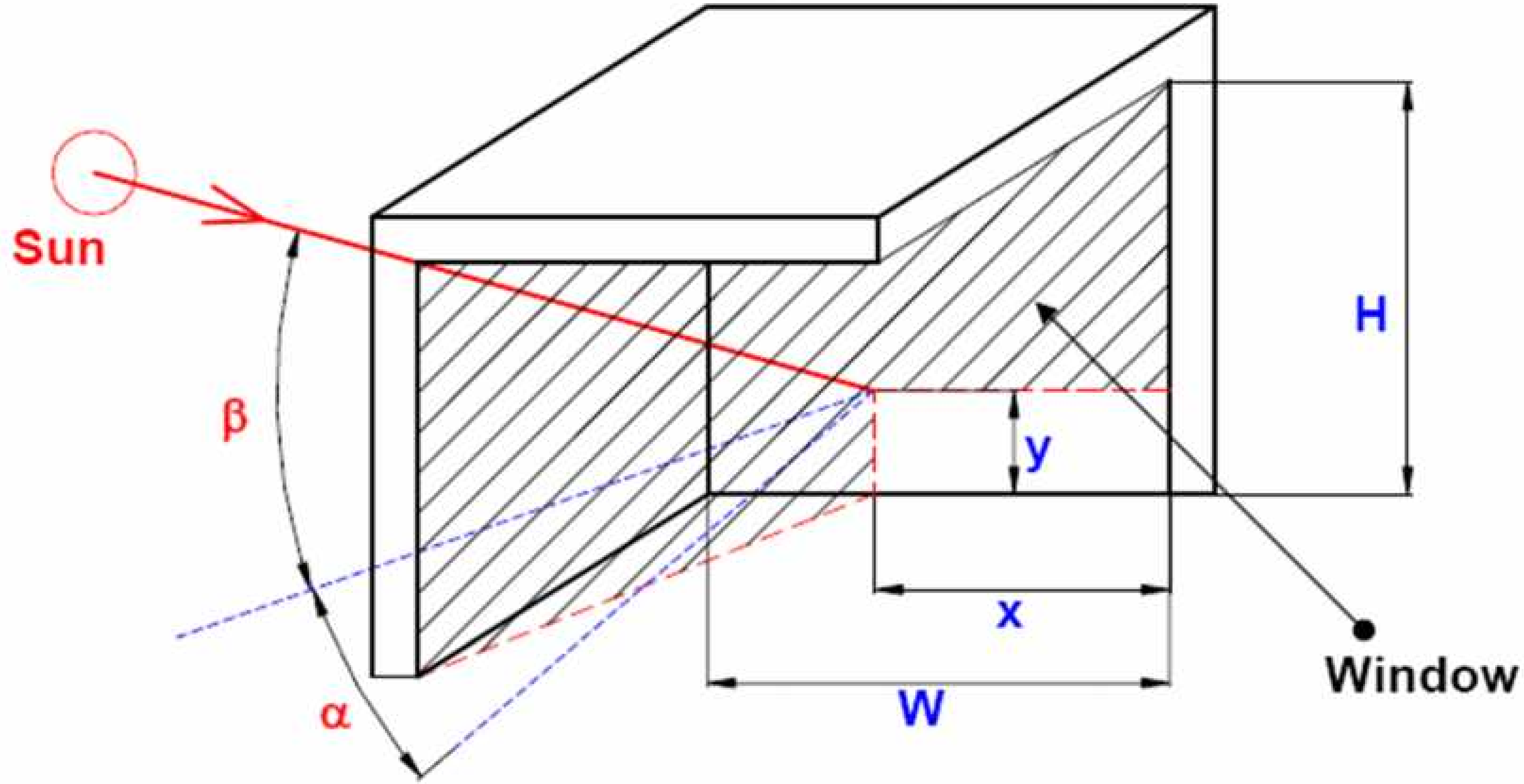
Using solar geometry the area of the window that is not shaded at any location at a particular instant can be calculated. It can be shown that x and y are given by:

$$x = W - d(\tan\alpha)$$

$$y = H - d\left(\frac{\tan\beta}{\cos\alpha}\right)$$

where β is the altitude angle and α is the wall solar azimuth angle.

Fig.33.2: Shadow cast by an inset window



It should be noted that the overhang provides shade against direct solar radiation only and cannot prevent diffuse and reflected radiation.

Complete shading of the window can be provided by selecting infinite combinations of overhang width (W_o) and separation dimensions (S), as shown in Fig3. It should however be noticed that for complete shading as the separation distance S increases, the width of the overhang W_o should also increase and vice versa.

Shade Line Factor (SLF) which is the ratio of the distance a shadow falls below the edge of an overhang to the width of the overhang. Thus from the knowledge of the SLF and the dimensions of the window with overhang, one can calculate the unshaded area.

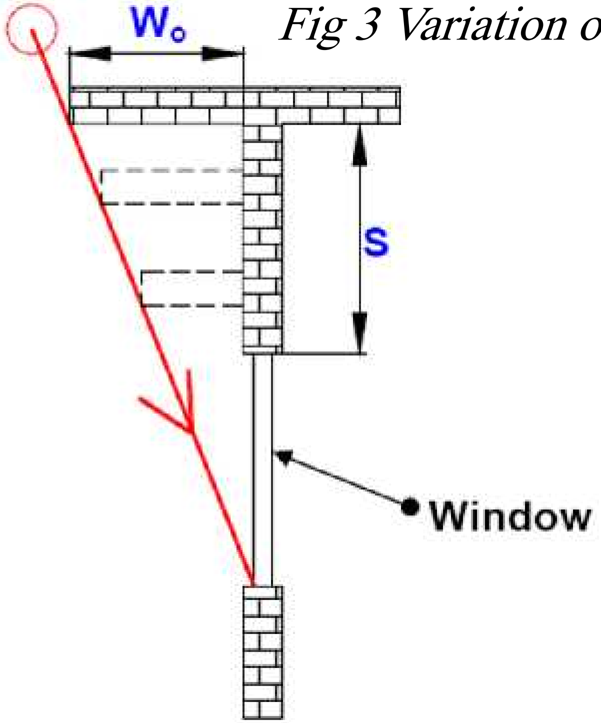


Fig 3 Variation of overhang width with separation for complete shading

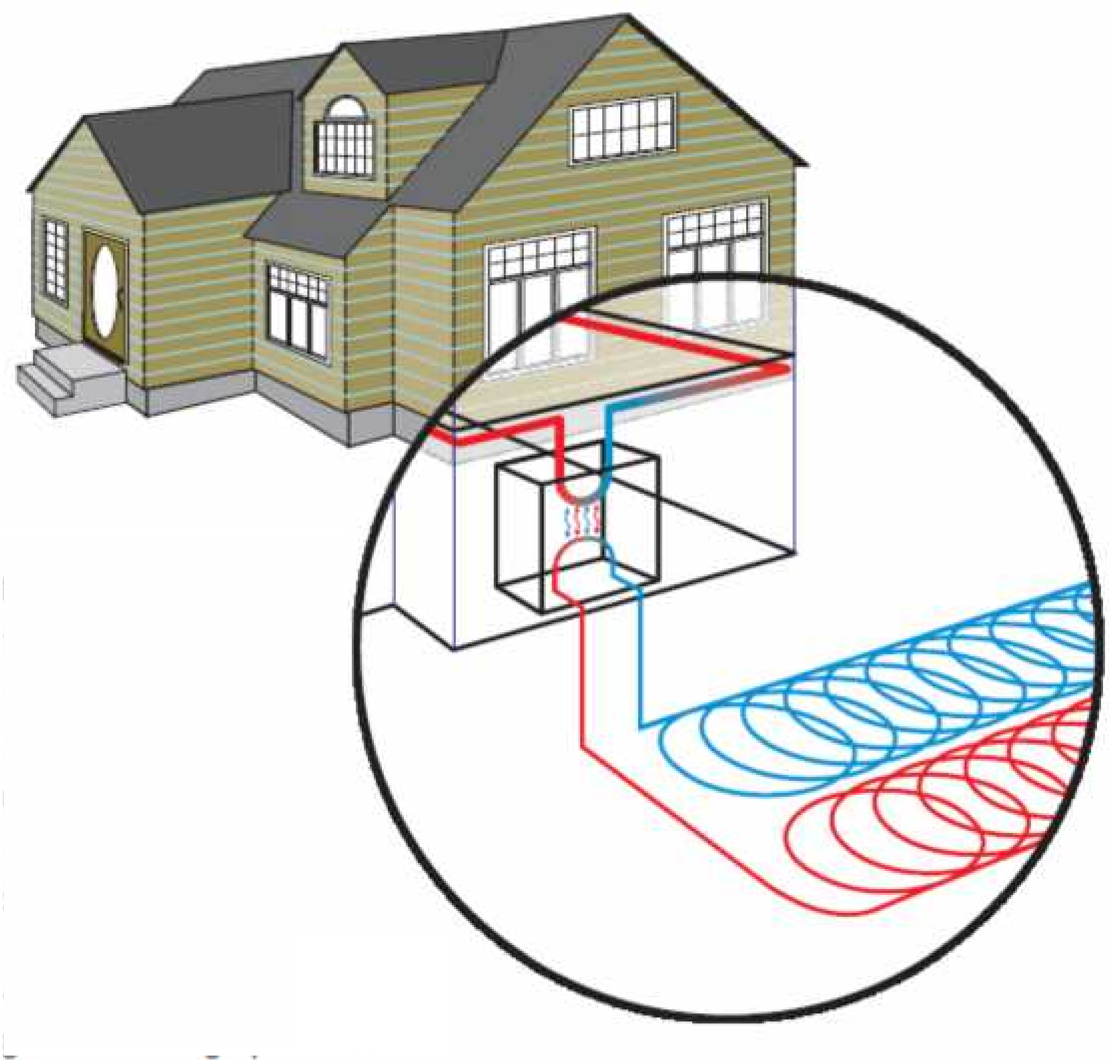
Though overhangs, if properly designed can lead to significant reduction in solar heat gain during summer, they do have certain limitations. These are:

a) An external overhang provides protection against direct solar radiation only. It cannot reduce diffuse and reflection radiations.

b) The reflectivity of the glazed surfaces increases and transmittivity reduces with angle of incidence. Thus in summer when the angle of incidence on a vertical surface is large, most of the solar radiation incident on the glazed surface is reflected back and only about 40% of the incident radiation is transmitted into the building.

c) For practical purposes, overhangs are truly effective for windows facing 30–45^{o} of south. During mornings and evenings when the sun is striking the east and west walls and is so low in the sky that overhangs can provide only minimum protection.

Ground-source Heat Pumps



1-Ground Source Heat Pump – GSHP

A ground source heat pump extracts heat from the ground – whose temperature will be warmer than the air in winter (and cooler than the air in summer). For this reason they are more efficient than air source heat pumps, especially in the coldest weather when they are most needed. They generate very little noise and should last for many years with minimal servicing.

The most practical way of extracting this energy is through water circulating through pipes in the ground. The pipes for the ground loop are usually laid in horizontal trenches at two meters deep, but vertical boreholes are an alternative, if more expensive, way of achieving similar results where there is not enough land to lay pipes horizontally.

At depths below six meters, the ground temperature does not vary much from the Mean Annual Air Temperature (around 9°C -11°C in the UK depending on location). At a depth below two meters, there is a large store of warmth that can be tapped for heating in the winter. However, this temperature will drop quickly where a heat pump is extracting a lot of heat from a small ground loop – it is therefore very important that the size of the ground loop matches the heating load of the building. The key to achieving this balance is a full thermal modeling exercise.

2-Components

Ground-source heating systems generally require three main components: the heat exchanger (ground loop), a heat pump (condensing unit) and a distribution system such as air ducts or in-floor tubing (Figure 2.) The heat exchanger or loop is simply a length of tubing placed underground and used to transfer the heat from the ground to the heat pump. The heat pump concentrates the heat using a condensing unit. In the winter، that heat is transferred to the distribution system and released through the buildings air ducting systems or in-floor hot water (hydronic) heating system. The process can be reversed for cooling. A water-antifreeze mixture is used as the transfer medium between the heat source (the ground) and heat pump. The heat pump concentrates the heat and disperses it into the home. Household air is never in direct contact with the heat source (air, soil or water).

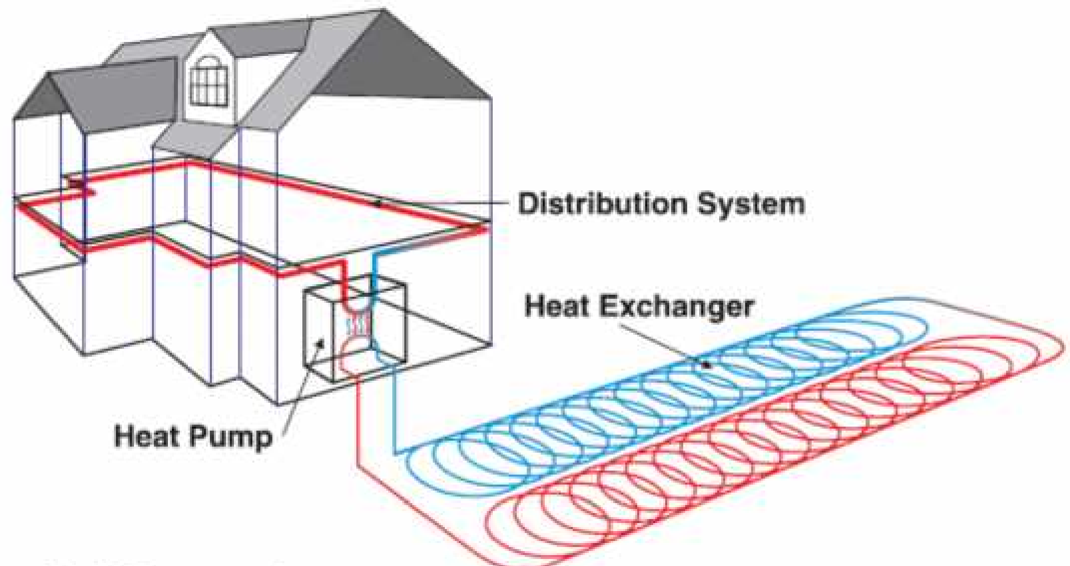


Figure 2. Three components

3-How Ground Source Heat Pumps Work

Ground source heat pumps work by absorbing heat from the ground and transferring the heat into buildings – to heat the buildings without burning fossil fuels.

The heat pump itself is located in the building and works on the same principles as a domestic fridge: the heat pump in a fridge transfers heat out of the fridge and use a heat exchanger to disperse the heat from a small radiator at the back of the fridge into the room.

A ground source heat pump absorbs heat from the ground – by circulating water though piping in the ground – and transfers the heat into the building by circulating hot water though radiators, or under floor piping circuits.

The heat pump is able to increase the temperature it receives from the ground before circulating it into the house. It does this by compressing refrigerant gases. When a large volume of gas is compressed into a small space the heat energy in the gas becomes concentrated – the gas becomes very hot. The heat pump uses a heat exchanger to transfer that heat to the heating circuit in the building.

After the high pressure gas has yielded up its heat, the pressure of the gas is released and it then becomes very cold. The heat pump uses a heat exchanger to transfer that cold to the ground loop circuit. As the cold water is circulated through the ground it absorbs heat from the surrounding ground and the cycle can begin again.

4-Installation

Ground-source heat exchangers can be installed in a variety of ways. The majority of installations are closed-loop that involves the installation of a sealed loop of piping through which a liquid solution is circulated to exchange heat (Figure 3). Some open-loop systems circulate water from a lake pond, stream or well. Open-loop systems are limited due to the lack of water and problems related to the pipe clogging. In either application the piping is used to transfer the heat. For closed-loop systems, the pipes can be installed either horizontally or vertically in the ground or in a pond or lake. If the building is on a large lot، the tubing can be installed in a horizontal trench. The trench depth varies depending on the frost line in your area. In North Dakota, depths of 6 to 10 feet are typical. Trenches

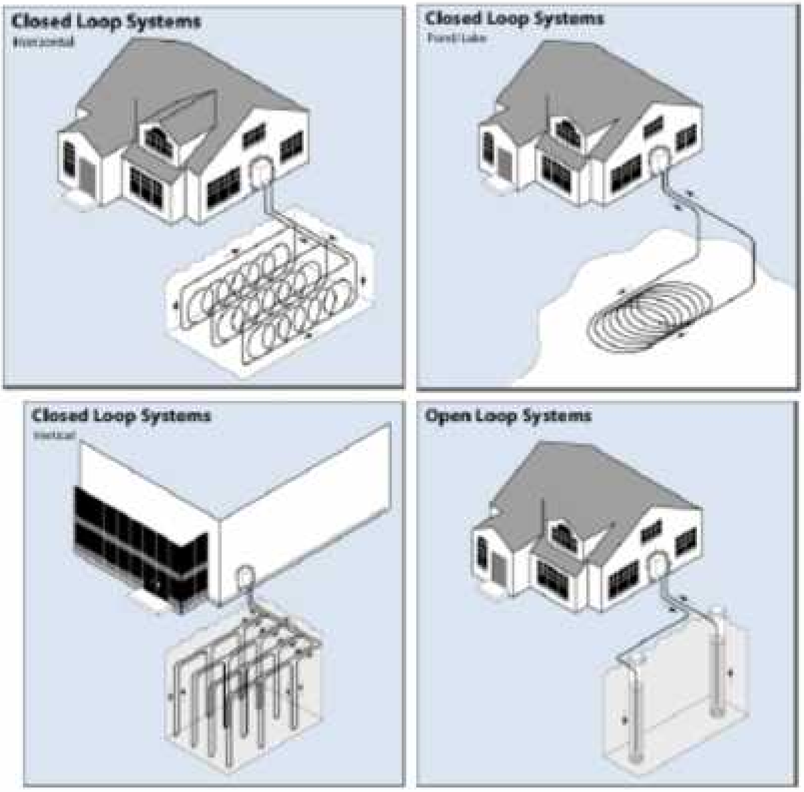


Figure 3. U.S. Department of Energy

are dug and pipe of the correct diameter is installed. The compaction of the soil around the pipe is critical to ensure efficient heat transfer between the pipe and the ground.Overlapping the piping, such as installation in a "slinky" configuration, will reduce the efficiency of the heat exchanger but may be a necessary tradeoff to take advantage of available space (Figures 4 and 5.(For installations where the land area is not available, vertical bore holes are used and the pipe is installed in the vertical bore holes or wells. The wells are generally around 200 feet deep in North Dakota and are placed approximately 15 feet apart The vertical pipes are connected in parallel to make the flow loops essentially equal. Grout is used in the bore holes to ensure good heat transfer between the pipe and the ground.

For horizontal and vertical installations, the buried pipe is connected to a manifold of larger diameter pipe and runs into heating equipment in the building. Vertical ground-source heat exchange installations can be seen in Figures 6 and 7.

Figure 4. Horizontal "slinky" system installation (before)

Figure 5. Horizontal ground loop (after)

Figure 6. Drill rig installing vertical ground loop

Figure 7. Installed vertical ground loop

5-How efficient is a Ground Source Heat Pump?

A heat pump uses electricity to work its compressor and uses electricity to pump water through its circuits. However, most of the energy transferred into the building is transferred from the ground and this energy is free. Therefore a heat pump is very efficient at providing more heat energy than it uses to perform the work needed. A well designed ground source heat pump installation can provide three or four kilowatts of heat for the consumption of one kilowatt of electricity.

The ratio of heat provided to electricity consumed over the heating season depends not only on the efficiency of the heat pump itself, but also the properties of the building, the heat distribution system within the building and the size and efficiency of the ground loop circuit.

It also depends on the temperature available from the ground.

6-How Ground Source Heat Pumps Work to save money

Ground Source Heat Pumps save money. Heat pumps are much cheaper to run than direct electric heating systems. GSHPs are cheaper to run than oil boilers and can be cheaper than running gas boilers.

Because heat pumps can be fully automated they demand much less work than biomass boilers – this also saves you money.

Heat pumps save space. There are no fuel storage requirements.

Heat pumps are safe. There is no combustion involved and no emission of potentially dangerous gases. No flues are required.

GSHPs require less maintenance than combustion based heating systems. They also have a longer life than combustion boilers. The ground heat exchanger element of a ground source heat pump installation has a design life of over 50 years.

Heat pumps save carbon emissions. Unlike burning oil, gas, LPG or biomass, a heat pump produces no carbon emissions on site (and no carbon emissions at all, if a renewable source of electricity is used to power them

GSHPs are safe, silent, unobtrusive and out-of-sight: they require no planning permission.

Heat pumps can also provide cooling in summer, as well as heating in winter.

The owner of a ground source heat pump installation is also entitled to receive the Renewable Heat Incentive.

7-Advantages of Ground Source Heat Pumps

Heat pumps save money. Heat pumps are much cheaper to run than direct electric heating. They are cheaper to run than oil boilers and can be cheaper than running gas boilers. Because heat pumps can be fully automated they demand much less work than biomass boilers.

Heat pumps save carbon emissions. Unlike burning oil, gas, LPG or biomass, a heat pump produces no carbon emissions on site (and no carbon emissions at all, if a renewable source of electricity is used to power them.

Heat pumps save space. There are no fuel storage requirements.

Heat pumps are safe. There is no combustion involved and no emission of potentially dangerous gases. No flues are required.

Heat pumps require less maintenance than combustion based heating systems.

A well designed ground source heat pump system will increase the sale value of your property.

Heat pumps can provide cooling in summer, as well as heating in winter.

The benefits offered by GeoExchange systems can be summarized as follows:

- One appliance provides both heating and cooling, reducing maintenance compared to conventional fossil fuel and cooling tower systems؛
- Flexible layout with a reduction in mechanical space؛
- As the atmosphere is not used as a heat sink, bulky and noisy exterior equipment such as cooling towers and condensing units are not necessary؛
- High coefficients of performance due to favorable ground temperatures leading to economical operating costs؛
- Hot water for domestic or snow melting use can be scavenged any time the compressors are running؛
- The fossil fuel used is burned at a large, industrial generating facility where air scrubbers and other anti-pollution equipment can be installed due to the economy of scale.
- Chilled water is available, which has superior latent cooling capabilities.
- Excellent zoning and part load performance

A geothermal heat pump installation are the smallest portion of the Heating, Ventilation and Air Conditioning (HVAC) market today, but is growing at the rate of 20% per year2. Primary advantages of the GeoExchange systems are low operational cost. 1993study by the U.S. Environmental Protection Agency3 showed today's geothermal heat pumps:

- Provide the lowest cost heating & cooling, even when higher first costs are factored into analysis
- Geothermal Heat Pumps had the lowest CO2 (greenhouse gas) emissions and the lowest over all environmental cost
- Can be highly cost-effective for utility conservation programs

• Provide strategic partnerships to promote advance space conditioning equipment

8-Ground source heat pumps disadvantages:

- Relatively high installation costs
- Need electricity to operate - the generation of which has its own CO2 emissions which need to be accounted for
- Require electricity to drive the pump
- For water heating purposes, an auxiliary heat source is required
- Require large trench to be dug during installation, especially for the horizontal loop system
- Use toxic refrigerants
- Heating performance depends on the weather conditions
- Least effective when ground temperature is low
- Manufacturers' claims of COPs (Coefficient of Performance) of 3-4 are not generally being realized in practice where COPs of around 2 are more common.

9- General design

The most important first step in the design of a GSHP installation is accurate calculation of the building’s heat loss, its related energy consumption profile and the domestic hot water requirements. This will allow accurate sizing of the heat pump system. This is particularly important because the capital cost of a GSHP system is generally higher than for alternative conventional systems and economies of scale are more limited. Oversizing will significantly increase the installed cost for little operational saving and will mean that the period of operation under part load is increased. Frequent cycling reduces equipment life and operating efficiency. Conversely if the system is undersized design conditions may not be met and the use of top-up heating usually direct acting electric heating will reduce the overall system efficiency.

A GSHP system can be designed to provide all the required heat (a monovalent system). However, because of the relatively high capital cost, it may be economic to consider a bivalent system where the heat pump is designed to cover the base heating load, while an auxiliary system covers the additional peak demand eg if the savings in capital cost offset any increase in running costs. Reducing the output temperature required from the heat pump will increase its performance. Currently available heat pumps have an operating temperature limit of 50ºC – 55ºC in most applications and are not suitable for monovalent operation in combination with traditionally sized wet radiator distribution systems.

The performance of the heat pump depends on the performance of the ground loop and vice versa. It is therefore essential to design them together. Closed-loop ground source heat pump systems will not normally require permissions/authorizations from the environment agency)see back page). However, the agency can provide comment on proposed schemes with a view to reducing the risk of groundwater pollution or derogation that might result. The main concerns are:

- Risk of the underground pipes/boreholes creating undesirable hydraulic connections between different water bearing strata

- Undesirable temperature changes in the aquifer that may result from the operation of a GSHP

- Pollution of groundwater that might occur from leakage of additive chemicals used in the system Where there is a risk of or actual releases of polluting matter to groundwater the agency can serve statutory notices to protect groundwater