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DEVELOPMENT OF GREEN ENERGY SAVING MECHANISMS

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ABSTRACT: *Geothermal energy is the natural heat that exists within the earth and that can be absorbed by fluids occurring within, or introduced into, the crystal rocks. Although, geographically, this energy has local concentrations, its distribution globally is widespread. The amount of heat that is, theoretically, available between the earth's surface and a depth of 5 km is around 140 x 10^{24} joules. Of this, only a fraction (5 x 10^{21} joules) can be regarded as having economic prospects within the next five decades, and only about 500 x 10^{18} joules is likely to be exploited by the year 2020. Three main techniques used to exploit the heat available are: geothermal aquifers, hot dry rocks and ground source heat pumps (GSHPs). The GSHPs play a key role in geothermal development in Central and Northern Europe. With borehole heat exchangers as heat source, they offer de-central geothermal heating at virtually any location, with great flexibility to meet given demands. In the vast majority of systems, no space cooling is included, leaving the GSHPs with some economic constraints. Nevertheless, a promising market development first occurred in Switzerland and Sweden, and now also is obvious in Austria and Germany. Approximately 20 years of R&D focusing on borehole heat exchangers resulted in a well-established concept of sustainability for this technology, as well as in sound design and installation criteria. The market success brought Switzerland to the third rank worldwide in geothermal direct use. The future prospects are good, with an increasing range of applications including large systems with thermal energy storage for heating and cooling, The GSHPs in densely populated development areas, borehole heat exchangers for cooling of telecommunication equipment, etc. This communication reviews some interactions between buildings and environment. The correct assessment of climate helps to create buildings, which are successful in their external environment, while knowledge of sick buildings helps to avoid unsuccessful internal environments. The sections on energy conservation and green buildings suggest how the correct design and use of buildings can help to improve total environment.*

KEYWORDS: GREEN buildings, Ground Source Heat Pump, Environment

INTRODUCTION

Today, the challenge before many cities is to support large numbers of people while limiting their impact on the natural environment. Buildings are significant users of energy and materials in a modern society and, hence, energy conservation in buildings plays an important role in urban environmental sustainability (ASHRAE, 1993). A challenging task of architects and other building professionals, therefore, is to design and promote low energy buildings in a cost effective and environmentally responsive way (Jones and Cheshire, 1996). Passive and low energy architecture has been proposed and investigated in different locations around the world (Yuichiro, Cook and Simos, 1991) and design guides and handbooks have been produced for promoting energy efficient buildings (Givoni, 1994). However, at present, little information is available for studying low energy building design in densely populated areas (Abdeen, 2008b). Designing low energy buildings in high-density areas requires special

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treatment of the planning of urban structure, co-ordination of energy systems, integration of architectural elements, and utilisation of space. At the same time, the study of low energy buildings will lead to a better understanding of the environmental conditions and improved design practices. This may help people study and improve the quality of the built environment and living conditions (CIBSE, 1998).

Industry's use of fossil fuels has been blamed for warming the climate. When coal, gas and oil are burnt, they release harmful gases, which trap heat in the atmosphere and cause global warming. However, there has been an ongoing debate on this subject, as scientists have struggled to distinguish between changes, which are human induced, and those, which could be put down to natural climate variability. Nevertheless, industrialised countries have the highest emission levels, and must shoulder the greatest responsibility for global warming. However, action must also be taken by developing countries to avoid future increases in emission levels as their economies develop and populations grows, as clearly captured by the Kyoto Protocol (FSEC, 1998). Notably, human activities that emit carbon dioxide (CO_2), the most significant contributor to potential climate change, occur primarily from fossil fuel production. Consequently, efforts to control CO_2 emissions could have serious, negative consequences for economic growth, employment, investment, trade and the standard of living of individuals everywhere (Abdeen, 2008a).

Scientifically, it is difficult to predict the relationship between global temperature and greenhouse gas (GHG) concentrations. The climate system contains many processes that will change if warming occurs. Critical processes include heat transfer by winds and tides, the hydrological cycle involving evaporation, precipitation, runoff and groundwater and the formation of clouds, snow, and ice, all of which display enormous natural variability.

The equipment and infrastructure for energy supply and use are designed with long lifetimes, and the premature turnover of capital stock involves significant costs. Economic benefits occur if capital stock is replaced with more efficient equipment in step with its normal replacement cycle. Likewise, if opportunities to reduce future emissions are taken in a timely manner, they should be less costly. Such a flexible approach would allow society to take account of evolving scientific and technological knowledge, while gaining experience in designing policies to address climate change (SP, 1993).

However, the RETs have the benefit of being environmentally benign when developed in a sensitive and appropriate way with the full involvement of local communities. In addition, they are diverse, secure, locally based and abundant. In spite of the enormous potential and the multiple benefits, the contribution from renewable energy still lags behind the ambitious claims for it due to the initially high development costs, concerns about local impacts, lack of research funding and poor institutional and economic arrangements (Watson, 1993).

Hence, an approach is needed to integrate renewable energies in a way that meets high building performance requirements. However, because renewable energy sources are stochastic and geographically diffuse, their ability to match demand is determined by adoption of one of the following two approaches (Abdel, 1994): the utilisation of a capture area greater than that occupied by the community to be supplied, or the reduction of the community's energy demands to a level commensurate with the locally available renewable resources.

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The term low energy is often not uniquely defined in many demonstration projects and studies (Todesco, 1996). It may mean achieving zero energy requirements for a house or reduced energy consumption in an office building. A major goal of low energy building projects and studies is usually to minimise the amount of external purchased energy such as electricity and fuel gas. Yet, sometimes the target may focus on the energy costs or a particular form of energy input to the building. As building design needs to consider requirements and constraints, such as architectural functions, indoor environmental conditions, and economic effectiveness, a pragmatic goal of low energy building is also to achieve the highest energy efficiency, which requires the lowest possible need for energy within the economic limits of reason. Since many complicated factors and phenomena influence energy consumption in buildings, it is not easy to define low energy building precisely or to measure and compare the levels of building energy performance. The loose fit between form and performance in architectural design also makes quantitative analysis of building energy use more difficult. Nevertheless, it is believed that super-efficient buildings, which have significantly lower energy consumption, can be achieved through good design practices and effective use of energy efficient technology (Owens, 1986).

In an ideal case, buildings can even act as producers rather than consumers of energy. Besides the operational energy requirements of buildings, it is important to consider two related energy issues. The first one is the transport energy requirements as a result of the building and urban design patterns and the second one is the embodied energy or energy content of the building materials, equipment or systems being used. Transport energy is affected by the spatial planning of the built environment, transport policies and systems, and other social and economic factors. It is not always possible to study the effect of urban and building design on transport energy without considering the context of other influencing factors. The general efficiency rules are to promote spatial planning and development, which reduce the need to travel, and to devise and enforce land-use patterns that are conducive to public transport (Treloar, Fay, and Trucker, 1998). Embodied energy, on the other hand, is the energy input required to quarry, transport and manufacture building materials, plus the energy used in the construction process. It represents the total life-cycle energy use of the building materials or systems and can be used to help determine design decisions on system or materials selection (Omer, 2009). At present, the field of embodied energy analysis is generally still only of academic interest and it is difficult to obtain reliable data for embodied energy. Research findings in some countries indicate that the operating energy often represents the largest component of life-cycle energy use. Therefore, most people, when studying low energy buildings, would prefer to focus on operating energy, and perhaps carry out only a general assessment of embodied energy (Abdeen, 2008c).

This approach comprises a comprehensive review of energy sources, the environment and sustainable development. It includes the renewable energy technologies, energy efficiency systems, energy conservation scenarios, energy savings and other mitigation measures necessary to reduce climate change.

Climate and Energy Performance

A building site may have natural microclimates caused by the presence of hills, valleys, slopes, streams and other features. Buildings themselves create further microclimates by shading the ground, by drying the ground, and by disrupting the flow of wind. Further microclimates occur in different parts of the same building, such as parapets and corners,

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which receive unequal exposures to the sun, wind and rain. An improved microclimate around a building brings the following types of benefits:

- Lower heating costs in winter.
- Reduction of overheating in summertime.
- Longer life for building materials.
- Pleasant outdoor recreation areas.
- Better growth for plants and trees.
- Increased user satisfaction and value.

These factors can vary by the hour, by the day and by the season. Some of the variations will cycle in a predictable manner like the sun, but others such as wind and cloud cover will be less predictable in the short term. Information about aspects of climatic factors is collected over time and made available in a variety of data forms including the followings:

- Maximum or minimum values.
- Average values.
- Probabilities or frequencies.

The type of climatic data that is chosen depends upon design requirements. Peak values of maximum or minimum are needed for some purposes, such as sizing heating plant or designing wind loads. Longer terms averages, such as seasonal information, are needed for prediction of energy consumption (Abdeen, 2008d).

A fundamental reason for the existence of a building is to provide shelter from the climate, such as the cold and the heat, the wind and the rain. The climate for a building is the set of environmental conditions, which surround that building and links to the inside of the building by means of heat transfer. Climate has important effects on the energy performance of buildings, in both winter and summer, and on the durability of the building fabric. Although the overall features of the climate are beyond our control, the design of a building can have a significant influence on the climatic behaviour of the building. The following measures can be used to enhance the interaction between buildings and climate:

- Selection of site to avoid heights and hollows.
- Orientation of buildings to maximise or minimise solar gains.
- Spacing of buildings to avoid unwanted wind and shade effects.
- Design of windows to allow maximum daylight in buildings.
- Design of shade and windows to prevent solar overheating.
- Selection of trees and wall surfaces to shelter buildings from driving rain and snow.
- Selection of ground surfaces for dryness.

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The large-scale climate of the earth consists of inter-linked physical systems powered by the energy of the sun. The built environment generally involves the study of small systems for which the following terms are used:

- Macroclimate: the climate of a larger area, such as a region or a country.
- Microclimate: the climate around a building and upon its surfaces.

A building site may have natural microclimates caused by the presence of hills, valleys, slopes, streams and other features. Buildings themselves create further microclimates by shading the ground, by drying the ground, and by disrupting the flow of wind. Further microclimates occur in different parts of the same building, such as parapets and corners, which receive unequal exposures to the sun, wind and rain.

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Temperature

In a qualitative manner, the temperature of an object determines the sensation of warmth or coldness felt from contact with it. A thermometer is an instrument that measures the temperature of a system in a quantitative way. The air in the bulb is referred to as the thermometric medium, i.e., the medium whose property changes with temperature. Fahrenheit measured the boiling point of water to be 212 and the freezing point of water to be 32, so that the interval between the boiling and freezing points of water could be represented by the more rational number 180. To convert from Celsius to Fahrenheit, multiply by 1.8 and add 32.

$$^{o}F = 1.8^{o}C + 32 \quad (1)$$

To convert from Celsius to Kelvin, add 273.

$$K = {}^{o}C + 273 \quad (2)$$

The method of degree-days or accumulated temperature difference (ATD) is based on the fact that the indoor temperature of an unheated building is, on average, higher than the outdoor. In order to maintain an internal design temperature of 18.5^{o}C, the building needs heating when the outdoor temperature falls below 15.5^{o}C. This base temperature is used as a reference for counting the degrees of outside temperature drop and the number of days for which such a drop occurs. The accumulated temperature difference total for a locality is a measure of climatic severity during a particular season and typical values are given in Table 1. This data, averaged over the years, can be used in the calculation of heat loss and energy consumption.

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Accumulated temperature differences were used base temperature of 15.5^{o}C, September to May.

Table 1. Climatic severities (ASHRAE, 1993)

Area	Degree-days
England	
South west	1800-2000
South east	2000-2100
Midlands	2200-2400
North	2300-2500
Wales	2000-2200
Scotland	2400-2600

Wind

The main effects of wind on a building are those of force, heat loss and rain penetration. These factors needed to be considered in the structural design and in the choice of building materials. Wind chill factor relates wind to the rate of heat loss from the human body rather than the loss from buildings. The unfavourable working conditions caused by wind chill have particular relevance to operations on exposed construction sites and tall buildings.

The force of a wind increases with the square of the velocity, so that a relatively small increase in wind speed produces a larger than expected force on a surface such as a building. The cooling effect of wind, measured by wind chill, also greatly increases with the speed of the wind. Typical wind speeds range between 0 m/s and to 25 m/s, as described below:

- 5 m/s wind disturbs hair and clothing.
- 10 m/s wind force felt on body.
- 15 m/s wind causes difficulty walking.
- 20 m/s wind blows people over.

The airflow around some parts of a building, especially over a pitched roof, may increase sufficiently to provide an aerodynamic lifting force by using the principle of Bernoulli. The force can be strong enough to lift roofs and also to pull out windows on the downwind side of buildings. The direction of the wind on a building affects both the structural design and the thermal design. The directional data of wind can be diagrammatically shown by a 'rose' of arms around a point which represent the frequency that the wind blows from each direction as shown in Figure 1. Directions with longer arms will indicate colder winds, which affects energy construction. Other systems of roses may indicate the direction of wind chill factors, which affect human comfort and operations on a building site.

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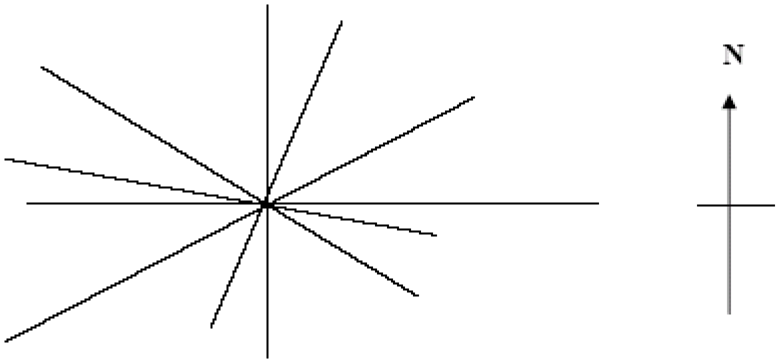

Figure 1. Directional wind rose of mean wind speeds.

The existence of buildings can produce unpleasantly high winds at ground level. It is possible to estimate the ratio of these artificial wind speeds to the wind speed that would exist without the building being present. A typical value of wind speed ratio around low buildings is 0.5, while around tall buildings the ratio might be as high as 2. Wind speed ratios of 2 will double normal wind speed (Jones and Cheshire, 1996). A maximum wind speed of 5 m/s is a suitable design figure for wind around buildings at pedestrian level.

General rules for the reduction of wind effects are given below:

- Reduce the dimensions, especially the height and the dimensions facing the prevailing wind.
- Avoid large cubical shapes.
- Use pitched roofs rather than flat roofs; use hips rather than gable ends.
- Avoid parallel rows of buildings.
- Avoid funnel-like gaps between buildings.
- Use trees, mounds and other landscape features to provide shelter.

Solar

The effects of the sun on buildings requires the following categories of knowledge about the sun, position in the sky and the angle made with building surfaces, quantity of radiant energy received upon the ground or other surface, and obstructions and reflections caused by clouds, landscape features and buildings. The path that the sun makes across the sky changes each day but repeats in a predictable manner, which has been recorded for centuries. For any position of the sun, the angle that the solar radiation makes with the wall or roof of a building can be predicted by geometry. The angle of incidence has a large effect as the energy received as solar radiation obeys the Cosine Law of Illumination. The intensity of solar radiation falling on a surface, such as the ground, can be measured in Watts per square metre (W/m^2) of that surface. The Watt is defined as a joule per second so this is an instantaneous measurement of the energy received per second on each square metre. When the solar energy is measured over a period of time, such as a day or year, the units will be joules or megajoules per square metre (MJ/m^2). The local metrological conditions the measured radiation (global radiation, diffuse radiation), and the ambient temperatures for Nottingham as summarised in Figures 2-3.

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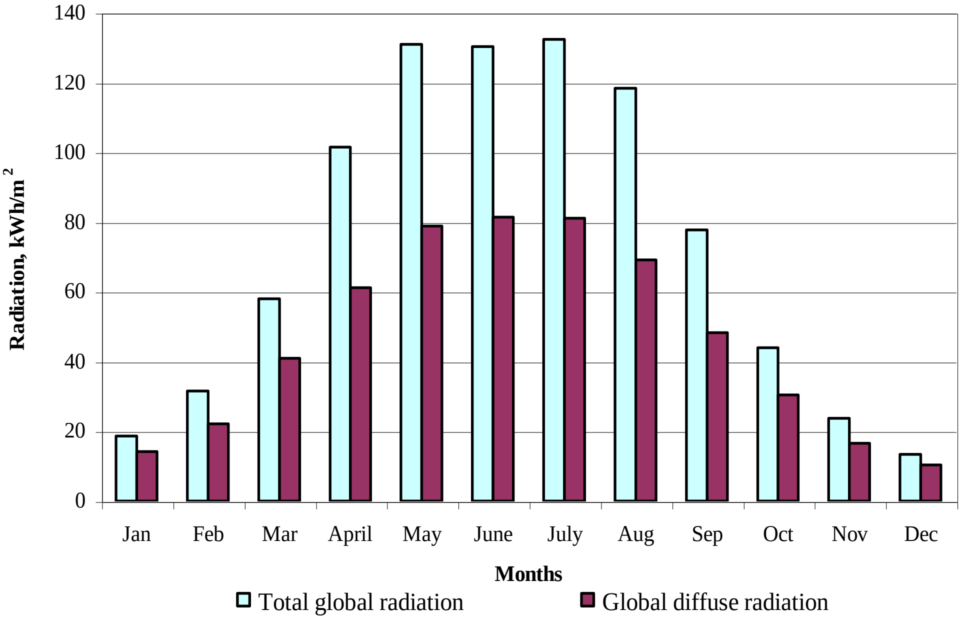

Figure 2. Average monthly global and diffuse radiations over Nottingham.

All buildings gain some casual heat from the sun during winter but more use can be made of solar energy by the design of the building and its services. Despite the high latitude and variable weather of countries in the North Western Europe, like the United Kingdom, there is considerable scope for using solar energy to reduce the energy demands of buildings. The utilisation of solar energy need not depend upon the use of special 'active' equipment such as heat pumps. Passive solar design is a general technique, which makes use of the conventional elements of a building to perform the collection, storage and distribution of solar energy. For example, the afternoon heat in a glass conservatory attached to a house can be stored by the thermal capacity of concrete or brick walls and floors. When this heat is given off in the cool of the evening it can be circulated into the house by natural convection of the air. Heat is transferred from the sun to the earth through space where conduction and convection is not possible. The process of radiation is responsible for the heat transfer through space and for many important effects on buildings as shown in Figure 4. Heat radiation occurs when the thermal energy of surface atoms in a material generates electromagnetic waves in the infrared range of wavelengths. These waves belong to the large family of electromagnetic radiations, including light and radio waves. The rate at which a body emits or absorbs radiant heat depends upon the nature and temperature of its surface. The wavelengths of the radiation emitted by a body depend upon the temperature of the body. High temperature bodies emit a larger proportion of short wavelengths, which have a better penetration than longer wavelengths.

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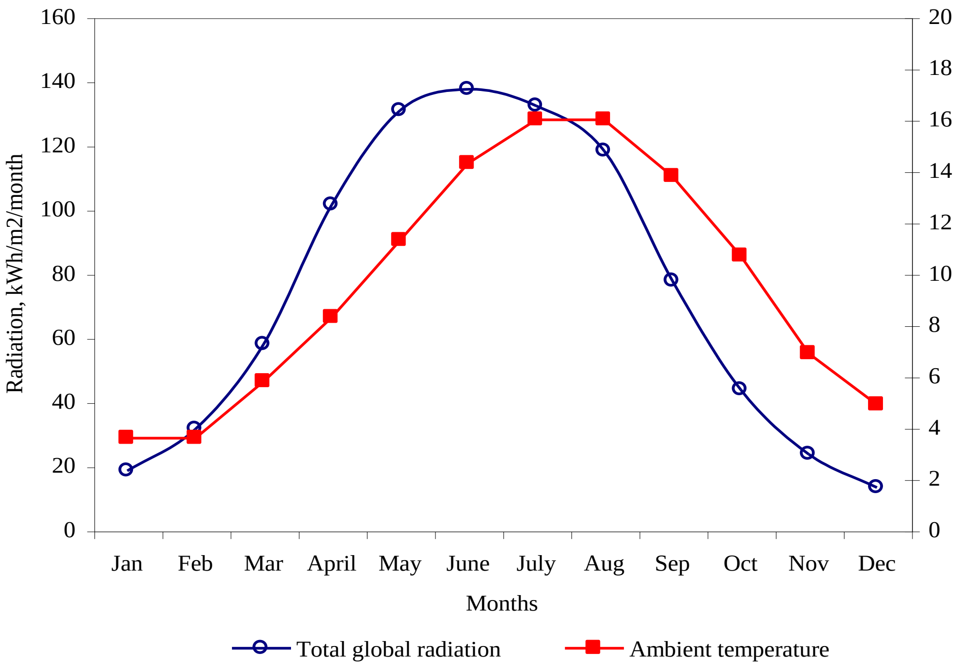

Figure 3. Average monthly solar radiation and ambient temperature over Nottingham.

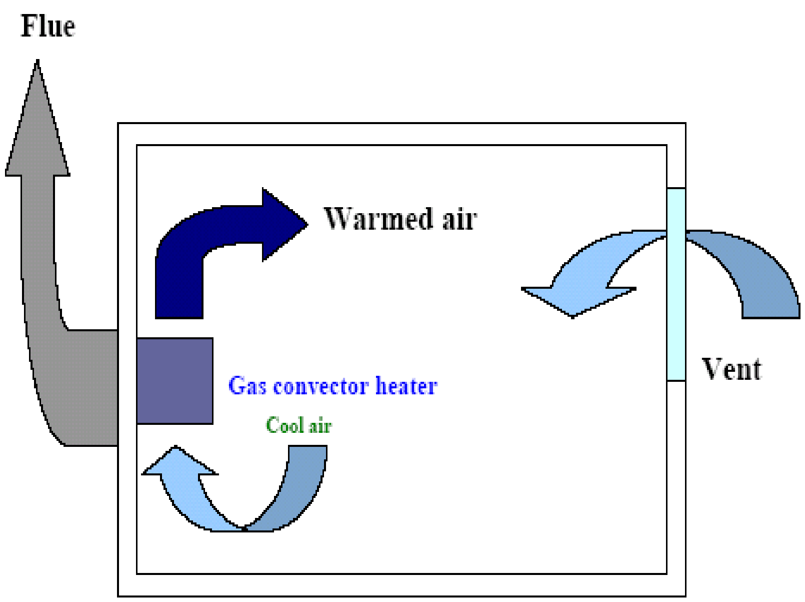

Figure 4. Convection currents in room.

Rain

The annual driving rain index (DRI) is a combined measure of rainfall and wind speed. The DRI takes account of the fact that rain does not always fall vertically upon a building and that rain can therefore penetrate walls. The DRI is also associated with the moisture content of exposed masonry walls whose thermal properties, such as insulation, vary with moisture content. Driving rain is usually caused by storms but intense driving rain can also occur in heavy showers, which last for minutes rather than hours. These conditions are more likely in

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exposed areas such as coasts, where high rainfall is accompanied by high winds. Table 2 gives typical values of driving rain index for different types of area. High buildings, or buildings of any height on a hill, usually have an exposure one degree more than indicated.

Table 2. Driving-rain indices for British Isles

Exposure grading	Driving-rain index	Example
Sheltered	3 or less	Within towns
Moderate	3 to 7	Countryside
Severe	7 or more	West coastal areas

Energy Conservation

At present, most of the energy used to heat buildings, including electrical energy, comes from fossil fuels such as oil and coal. This energy originally came from the sun and was used in the growth of plants such as trees. Then, because of changes in the earth's geology, those ancient forests eventually became a coal seam, an oil field or a natural gas field. The existing stocks of fossil fuels on earth cannot be replaced and unless conserved, they will eventually run out. Primary energy is used for building services such as heating, lighting and electricity. Most of the energy consumed in the domestic sector is used for space heating. Reducing the use of energy in buildings will therefore be of great help in conserving energy resources and in saving money for the occupants of buildings.

Methods of conserving energy in buildings are influenced by the costs involved and in turn, these costs vary with the types of building and the current economic conditions. There are alternative energy sources available for buildings and the energy consumption of buildings can also be greatly reduced by changes of their design and use (Abdeen, 2009a).

Energy Efficiency

Large amounts of energy are contained in the world's weather system, which is driven by the sun, in the oceans, and in heat from the earth's interior, caused by radioactivity in rocks. This energy is widely available at no cost except for the installation and running of conversion equipment. Devices in use include electricity generators driven by wind machines, wave motion and geothermal steam (Abdeen, 2009b). With improvement of the people's living standards and development of the economies, heat pumps have become widely used for air conditioning.

The total energy of the universe always remains constant but when energy converted from one form to another some of the energy is effectively lost to use by the conversion process. For example, hot gases must be allowed to go up the chimney flue when a boiler converts the chemical energy stored in a fuel into heat energy. Around 90 percent of the electrical energy used by a traditional light bulb is wasted as heat rather than light.

New techniques are being used to improve the conversion efficiency of devices used for services within buildings. Condensing boilers, for example recover much of the latent heat from flue gases before they are released. Heat pumps can make use of low temperature heat sources, such as waste air, which have been ignored in the past.

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Although electrical appliances have a high-energy efficiency at the point of use, the overall efficiency of the electrical system is greatly reduced by the energy inefficiency of large power stations built at remote locations. The ‘cooling towers’ of these stations are actually designed to waste large amounts of heat energy (Abdeen, 2009c).

It is possible to make use of this waste heat from power stations both in industry and for the heating of buildings. These techniques of combined heat and power (CHP) can raise the energy efficiency of electricity generation. The CHP techniques can also be applied on a small-scale to meet the energy needs of one building or a series of buildings. Electrical energy will still be required for devices such as lights, motors and electronics but need not be used for heating.

Thermal Insulation

External walls, windows, roof and floors are the largest areas of heat loss from a building. The upgrading of insulation in existing buildings can be achieved by techniques of roof insulation, cavity fill, double-glazing, internal wall lining, and exterior wall cladding.

Renewable Energy

Renewable energy is energy obtained from sources that will not run out. It does not depend on the continued extraction of fossil fuels and does not contribute to CO_2 emissions. The sources of renewable energy that appear most promising are:

- The sun- used directly to heat water or buildings or indirectly to generate electricity.
- Hydroelectric- using turbines to convert the energy of rivers and streams into electricity.
- Wind- again using turbines sited either on or offshore.
- Biomass- burning energy crops or agricultural waste to produce heat for electricity generation.
- Energy from waste- burning solid waste collected by local authorities or landfill gas.

The term sustainable development is generally defined as development that leads to economic growth and social improvement without harming the environment and without depleting the earth’s reserves of resources. Buildings would be designed to be energy efficient utilising low power input for lighting and environment comfort (Abdeen, 2009c).

Ventilation

The warm air released from a building contains valuable heat energy, even if the air is considered ‘state’ for ventilation purposes. The heat lost during the opening of doors or windows becomes a significant area of energy conservation, especially when the cladding of buildings is insulated to high standards. These ventilation loses are reduced by better seals in the construction of the buildings, by air-sealed door lobbies, and the use of controlled ventilation. Some of the heat contained in exhausted air can be recovered by heat exchange techniques such as heat pumps. Larger windows provide better daylighting but also cause greater heat losses in winter and larger heat gains in summer. The accompanying Table 3 of environmental factors indicates some of the major interactions between different design decisions.

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Natural and international bodies, societies and environmentalists are aware that air-conditioning systems constitute about 55% of our ozone layer depletion through the use of refrigerants such as chlorofluorocarbons (CFCs) and hydro fluorocarbons (HFCs). In most homes air-conditioning systems are used predominantly for internal environmental comfort. The truth of the fact is that, we endanger our environment by the use of these air-conditioning systems for internal environmental comfort. Due to high levels of carbon dioxide (CO_2) and GHG emissions, which occur daily through these systems, the environment now relies heavily on green issues for sustenance. There are currently about 325 parts per million (ppm) of CO_2 in the atmosphere (Fordham, 2000). When the earth's ozone layer, which acts as protective shield from the sun's ultra-violet rays, is broken or torn, we experience global climatic changes. This leads to an increase in global temperature, which tends to cause rising sea levels that lead to flooding in many coastal areas. It is predicted that by 2080 global temperatures would rise by $3^{o}C$ as a result of which 80 million people could be flooded and displaced each year in the coastal areas (Fordham, 2000). The GHG emissions are introduced into the environment by two main sources: fossil fuels usage and burning, and refrigerants leakages in air-conditioning system. For positive reduction of the GHG emissions the following should be addressed:

- Societal awareness to renewable energy utilisation and benefits.
- Efficient design and installation of air-conditioning systems.
- Environmental impact and services.

There are four key features of innovative building design, which are:

- Natural ventilation.
- External day lighting.
- Heat reclamation if necessary.
- Use of borehole cooling where affordable.

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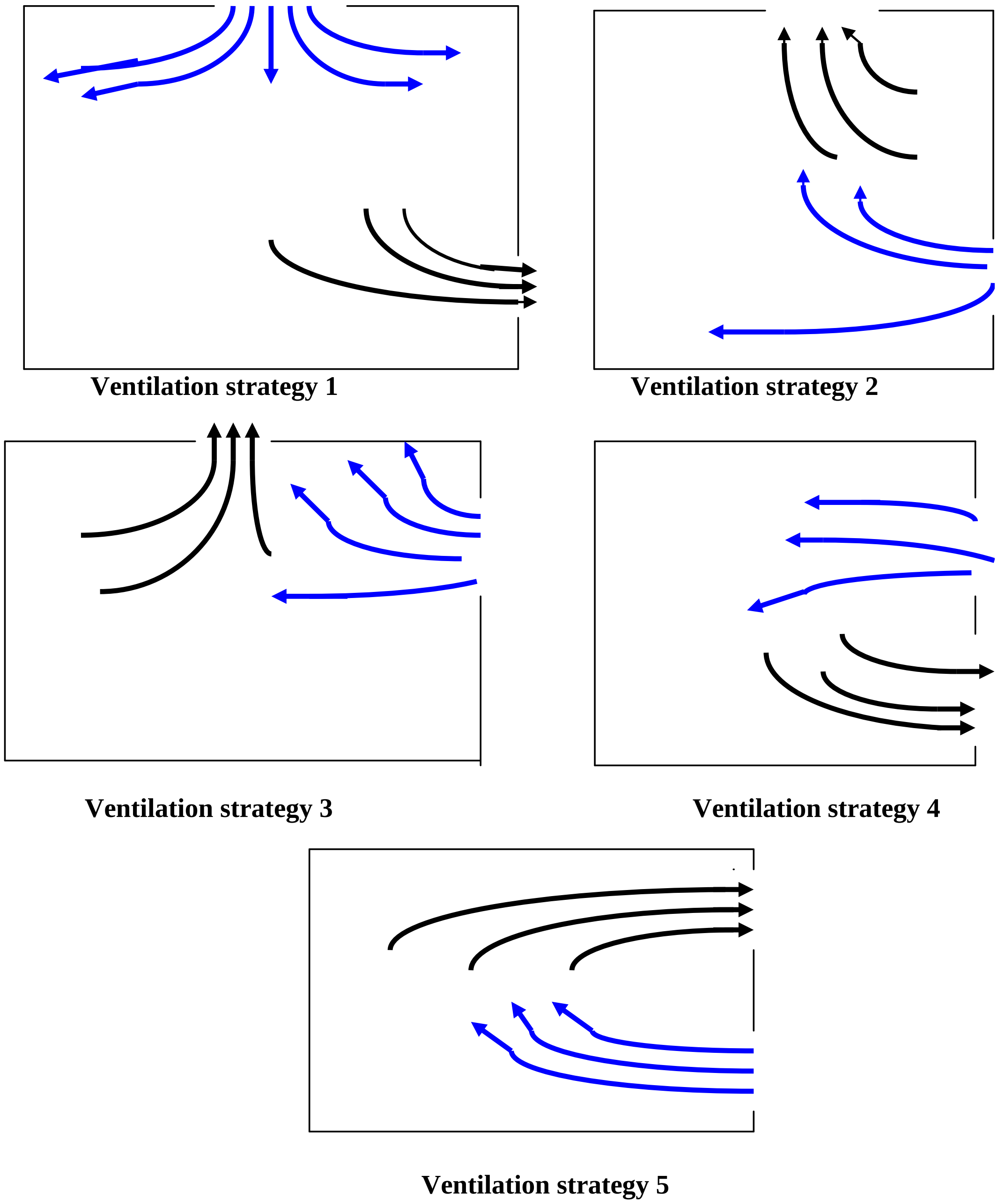

Figure 5. Different ventilation strategies.

Architects, consultants and contractors have to introduce new initiatives, ideas and concepts to the outlook of air-conditioning and ventilation systems operations. Such innovations and ideas would exist in the areas of:

- Design of energy efficient systems, which would make use of sources of renewable energies as a medium of heat transfer.
- Introduction of solar architectural designs in buildings reducing power consumption through electric bulbs during the day.
- Educating clients and users of buildings to understand the role of their buildings with respect to ozone layer depletion and environmental awareness.

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Particulate pollutants in buildings can have damaging effects on the health of occupants. Studies have shown that indoor aerosol particles influence the incidence of sick building syndrome (Fordham, 2000). Some airborne particles are associated with allergies because they transport viruses and bacteria. The concentration of indoor aerosol particles can be reduced by using different ventilation strategies (Figure 5) such as displacement and perfect mixing. However, there are insufficient data to quantify the effectiveness of these methods, as removal of particles is influenced by particle deposition rate, particle type, size, source and concentrations.

Natural Ventilation

Generally, buildings should be designed with controllable natural ventilation. A very high range of natural ventilation rates is necessary so that the heat transfer rate between inside and outside can be selected to suit conditions (Fordham, 2000). The ventilation rates required to control summertime temperatures are very much higher than these required to control pollution or odour. Any natural ventilation system that can control summer temperatures can readily provide adequate ventilation to control levels of odour and carbon dioxide production in a building. Theoretically, it is not possible to achieve heat transfer without momentum transfer and loss of pressure.

Mechanical Ventilation

Most medium and large size buildings are ventilated by mechanical systems designed to bring in outside air, filter it, supply it to the occupants and then exhaust an approximately equal amount of stale air. Ideally, these systems should be based on criteria that can be established at the design stage. To return afterwards in attempts to mitigate problems may lead to considerable expense and energy waste, and may not be entirely successful (Fordham, 2000). The key factors that must be included in the design of ventilation systems are: code requirement and other regulations or standards (e.g., fire), ventilation strategy and systems sizing, climate and weather variations, air distribution, diffuser location and local ventilation, ease of operation and maintenance and impact of system on occupants (e.g., acoustically). These factors differ for various building types and occupancy patterns. For example, in office buildings, pollutants tend to come from sources such as occupancy, office equipment, and automobile fumes. Occupant pollutants typically include metabolic carbon dioxide emission, odours and sometimes smoking. The occupants (and not smoking) are the prime source of pollution. Carbon dioxide acts as a surrogate and can be used to cost-effectively modulate the ventilation, forming what is known as a demand controlled ventilation system. Generally, contaminant sources are varied but, often, well-defined and limiting values are often determined by occupational standards (Table 3).

Table 3. Interactions of environmental decisions

Some design options	Heating	Ventilation	Lighting	Sound
Sheltered site loss and gain	Less heat	-	Less daylight	Less noise intrusion
Deep building shape	Less heat loss and gain	Reduced natural ventilation	Less daylight	-
Narrow building plan	More heat loss and gain	More natural ventilation	More daylight intrusion	More noise

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Heavy building materials	Slower heating and cooling	-	-	Better sound insulation
Increased window area	More heat loss and gain	-	More daylight	More noise intrusion
Smaller, sealed windows	Less heat loss and gain	Reduced natural ventilation	Less daylight	Less noise intrusion

There are increasing challenges facing people throughout the world to secure a reliable, safe and sustainable energy supply to meet their needs. In developing countries the demand for commercial energy is growing quickly. These countries are faced with substantial financial, environmental and energy security problems. In both developed and less developed countries pressure is growing to find workable alternatives to traditional energy supplies and to improve the efficiency of energy use in an attempt to limit emissions of gases that cause global climate change.

Ground Source Heat Pumps: A Technology review

This section provides a detailed literature based review of ground source heat pump (GSHP) technology and looks more briefly at applications of the technology, applicable standards and regulations, financial and other benefits and the current market status.

The first documented suggestion of using the ground as a heat source appears to be in 1912 in Switzerland in a patent filed by H. Zölly (Wirth, 1955) but at that time the efficiency of heat pumps was poor and energy prices were low so the idea was not followed up. In the forties investigation into the GSHPs started up again both in the USA and the UK. In the UK, Sumner first used the ground as a source for a heat pump for space heating in a single house in the mid 1940s (Sumner, 1976). A horizontal collector at a depth of about 1 m was used to supply heat via copper pipes buried in a concrete floor. A coefficient of performance (COP) of 2.8 was achieved. In 1948 he installed 12 prototype heat pump systems using ground collectors each with a 9 kW output. The average COP of these installations was 3. However, this study was stopped after two years (Wirth, 1955). The first ground source heat pump in the North America was installed in a house in Indianapolis in October 1945 (Crandall, 1946). This consisted of copper tubes buried at a depth of about 1.5 m in the ground with the refrigerant circulating directly through them. In the next few years virtually all the methods of exploiting the ground as a heat source/sink, which are used today, were investigated in the USA (Kemler, 1947) and a study in 1953 listed 28 experimental installations. Studies were also carried out in Canada, where the emphasis was on understanding the theoretical basis of using heat from the ground (Kemler, 1947). The first Canadian system was in an experimental house at Toronto University (Kusuda and Achenbach, 1965). Commercial use of the ground as a heat source/sink did not begin until after the first oil shock in 1973 but was well established by the end of the seventies by which time there were over 1000 ground source heat pumps installed in Sweden (Granryd, 1979). The vertical earth heat exchanger was introduced into Europe in the late 70s (Rosenblad, 1979), and from that time on has been used in various types mainly in Sweden, Germany, Switzerland and Austria (Drafz, 1982). Since 1980 there have not been any major technological advances in the heat pump itself except for improved reliability. However, considerable progress has been made in other areas such as system integration, reducing costs for the ground heat exchanger, improving collector

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configuration and control systems and strategies (Sanner, Hopkirk, Kabus, Ritter and Rybach, 1996).

Today the GSHPs are an established technology with over 400,000 units installed worldwide (around 62% of which are in the USA) and about 45,000 new units installed annually (Drafz, 1982). They are receiving increasing interest in the North America and Europe because of their potential to reduce primary energy consumption and thus reduce the emission of the GHGs and other pollutants (Drafz, 1982).

The GSHPs as the technology for space heating and cooling had the highest potential energy efficiency. The Geothermal Heat Pump Consortium was thus set up in 1994 with the aim of stimulating uptake of the technology and increasing the number of installations from approximately (40,000 units/year) to (400,000 units/year) by the year 2000. It was estimated that this could save over 300 x 10^9 MJ/year and reduce GHG emissions by 1.5 million metric tons/year of carbon equivalent. Although this target was very ambitious, and will not be met, there has been sustained interest in the technology (Drafz, 1982).

Overall efficiencies for the GSHPs are high because the ground maintains a relatively stable source/sink temperature, allowing the heat pump to operate close to its optimal design point. Efficiencies are inherently higher than for air source heat pumps because the air temperature varies both daily and seasonally and air temperatures are lowest at times of peak heating demand and highest at times of peak cooling demand.

Heat recovery using waste ventilation air to heat water is another possibility; this is more worthwhile on larger flats and offices. There are also many commercial and industrial processes where heat is wasted: a heat pump can recover this energy to provide heat at a useful temperature. Often referred to as "Geothermal", the GSHP is becoming the most common system to be installed in the Northern Europe. The efficiency of any system will be greatly improved if the heated water is kept as low as possible. For this reason, underfloor heating is preferred to radiators. It is vital to ensure that the underfloor layout is designed to use low water temperatures, i.e., plenty of pipe and high flow-rates. Heat pumps have a different design emphasis to boiler systems (ACRI, 1991).

Most underfloor systems use zone valves that reduce the flow-rate. The heat pump can maintain the correct flow-rate in buildings. A buffer tank is suggested. If radiators are to be used, they must be large enough. Double the normal sizing (as used with a boiler) is a good starting point. Whilst this type of heat pump installation could provide all the heating needs, it is common practice, and often-economic sense to have a back-up boiler linked to the system to cope with the very cold periods. Electric back up is not ideal. This is putting a high load on the main supply at a time of peak demand. At this time the power station's net fuel efficiency is lower.

The ground pipe system must be planned carefully, especially as it will be there for well over 50 years. Any mistakes may be too difficult or costly to rectify later. The highest energy efficiency will result from systems that do not go below freezing point, therefore, the bigger the pipe system/ground area, the better; however, this is costly and gives diminishing returns. The pressure drop in the pipes should be compatible with standard low-head pumps.

Weather compensation will greatly improve the annual energy efficiency, by reducing the heated temperature to the minimum required, depending on outside temperature. Most heat

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pumps incorporate this in the controller; however, this facility can be retrofitted as an extra. To keep energy efficiency high, keep the heated water temperature as low as possible. Then, keep some zone valves fully open and control the temperature down by carefully adjusting the weather compensation controller. If there is not any weather compensation, simply adjust the water temperature as low as possible such that adequate heating is attained. If domestic hot water is provided by the heat pump, have a big enough cylinder such that the water can be stored at a slightly lower temperature. Avoid "thermal store" type systems. They require temperatures higher than heat pumps can efficiently provide. Heat pump compressors like to run for long periods. Stop-starts should be minimised. The use of buffer tanks, correctly set thermostat differentials and correctly positioned cylinder sensors will all help to maximise run periods. Noise could be a problem if not considered properly, at the design stage and this problem should be eliminated.

Hydropower Systems

The mechanical power from a water turbine or wheel is usually used to generate electricity. A heat pump can extract energy from the water to produce a heat energy output of three or more times that of a conventional hydroelectric system. Since space heating is by far the biggest single energy load, it is sometimes better to put all the hydro energy into a heat pump, while remaining grid-connected for general electrical needs. The heat pump can be driven directly by mechanical belt-drive, etc. However, this system requires a lot of maintenance. An electric drive heat pump driven from a hydroelectric source is probably the most practical.

Air-conditioning

Air-to-air systems are used throughout the world for air-cooling. The reversible version of these is the most common type of heat pump. In its heating mode, the efficiency is not as good as the previously mentioned water systems. In cooling mode, they consume large amounts of energy. In the UK, the suggestion that a large ventilation-rate combined with sun shading is more appropriate for cooling, as fans use far less power. If mechanical air-cooling is necessary, then a water- or ground-coupled heat pump system will be the most energy efficient.

If air-conditioning is used, then good housekeeping to reduce energy consumption should not be overlooked. This should include good shading from sunlight by use of automatic or manually controlled blinds. The room temperature should not be set too low, as is often the case. The term coefficient of performance’s (COP) usually used to describe a heat pump's efficiency. A COP of 3 is typical, i.e., 1 kilowatt (kWatt) of power input will provide 3 kWatts of useful output. This is equivalent to 300% efficiency. (The extraction of heat from outside makes this possible). The COP depends on the type of application. In general, the closer the difference in temperature between the source and the sink, the higher the efficiency, e.g., a COP of 5 can be attained with a good heat pump with a spring source feeding well designed underfloor heating, whereas a COP as low as 2 may result in heating bath water from an air source system in winter.

1) The word "Efficiency" is defined as the ratio of useful heat output to energy input, e.g., if an open fireplace loses half its energy up the chimney it is said to be 50% efficient.

2) The COP or "Coefficient of performance" is found by dividing the useful heat output by the energy input, e.g., a heat pump that produces 3 kWatts of heat for 1 kWatt of input

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power has a COP of 3. The open fireplace example with 50% efficiency would have a COP of 0.5 (1/2).

3) The heat "Source" is the outside air, river or ground, wherever the heat is being extracted from. Sometimes is referred to as an ambient source.

4) The "Sink" is the name given to the part where the heat is usefully dissipated, such as radiators in the room, underfloor heating, hot water cylinder, etc.

Technical Definitions

Slinky:

The name Slinky is given to the way that ground collector pipes can be coiled before buying in a trench.

Horizontal collector:

This can be either coiled 'Slinky' or straight pipes that are buried 1.5 m to 2 m deep in open ground (in gardens). The pipe is usually plastic and contains a Glycol antifreeze solution.

Antifreeze:

This is simply an additive to water that makes its freezing point lower. Common salt does the same thing, but Ethylene or Propylene Glycol is more practical for heat pump systems.

Refrigerant:

This is the working fluid within the heat pump. It evaporates in one part and condenses in another. By doing so, heat is transferred from cold to hot. This fluid is sealed in and will not degrade within the heat pumps life.

Heat exchanger:

This is a simple component that transfers heat from one fluid to another. It could be liquid-to-liquid, or liquid-to-air, or air-to-air. Two heat exchangers are housed within the heat pump, one for the hot side (the condenser), and one for the cold side (the evaporator).

Passive heat exchange:

When waste hot water preheats cold input water, it is said to be ‘passive’. This costs nothing to run. A heat pump is said to be 'active' it can extract heat from cold waste water but requires a relatively small power input.

Commercial Building Applications

Ground-coupled heat pumps (GCHPs) are often confused with a much more widely used commercial system, the water loop heat pump (WLHP) or water source heat pump. Although the piping loop inside the building is similar, there are several important differences. Water-to-air heat pumps are located throughout the building. Local zone temperature is achieved with conventional on-off thermostats. Ductwork is minimised because the units are in the zone they serve. A central piping loop is connected to all the units. The temperature of this

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loop is typically maintained between 60°F (16°C) and 90°F (32°C). A cooling tower is used to remove heat when the loop temperature exceeds 90°F and heat is added with a boiler if the temperature falls below 60°F (ACRI, 1991).

The WLHPs are most successful when internal building loads are sufficient to balance the heat loss through the external surfaces and ventilation. If heat losses exceed internal loads, the energy requirements of the WLHPs can become significant. Energy must be added in both the boiler and heat pumps. This is not true in cooling because the heat is dissipated through the cooling tower, which only has pump and fan motor requirements.

The WLHPs are designed to operate in the narrow range of 60 to 90°F. This will not perform adequately in a GCHP system. The units used in the GCHP systems must be extended range water-to-air heat pumps. Some manufacturers create extended range heat pumps by replacing the fixed expansion device of a WLHP with a thermostatic expansion valve (TEV). Others make this modification and add improved compressors, air and water coils, fans, and controls. This has resulted in units that operate with higher efficiencies than conventional WLHPs even when operating with water temperatures outside the 60 to 90°F range. It is obvious that the ground coil can add to the cost of the system. Also many high-rise commercial applications may not have sufficient land area to accommodate a full size ground coil. A hybrid ground-coupled water-loop heat pump (GCWLHP) would be a viable option to reduce the size of the ground coil. The coil would be sized to meet the heating requirement of the building. This is typically one-half the size required for meeting the cooling load. There are several reasons for the smaller size:

- In the heating mode only about 70% of the heat requirement of the building must come from the ground coil. The remaining 30% comes from the power input to the compressor and fan motors. So the coil transfers about 8,400 Btuh/ton. In cooling the coil must transfer the building load and the added heat of the motors. This means 130% or 15,600 Btuh/ton must be moved through the ground coil (MGA, 1992).

- The cooling requirement of commercial buildings with high lighting and internal loads usually exceeds the heating requirement.

- The heating requirement of commercial buildings is often in the form of a morning "spike" followed by a reduced load. Ground coils are well suited to handling spikes because of the large thermal mass of the earth. Therefore, lengths can be reduced compared to systems designed for continuous loads. Since the ground coil for a GCWLHP would not be able to meet the cooling load in most climates, a downsized cooling tower would be added to the loop.

The GCHPs can also be integrated into "free cooling" or thermal storage schemes. For example, hydronic coils could be added to core heat pumps of a GCWLHP system. When the outdoor temperature was cold enough the cooling tower could be started. This would bring the loop temperatures below 50°F (10°C) to cool the core zones without activating the compressors. The heat pumps in perimeter zones could operate simultaneously in the heating mode if required. A variety of other systems are possible because of the simplicity and flexibility of ground-coupled heat pumps.

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Examples of Commercial Installations

Very few building owners, engineers, and architects consider GCHPs because in the past implementation was difficult. There were very few qualified loop installers, design guides were hard to find, and the traditional HVAC&R network balked at the thought of linking equipment to plastic pipe buried in the ground. However, the experiences of those who tried this "new" concept have led to a sound methodology for the design and installation of highly reliable and efficient systems. One such firm operates in Pennsylvania (MGA, 1992). This firm designs, installs and operates GCHP systems. The ground coils are typically 200 to 500 ft deep with 1½ inch (4 cm) polyethylene U-bends. Drilling in the area is very difficult compared to the rest of the USA (MGA, 1992). However, several successful systems have been and are continuing to be installed and operated. A listing is given in Table 4.

Similar firms are operating profitably in areas all over the USA. Texas has several new schools and other commercial buildings that have GCHPs. Activities in Canada are very high compared to the USA (MGA, 1992) with utilities promoting the technology with rebates and technical assistance. Oklahoma, a state that derives much of its income from oil and gas, is in the process of installing a GCHP system to heat and cool its state capital complex. The common thread in successful GCHP programmes appears to be an individual or set of individuals in a particular location who recognise the advantages of the GCHPs. These individuals have the initiative to push forward in spite of the many skeptics who contend that GCHPs will not work (MGA, 1992).

In heating applications, heat pumps save energy by extracting heat from a natural or waste source, using a mechanism similar to that found in a refrigerator. They can be used for any normal heating needs. However, this technology is not new. Several heat pumps were installed in the 1950's in a bid to save energy and fuel costs. One of the most famous of these was used to heat the Royal Festival Hall in London by extracting heat from the River Thames (MGA, 1992).

Table 4. Listing of systems installed and operated by Pennsylvania GCHP Firm (MGA, 1992)

Building Type	Area (sq. ft)	Capacity (tons)	Units	Bores
Bank	5,500	13	3	3
Retired Community	420,000	840	316	187
Elementary School	24,000	59	21	20
Doctor's Office	11,800	35	7	7
Condominiums	88,000	194	74	40
Middle School	110,000	412	96	106
Restaurant	6,500	36	6	7
Office/Lab	104,00	252	43	62
Elderly Apts.	25,000	89	76	12
Life Care Comm.	390,000	1,100	527	263
Ron. McDonald House	2,000	5	4	1

Efficiency

Heat pump efficiency is primarily dependent upon the temperature difference between the building interior and the environment. If this difference can be minimised, heat pumps

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efficiency (and capacity) will improve. Ground temperatures are almost always closer to room temperature than air temperatures. Therefore, the GCHPs are inherently more efficient than units that use outdoor air as a heat source or sink if the ground coil is correctly designed. This principle is one of Mother Nature's rules and is referred to as Carnot's Law. Secondly, it is important to have large coils for high efficiency. Water is far superior to air with regard to "convection" heat through coil surfaces. Therefore, the water coils in the GCHP are smaller and much more "efficient" in transferring heat. The part-load efficiency of a GCHP is actually improved compared to full load efficiency. When the ground coil is partially loaded, the water loop temperature more closely approaches the earth temperature. This temperature is cooler in the cooling mode and warmer in the heating mode. Therefore, system efficiency is improved. Auxiliary power requirement can be reduced significantly compared to conventional systems.

In addition to being a better heat transfer fluid compared to air, water requires much less energy to be circulated. Although it is heavier than air, a given volume of water contains 3500 times the thermal capacity of atmospheric air. Therefore, the pump motors circulating water through a GCHP system are much smaller than outdoor air or cooling tower fan motors of conventional systems. The indoor fan power is also reduced because the units are in the zone and duct runs are very short and non-existent. Therefore, low pressure (and power) fans can be used. Unfortunately, the efficiency ratings used for the GCHPs do not match with the ratings of conventional equipment. For comparison consider a central chiller and GCHP. Table 5 is a comparison of the full load efficiency of a 100 tons central chiller to a GCHP (HPA, 1992).

Advantages of the GCHPS

Major advantages of the GCHPS are summarised as follows:

Space

The GCHP systems require a small amount of space if properly designed. A 5 tons (18 kW) water-to-air heat pump in a horizontal package can be as small as 20x25x45 inches (50x64x115cm) and easily located above the ceiling in a typical office. Vertical packages can be placed in small closets. Some units used in the WLHP systems may have excessive noise levels for these locations. However, the improved units recommended for the GCHP systems have quieter compressors and large, low velocity fan wheels that reduce noise levels.

Table 5. Efficiency comparison of high efficiency central chiller with the GCHP (HPA, 1992)

1. Chiller @ 85°F Cond. water and 45°F chilled water (0.6 kW/ton)	60 kW
2. Indoor fans (40,000 cfm, 3.0 in. ESP, 90% motors)	25 kW
3. Cooling tower fan (5 hp)	4 kW
4. Cooling tower pump (5 hp)	4 kW
5. Indoor circulation pump (5 hp)	4 kW
Total	97 kW

The central distribution system requires relatively little space, and the relative requirements for a high velocity air system, a low velocity air system, and a GCHP. It also indicates the required power of the GCHP pump is much smaller than the fans of either air systems.

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Aesthetics

One pleasant advantage of a GCHP system is the absence of unsightly outdoor equipment. The ground above outdoor coil can become a greenspace or a parking lot. This is especially suited to schools where outdoor equipment may pose a safety hazard to small children or a vandalism target for not so small children.

Simplicity

The conventional GCHP system is extremely simple. The water-to-air unit consists of a compressor, a small water coil, a conventional indoor air coil, one bi-flow expansion device, and a few electrical controls. The flow control can be either a single circulation pump on each unit (that is turned on with the compressor relay) or a normally closed two-way valve for systems with a central circulation pump. If the designer chooses an extended range heat pump as recommended, no water regulating control valves are necessary.

Control

Control is also very simple. A conventional residential thermostat is sufficient. Since units are located in every zone, a single thermostat serves each unit. Zones can be as small as ½ ton (1.8 kW). However, each unit can be linked to a central energy management system if desired. Air volume control is not required. Larger water-to-air heat pumps are available if multi-zone systems are required. This would complicate one of the most attractive benefits of the GCHPs, local zone control. The simple system can be installed and serviced by technicians with moderate training and skills. The building owner would no longer be dependent on the controls vendor or outside maintenance personnel. The simple control scheme would interface with any manufacturers' thermostats.

Comfort

The GCHPs eliminate the Achilles' heel of conventional heat pumps in terms of comfort, "cold blow". Commercial systems can be designed to deliver air temperatures in the 100° to 105°F (38° to 41°C) range without compromising efficiency (Bose, 1988). Moisture removal capability is also very good in humid climates. The previously discussed advantage of local zone control is also critical to occupant comfort.

Maintenance

One of the most attractive benefits of the GCHPs is the low level of maintenance. The heat pumps are closed packaged units that are located indoors. The most critical period for a heat pump compressor is start-up after defrost. The GCHPs do not have a defrost cycle. The simple system requires fewer components. Logic dictates that the fewer components, the lower the maintenance. Because of the limited amount of data for the GCHPs, not a great deal of data is available to support the claim of low maintenance in commercial buildings. However, a detailed study of a WLHP system was conducted and the median service life of compressors in perimeter heat pumps was projected to be 47 years (Ross, 1990).

Disadvantages

Various disadvantages are as follows:

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New Technology

The GCHPs face the typical barriers of any new technology in the heating and cooling industry. Air source heat pump and natural gas heating technology has been successful. The technical personnel have been needed to install and service this equipment. A great deal of research and development has been successfully devoted to improving this technology. The GCHP technology faces an additional barrier in the lack of an infrastructure to bridge two unrelated networks: the HVAC industry and the drilling/trenching industry. There is little motivation on either side to unite. The HVAC industry prefers to continue marketing a proven technology and well drillers continue to profit on existing water well, environmental monitoring well, and core sampling work. It is the task of the two sectors that benefit the most from the GCHPs, customers and electric utilities, to force a merger of the two networks.

Limited Profit for HVAC Equipment Manufacturers

Some equipment manufacturers are resistant to the GCHPs because of the reduced need of their products. Water-to-air heat pumps are relatively simple and potentially inexpensive devices. The control network is especially simple and inexpensive. There will be no need for manufacturer’s technicians to trouble-shoot and service control systems. There will be no need to lock into one manufacturer’s equipment because of incompatibility. The GCHPs are not inexpensive. However, approximately 50% of the system’s first cost must be shared with a driller/trencher. Therefore, some HVAC manufacturers may be reluctant to support the implementation of the GCHPs.

Installation Cost

The most formidable barrier to the GCHP systems is currently high installation costs. While this is especially true in the residential sector, it also applies to commercial applications. Residential premiums compared to a standard electric cooling/natural gas heating system (9.0 SEER, 65% AFUE) are typically $600 to $800 per ton for horizontal systems and $800 to $1000 per ton for vertical systems. Simple payback is typically five to eight years (ASHRAE, 2000). The percent increase is somewhat less for commercial GCHPs as shown in the following section.

Projected Cost of Commercial GCHPS

The cost of vertical ground coil ranges from ($2.00 to $5.00 per ft) of bore. Required bore lengths range between 125 ft per ton for cold climate, high internal load, and commercial buildings to 250 ft per ton for warm climate installations. Pipe cost can be as low as $0.20 per ft of bore ($.10/ft of pipe) for 3/4 inch (2.0 cm) and as high as $1.00 per ft of bore ($0.50/ft of pipe) for 1½ inch (4.0 cm) polyethylene pipe. Drilling costs range from less than $1.00 per ft to as high as $12.00 per ft. However, $5.00 per ft is typically the upper limit for a drilling rig designed for the small diameter holes required for the GCHP bores even in the most difficult conditions. It should be noted that larger diameter pipes result in shorter required bore lengths. Table 6 gives typical costs for low and high drilling cost conditions for 3/4 and 1½ inch U-bends for a 10 ton system (Pietsch, 1988).

The total cost will be in the range of $400 to $850 per ton. If the cost of the WLHP boiler, drains, and cooling tower is deducted from the total and the cost of the ground coil and

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current cost of improved heat pumps ($100/ton) is added, a cost range for the GCHPs results (Pietsch, 1988). For low cost drilling sites the cost of the GCHPs is actually lower than conventional 2-pipe VAV systems (Cavanaugh, 1992).

Table 6. Cost of vertical ground coils (Pietsch, 1988)

Systems	$1.50/ft Drilling cost	$4.00/ft. Drilling cost
	¾'' (2000')	1.5'' (1700')
Drilling	$3000	$2550
Pipe	$600	$1360
Fittings	$300	$300
Total	$3900	$4210
Cost/ton	$390	$421

Operating Costs

Limited data is available documenting the operating cost of the GCHPs in commercial applications. The steady state and part load cooling efficiencies of vertical GCHPs appear to be superior to high efficiency central systems. The heating efficiencies are very good, especially when the ground coil is sized to meet the cooling requirement. However, these high efficiencies will not be realised if ground coils are undersized or low and moderate efficiency water-to-air heat pumps are used.

A comprehensive study of the GCHP operating costs in commercial buildings must be conducted. This study is needed to expand the limited design guidelines currently available for the GCHPs.

Facing the Competition with the GCHPS

Electric utilities may argue that these figures may be exaggerated. There is a strong element of truth in each. Air source heat pumps do not heat well in cold weather (Mother Nature will not allow it). Air heat pumps do blow large amounts of air at temperatures below body temperature. In the heating mode, the air heat pump consumes more net energy than high efficiency gas furnaces.

The electrical utility has focused the bulk of its response on aggressive marketing that in some cases is equally as misleading document. This marketing includes advertising and reduced rates for customers who choose electric heat. To a lesser degree, the response has included development of advanced heat pumps. In the commercial sector, this has generally excluded the GCHPs. Most of the developmental activity for the GCHPs has been confined to the residential market.

The electric utility would be the benefactor. Even when the air is 0°F and below, the ground is 45°F and above, the GCHPs can operate very well and can deliver air at a comfortable temperature. For every 10 Btus used at the power plant at least 10 Btus are delivered to the home. They offer all of the many advantages of conventional electric heat pumps plus higher efficiency, simplicity, reliability, reduced demand, removal of unsightly outdoor equipment, comfort, and long life. They offer a system whose performance cannot be matched by natural gas equipment.

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Discussions

At present, the field of embodied energy analysis is generally still only of academic interest and it is difficult to obtain reliable data for embodied energy. However, research findings in some countries indicate that the operating energy often represents the largest component of life-cycle energy use. Accordingly, most people, when studying low energy buildings, would prefer to focus on operating energy, and perhaps carry out only a general assessment of embodied energy.

The increased availability of reliable and efficient energy services stimulates new development alternatives (Omer, 2009). This study discusses the potential for such integrated systems in the stationary and portable power market in response to the critical need for a cleaner energy technology. Anticipated patterns of future energy use and consequent environmental impacts (acid precipitation, ozone depletion and the greenhouse effect or global warming) are comprehensively discussed in this approach. Throughout the theme several issues relating to renewable energies, environment and sustainable development are examined from both current and future perspectives. It is concluded that renewable environmentally friendly energy must be encouraged, promoted, implemented and demonstrated by full-scale plant (device) especially for use in remote rural areas.

In many countries, global warming considerations have led to efforts to reduce fossil energy use and to promote renewable energies in the building sector. Energy use reductions can be achieved by minimising the energy demand, by rational energy use, by recovering heat and cold and by using energy from the ambient air and from the ground. To keep the environmental impact of a building at sustainable levels (e.g., by greenhouse gas (GHG) neutral emissions), the residual energy demand must be covered with renewable energy. In this theme integral concepts for buildings with both excellent indoor environment control and sustainable environmental impact are presented. Special emphasis is put on ventilation concepts utilising ambient energy from the air, the ground and other renewable energy sources, and on the interaction with heating and cooling. It is essential to avoid the need for mechanical cooling, e.g., by peak load cutting, load shifting and the use of ambient heat or cold from the air or the ground. Techniques considered are hybrid (controlled natural and mechanical) ventilation including night ventilation, thermo-active building mass systems with free cooling in a cooling tower, and air intake via ground heat exchangers. For both residential and office buildings, the electricity demand remains one of the crucial elements to meet sustainability requirements. The electricity demand of ventilation systems is related to the overall demand of the building and the potential of photovoltaic systems and advanced co-generation units.

In climate-sensitive architecture, strategies are adopted to meet occupants' needs, taking into account local solar radiation, temperature, wind and other climatic conditions. Different strategies are required for the various seasons. These strategies can themselves be subdivided into a certain number of concepts, which represent actions.

The heating strategy includes four concepts:

- Solar collection: collection of the sun's heat through the building envelope.
- Heat storage: storage of the heat in the mass of the walls and floors.

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- Heat distribution: distribution of collected heat to the different spaces, which require heating.
- Heat conservation: retention of heat within the building.

The cooling strategy includes five concepts:

- Solar control: protection of the building from direct solar radiation.
- Ventilation: expelling and replacing unwanted hot air.
- Internal gains minimisation: reducing heat from occupants, equipments and artificial lighting.
- External gains avoidance: protection from unwanted heat by infiltration or conduction through the envelope (hot climates).
- Natural cooling: improving natural ventilation by acting on the external air (hot climates).

The daylighting strategy includes four concepts:

- Penetration: collection of natural light inside the building.
- Distribution: homogeneous spreading of light into the spaces or focusing.
- Protect: reducing by external shading devices the sun's rays penetration into the building.
- Control: control light penetration by movable screens to avoid discomfort.

The admission of daylight into buildings alone does not guarantee that the design will be energy efficient in terms of lighting. In fact, the design for increased daylight can often raise concerns relating to visual comfort (glare) and thermal comfort (increased solar gain in the summer and heat losses in the winter from larger apertures). Such issues will clearly need to address in the design of the window openings, blinds, shading devices, heating systems, etc. Simple techniques can be implemented to increase the probability that lights are switched off (Omer, 2009). These include: (1) making switches conspicuous (2) locating switches appropriately in relation to the lights (3) switching banks of lights independently, and (4) switching banks of lights parallel to the main window wall.

Large energy savings cover a wide range of issues including:

- Guidelines on low energy design.
- Natural and artificial lighting.
- Solar gain and solar shading.
- Fenestration design.
- Energy efficient plant and controls.
- Examining the need for air conditioning.

The strategy

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- Integration of shading and daylighting: an integral strategy is essential and feasible where daylighting and shading can be improved simultaneously.
- Effect of shading on summer comfort conditions: solar shading plays a central role in reducing overheating risks and gives the potential for individual control, but should be complimented with other passive design strategies.
- Effect of devices on daylighting conditions: devices can be designed to provide shading whist improving the daylight conditions, notably glare and the distribution of light in a space, thus improving the visual quality.
- Energy savings: energy savings from the avoidance of air conditioning can be very substantial, whilst daylighting strategies need to integrated with artificial lighting systems to be beneficial in terms of energy use.

The energy potential of daylighting is thus inextricably linked with the energy use of the associated artificial lighting systems and their controls. The economics of daylighting are not only related to energy use but also to productivity. Good daylighting of workspaces helps to promote efficient productive work, and simultaneously increases the sense of well-being. However, energy and economics should not become the sole concern of daylighting design to the exclusion of perceptual considerations.

The comfort in a greenhouse depends on many environmental parameters. These include temperature, relative humidity, air quality and lighting. Although greenhouse and conservatory originally both meant a place to house or conserve greens (variegated hollies, cirrus, myrtles and oleanders), a greenhouse today implies a place in which plants are raised while conservatory usually describes a glazed room where plants may or may not play a significant role. Indeed, a greenhouse can be used for so many different purposes. It is, therefore, difficult to decide how to group the information about the plants that can be grown inside it. Whereas heat loss in winter a problem, it can be a positive advantage when greenhouse temperatures soar considerably above outside temperatures in summer. Indoor relative humidity control is one of the most effective long-term mite control measures. There are many ways in which the internal relative humidity can be controlled including the use of appropriate ventilation, the reduction of internal moisture production and maintenance of adequate internal temperatures through the use of efficient heating and insulation.

The introduction of a reflecting wall at the back of a greenhouse considerably enhances the solar radiation that reaches the ground level at any particular time of the day. The energy yield of the greenhouse with any type of reflecting wall was also significantly increased. The increase in energy efficiency was obtained by calculating the ratio between the total energy received during the day in greenhouse with a reflecting wall, compared to that in a classical greenhouse. Hence, the energy balance was significantly shifted towards conservation of classical energy for heating or lighting. The four-fold greater amount of energy that can be captured by virtue of using a reflecting wall with an adjustable inclination and louvers during winter attracts special attention. When sky (diffuse) radiation that was received by the ground in amounts, were taken into account, the values of the enhancement coefficients were reduced to some extent: this was due to the fact that they added up to the direct radiation from the sun in both new and classical greenhouses. However, this is a useful effect as further increases overall energy gain. There is also an ironing out effect expressed in terms of the ratios between peak and average insolations.

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Finally, the presented theory can be used to calculate the expected effects of the reflecting wall at any particular latitude, under different weather conditions, and when the average numbers of clear days are taken into account. Thereby an assessment of the cost of a particular setup can be obtained. Under circumstances of a few clear days, it may still be worthwhile from a financial point of view to turn a classical greenhouse into one with a reflecting wall by simply covering the glass wall on the north-facing side with aluminum foil with virtually negligible expenditure.

CONCLUSION

With environmental protection posing as the number one global problem, man has no choice but to reduce his energy consumption. One way to accomplish this is to resort to passive and low-energy systems to maintain thermal comfort in buildings. The conventional and modern designs of wind towers can successfully be used in hot arid regions to maintain thermal comfort (with or without the use of ceiling fans) during all hours of the cooling season, or a fraction of it. Climatic design is one of the best approaches to reduce the energy cost in buildings. Proper design is the first step of defence against the stress of the climate. Buildings should be designed according to the climate of the site, reducing the need for mechanical heating or cooling. Hence maximum natural energy can be used for creating a pleasant environment inside the built envelope. Technology and industry progress in the last decade diffused electronic and informatics' devices in many human activities, and also in building construction. The utilisation and operating opportunities components, increase the reduction of heat losses by varying the thermal insulation, optimising the lighting distribution with louver screens and operating mechanical ventilation for coolness in indoor spaces. In addition to these parameters the intelligent envelope can act for security control and became an important part of the building revolution. Application of simple passive cooling measures is effective in reducing the cooling load of buildings in hot and humid climates. 43% reductions can be achieved using a combination of well-established technologies such as glazing, shading, insulation, and natural ventilation. More advanced passive cooling techniques such as roof pond, dynamic insulation, and evaporative water jacket need to be considered more closely. The building sector is a major consumer of both energy and materials worldwide, and that consumption is increasing. Most industrialised countries are in addition becoming more and more dependent on external supplies of conventional energy carriers, i.e., fossil fuels. Energy for heating and cooling can be replaced by new renewable energy sources. New renewable energy sources, however, are usually not economically feasible compared with the traditional carriers. In order to achieve the major changes needed to alleviate the environmental impacts of the building sector, it is necessary to change and develop both the processes in the industry itself, and to build a favourable framework to overcome the present economic, regulatory and institutional barriers. Ground source heat pumps are receiving increasing interest because of their potential to reduce primary energy consumption and reduce emissions of the GHGs. The technology is well established in the North America and parts of Europe, but is at the demonstration stage in the United Kingdom. Benefits to the community at large will result from the reduction in fossil consumption and the resulting environment benefits. By reducing primary energy consumption, the use of the GSHPs has the potential to reduce the quantity of CO_2 produced by the combustion of fossil fuels and thus to reduce global warming.

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Some Useful Figures and Conversions

1 kW (kilowatt) is a unit of power, or a rate of energy (A 1 bar fire consumes 1 kW)

There are 3,411 Btus in 1 kWatt, i.e., 10 kWatts = 31,400 Btu/hr

There are 860 kcal/h in 1 kW

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1 kWh (Kilowatt hour) is a quantity of energy

(A 1 kW heater would use 24 kWhr per day)

I kWatt hr = 1 unit of electricity = 1 bar fire used for one hour

Gas bills now use kWhr instead of the old confusing units Thermo, etc.

1 kJoule x 3,600 = 1 kWhr

If 10 kWatts were extracted from water having a flow rate of 0.8 lit/sec, then the temperature would drop by 3^{o}C (3K).

0°C = 32°F (freezing point of water)

20°C = 68°F (room temperature)

100°C = 212°F (boiling point of water)

(°F-32)/(9x5)=°C, or °Cx9/5+32=°F

1 lit/sec = 13.19 Galls (UK)/min

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