Energy Efficiency in Commercial Buildings

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requirements for the degree of Master of Science
Sustainable Engineering: Energy Systems & the Environment

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Copyright Declaration

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"Engineering is the science of economy, of conserving the energy, kinetic and potential, provided and stored up by nature for the use of man. It is the business of engineering to utilize this energy to the best advantage, so that there may be the least possible waste."

William A. Smith, 1908

Abstract

The demand for energy keeps rising which requires the generation of vast amounts of electricity. Changes have been made to make buildings more energy efficient. Understanding the use of energy in buildings requires an insight into the amounts of energy consumed and the different types fuels used. Buildings that could help contribute to their energy demand through the generation of renewable energy would help reduce the amounts of Carbon Dioxide (CO_2) produced by the building. Hence to succeed in developing a sustainable society buildings will always need to be improved as technology improves.

The objective of this dissertation is to obtain a clear understanding of energy efficiency in buildings and specifically in commercial buildings outlining what would be the most feasible renewable technique to be adopted in commercial buildings, although there is a large amount of information available about energy efficiency in commercial buildings of which some are contradictory.

There are many renewable technologies available at present, of which some had succeeded and other didn't, succeeded in a sense of acceptability from the consumer of the building, for example in commercial buildings overheating is an issue that has to be tackled, the different case studies provided will assist in evaluating the benefits of each technology and to what extent it made an impact on the design features, construction and subsequent use.

Therefore the aim is to construct a review of the most recent consultations on what are the current trends achieved towards making buildings more intelligent, self-sufficient and what could be done to make buildings more sustainable. The energy performance of a building will directly impact on the resale and rental income of the building. The energy performance of buildings will be discussed in later chapters of this dissertation.

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List of Abbreviations

OPEC	Organization of Petroleum Exporting Countries
CHP	Combined Heat and Power
NHER	National Home Energy Rating
PV	Photovoltaic
BEMS	Building Energy Management Systems
BREEAM	Building Research Establishment Environmental Assessment Method
DTI	Department of Trade and Industry
EU	European Union
SAP	Standard Assessment Procedure
ERV	Energy Recovery Ventilators
PIR	Passive Infrared Detectors
DWT	Ducted Wind Turbine

Chapter 1: Introduction

1.1 Introduction and Background

The use of energy in buildings has increased in recent years due to the growing demand in energy used for heating and cooling in buildings. Without energy buildings could not be operated or inhabited. Improvements have been made in insulation, plant, lighting and controls and these are significant features that help towards achieving an energy efficient building. At this stage it is important to know what is meant by “Energy Efficiency”.[15]

1.2 Energy Efficiency

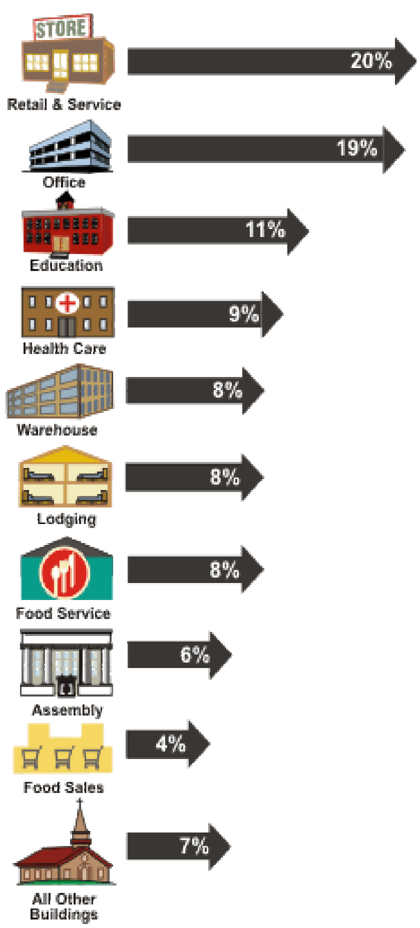
Energy efficiency means utilizing the minimum amount of energy for heating, cooling, equipments and lighting that is required to maintain comfort conditions in a building. An important factor impacting on energy efficiency is the building envelope. This includes all of the building elements between the interior and the exterior of the building such as: walls, windows, doors, roof and foundations. All of these components must work together in order to keep the building warm in the winter and cool in the summer.

The amount of energy consumed varies depending on the design of the fabric of the building and its systems and how they are operated.[15] The heating and cooling systems consume the most energy in a building, however controls such as programmable thermostats and building energy management systems can significantly reduce the energy use of these systems. Some buildings also use zone heating and cooling systems, which can reduce heating and cooling in the unused areas of a building. In commercial buildings, integrated space and water heating systems can provide the best approach to energy-efficient heating.[15]

For example, the energy used to heat water can be reduced by insulating water pipes to minimize heat loss and water heaters. In the past huge dependence on energy was not available, due to higher cost of production.

Energy audits can be conducted as a useful way of determining how energy efficient the building is and what improvements can be made to enhance efficiency. Tests should be undertaken to ensure that the heating, cooling, equipment and lighting all work together effectively and efficiently.

Buildings also produce Carbon Dioxide (CO_2) emissions, but this sector receives less attention compared to other pollution contributors such as the transportation and industry sectors. In addition to energy conservation and energy efficiency measures introducing renewable energy would be an advantage to the building sector as it will reduce the carbon dioxide emissions, and the energy generated from the renewable energy could be used for heating, cooling, ventilating or lighting.



Retail and service buildings utilize the most energy of all the commercial building types.

Offices use almost as great a share of energy as retail and service.

Education buildings, use 11% of all total energy, which is even more than all hospitals and other medical buildings combined!

Warehouses, lodging, and restaurants each use 8% of all energy.

Public assembly buildings, which can be anything from library as to sports arenas, use 6%; food sales buildings (like grocery stores and convenience stores) use 4%.

All other types of buildings, like places of worship, fire stations, police stations, and laboratories, account for the remaining 7% of commercial building energy.

It is easier to design energy efficient features into new buildings, however existing buildings comprise approximately 99% of the building stock. This sector thus provides the greater challenge for implementation of energy efficiency as well as the greater opportunity for overall energy efficiency gains. Although energy efficiency initiatives for existing buildings can be demonstrated to be cost effective, there has been limited success in convincing large organizations and building owners to undertake energy efficiency projects such as retrofits, and retro commissions.[8]

An important factor is the use of benchmarks which stand as representative standards against which buildings can be compared and the performance monitored. For example, the comparison of energy consumption with a square metre of floor area to the benchmark will allow the decision maker to notice and assess the amount of energy consumed and where improvements can be made to minimize the consumption within that specific area.

Energy efficient buildings do not cost necessarily more to build than normal buildings, if they are well maintained and manage energy effectively, they are set to be very reliable, comfortable and as productive as a normal building.

1.3 Problem Definition

Aim: The aims of this thesis are as follows:

- To identify what has been done so far towards making buildings more sustainable in terms of energy use and what could be done to improve the building.
- To maximise the use of day lighting ensuring the lighting levels are appropriate for the building.
- Considering renewable energy and combined heat and power in buildings.

Approach: The approach to this thesis is to start by giving an overview of what is energy efficiency and the history of energy conservation in buildings. Defining the problem is a primary aspect on which the project is based. In recent years all new buildings tend to address the issues, however there is an increasing challenge for existing buildings. Several case studies are reviewed and discussed to help set up a clear understanding of the use of energy conservation and most recent passive and active renewable energy techniques adopted by buildings.

Motivation: The main drivers for change towards sustainable buildings have been Under the Kyoto agreement, the UK Government is committed to reducing greenhouse gas emissions to 12.5% below 1990 levels by 2010. It also has a manifesto target to reduce emissions by 20% over the same period, which is supported in the Draft Regional Planning Guidance.[26]

While these targets are important, they will have only a limited impact on reversing global warming. The Royal Commission on Environmental Pollution suggests that a much higher target of a 60% reduction in carbon dioxide (CO_2) emissions by 2050 will be required.[26]

From January 2006 the EU Energy Performance of Buildings Directive (EPBD) will come into force in all member states requiring public buildings to display energy certificates and commercial buildings to have certificates available at point of sale or rent. These certificates will be accompanied by a list of measures that can be taken to improve the energy performance of the building. Buildings are by far the biggest cause of CO_2 emissions in the UK and hence it is in the development of buildings that the greatest savings can be made.[26]

Project Organisation:

CHAPTER 2: An introduction to energy performance of buildings is also outlined together with the EU energy policy towards the energy performance of buildings. Including the use of energy in the developing world.

CHAPTER 3: This chapter focuses on passive renewable technologies, illustrating the basic passive techniques adopted such as direct and indirect gain systems. The case studied provided demonstrate the impact of passive technologies on different scenarios and different type of buildings.

CHAPTER 4: This chapter focuses on the potential future role of renewable energy. In particular it focuses on the integration of small scale technologies at a city scale including the distribution of small scale renewable energy and benefits of local generation. In addition in provides case studies for each technology being adopted by new and existing buildings.

CHAPTER 5: This chapter includes the conclusions and recommendation for future work.

Chapter 2: Historical Overview of Energy use in Buildings

2.1 Introduction

This chapter focuses on giving a broad idea on giving an understanding on what is energy efficiency and what could be the possible impacts on both buildings and building regulation towards creating a sustainable environment that would last to benefit future generations and arise the awareness on the importance of sustainable building design.

2.2 Energy Efficiency in Buildings

The building stock includes, residential, commercial, institutional, and public structures. Opportunities to minimize energy requirements through energy efficiency and passive renewable energy in buildings encompass building design, building materials, heating, cooling, lighting, and appliances. These have been discussed in previous chapters of this thesis. This chapter will focus on small scale active renewable energy technology and their distribution and the benefits of local energy generation and in buildings generally and more embedded systems specifically in commercial buildings.

Commercial buildings include a wide variety of building types such as offices, hospitals, schools, police stations, places of worship, warehouses, hotels, libraries, shopping malls, etc. These different commercial activities all have unique energy needs but, as a whole, commercial buildings use more than half their energy for heating and lighting.[8]

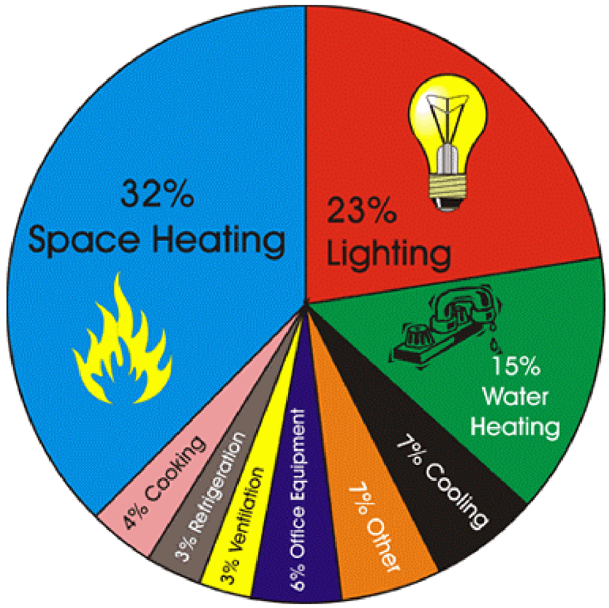


Figure 2.1 *Energy use in commercial buildings*

In commercial buildings the most common fuel types used are electricity and natural gas. Occasionally commercial buildings also utilize another source of energy in the form of locally generated group or district energy in the form of heat and/or power. This is most applicable in situations where many buildings are located close to each other such as is in big cities, university campus, where it is more efficient to have a centralized heating and cooling system which distributes energy in the form of steam, hot water or chilled water to a number of buildings. A district system can reduce equipment and maintenance costs, as well as save energy, by virtue of the fact that it is more efficient and economic to centralize plant and distribution.[22]

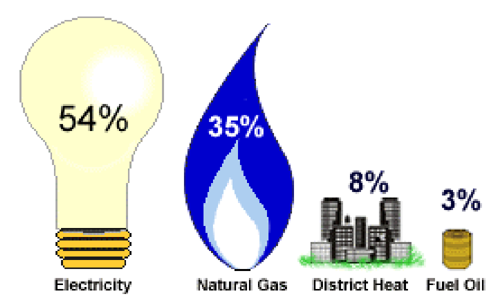


Figure 2.2 *Percentage distribution of energy consumption*

2.2.1 Energy Conservation

The imperative to conserve energy is as old as the use of energy. For most of human history, use of energy was limited to the amount of work that could be done by human beings, usually alone, but sometimes in large groups. Later, humans learned to use animals and teams of animals to do the tasks requiring heavy lifting and hauling. Energy conservation first consisted of doing less. Then, as intelligence evolved, it included finding easier ways to get work done. For example, the invention of the wheel was an early advance in energy conservation. Fire is the oldest major source of energy, other than muscle, that is controlled by humans.[6]

2.2.2 Growth in Energy use in the Developed World

Electrical power first emerged in the late 19th century, specifically for lighting. Electrical power was produced by increasingly efficient engines. However, lamps remained inefficient until the commercialization of fluorescent lighting, shortly before World War II.

The development of practical electric motors, largely by Nikola Tesla, occurred toward the end of the 19th century. This enormously expanded applications for mechanical power. The invention of innumerable small machines and labour saving devices made "energy" a ubiquitous commodity by the beginning of the 20th century.[6]

Unlike the development of mechanical equipment, the development of electrical equipment was largely based on theory. All practical electrical motors are efficient, when compared with combustion-driven machinery. However, the efficiency of applications served by inexpensive alternating-current motors is often limited by the fact that these motors are single-speed devices. Efficient variable-speed motors were developed early, but they had serious cost and maintenance limitations.

By the beginning of the 20th century, energy consumption *per capita* was accelerating, while the energy-consuming population of the earth also grew rapidly. Appliances displaced muscle power at home. Machines increased production in factories and in agriculture. Automobiles made transportation a major new consumer of fuels. Fuel replaced wind for the propulsion of ships. Air travel became another user of fuel, the available supply of energy continued to grow comfortably ahead of demand. Massive hydroelectric generation plants were built to provide jobs during the 1930’s. Electricity generation by nuclear fission arose as a by-product of nuclear weapons, becoming another major source of energy from the 1950’s onward.[6]

Until the early 1970’s, there was a popular conception of continually diminishing energy prices. For example, nuclear power advocates spoke of electricity that would be "too cheap to meter." As a result, efficiency ceased to be a major concern of the engineers who designed energy-using equipment, and efficiency faded as an issue with the public and the government.

However the warning about the rapid consumption of the world’s natural resources did concern scientists and environmentalists. Although some politicians warned about the possibility of the OPEC (Organisation of Petroleum Exporting Countries), countries using oil as a weapon to strangulate some countries, these notices seem to have gone unnoticed. The rise in oil prices in 1973 by the OPEC countries was unexpected by several developed western countries, and this resulted in energy crises. In many countries the majority of energy consumers such as industries, transportation and domestic systems came to a complete standstill.[20]

Since the 1973 oil crisis, successive U.K. Governments implemented a number of *adhoc* measures to encourage conservation. In 1974 the UK Secretary of State for Energy, announced a 12 point package to assist conservation in buildings. In 1978 the government formally introduced a Green Paper entitled *Energy Policy – a Consultative Document*.[10] This went on to spell out the main areas of government energy conservation policy as follows:

1. Energy prices need to reflect the cost of supply

2. Energy consumers need to be in a situation to make decisions in the light of adequate information about energy costs and about the ways in which energy can be more efficiently used. The government regards its role as ensuring that the information available is comprehensive. In appropriate cases it may be necessary to ensure via legislation the provision of comparative information.
3. Public authorities are responsible for 6% of energy use and the government has a particular responsibility for ensuring that potential reductions in consumption are achieved.
4. Public sector housing, which accounts for 9% of total energy use, is another area where no substantial progress can be expected without major public expenditure.
5. The government is identifying the areas where the research and development could lead to a considerable improvement in energy use.
6. In certain cases mandatory measures to promote energy conservation are appropriate.[10]

The Green Paper continued by saying that these policies needed to be reinforced by the adoption of a mixture of three courses of action designed to maximize conservation by raising energy prices to the consumer through:

- Taxation
- Reinforcing or extending mandatory measures
- Encouraging energy saving through grants and tax allowances.

2.2.3 Energy use in Hot Climates / Developing Countries

When it comes to the consumption of energy in tropical buildings, cooling using air conditioning consumes a higher proportion of energy compared with heating. However some tropical countries which incidentally fall within the developing countries, consume very little energy when compared to the developed countries.[5]

2.2.4 Addressing the need to Conserve Energy

Addressing the issue to minimize the effects of the present crises and future energy demands, the western and most developed countries who are considered responsible for the consumption of most of the world's energy, reached to the conclusion on four main aspects for conserving energy resources and they are as follows:[19]

- Reducing energy consumption in buildings, by energy management and energy efficient measures;
- The urgent requirement for alternatives and renewable energy sources of lower price;
- The design of buildings for the attainment of thermal efficiency including better insulation;
- Conserving water, materials and energy sources.

In terms of energy conservation by alternative or renewable sources, solar energy and its applications tend to be more practical in terms of linking local generation (supply and demand) and hence are the most attractive for the future. The table below shows opportunities for energy conservation and renewables: [21]

Energy Hierarchy	Domestic	Non-domestic
Reduce Demand	• Well designed layout • Passive solar design • Life cycle analysis of materials • High levels of insulation • High NHER (10 or above)	• Well designed layout • Passive solar design • Life cycle analysis of materials • Natural ventilation • High levels of insulation • BREEAM

Energy Efficiency	• Condensing boilers • Energy efficient white goods and lighting • Good heating controls • Influence behaviour	• Building Energy Management Systems • Energy efficient appliances and equipment • Condensing boilers • Energy efficient/Natural ventilation • Influence behaviour
Renewable Energy	• Passive solar design • Solar water/air heating • Photo voltaics • Small scale vertical axis wind turbines	• Passive solar design • Photo voltaics • Solar water/air heating • Small scale hydro • Small scale wind
CHP/District Heating	• District heating and CHP	• CHP with waste digestion • CHP feeding district heating

Table 2.1 *Opportunities for Energy Conservation and Renewables*

2.3 Energy Performance

It was not until energy use in buildings became a topic of concern that the search really began to look at establishing measures of energy performance. Energy performance indicators are measurements which provide the ability to compare different levels of energy use in the provision of a particular type of service. The objective of this is to establish an index that facilitates comparisons of buildings.

There are three factors to be considered in the construction of building energy performance indices and these are: the occupancy hours, severity of the climate and the type of activities in the building. Climatic severity and occupancy hours are best allowed for by dividing annual energy use per unit area by a factor that is constructed on the basis of climate or occupancy hours.[15]

Rating a building's energy performance is becoming an increasingly important factor of building operation. A highly rated building may be entitled for special recognition through a range of voluntary or compulsory programs, which increases its resale value and rental income. Energy Rating can help identify poorly operated buildings and opportunities for energy and cost savings.

A distinction can always be made between how to obtain a 'Low energy building' and how to obtain an 'Energy efficient building'. Energy efficient building solutions are often accomplished by selecting the lowest possible energy requirements with reasonable utilization of resources. In terms of installed equipment a strategy for identifying and rating low energy and energy efficient buildings is to define what shall be conserved and the purpose for it. Rating schemes are generally associated with certification. Certification means evaluating the building in the design stage.[15]

Therefore the main aim of energy performance is to encourage the practice of specifying materials, components and systems. The particular objective of an energy performance is to specify what is required from the building in terms of a target energy consumption.

2.3.1 Energy Consumption

Energy consumption in buildings can be categorized into three categories:

1. Primary Energy: This relates to the calorific value of the fossil fuels in their 'raw' state

2. Secondary Energy: This is available from electricity, and other types of energy manufactured from a primary energy source
3. Useful Energy: This refers to the energy required for the performance of a given task. This is usually applicable to space heating load evaluations and other efficiencies.

2.3.2 Building Regulations

Section 1 of the *Building Act 1984* gives the Secretary of State powers to make building regulations, which have three aims:[24]

1. Securing the health, safety, welfare and convenience of people in or about buildings and of others who may be affected by buildings or matters connected with buildings.
2. Preventing waste, undue consumption, misuse or contamination of water.
3. Furthering the conservation of fuel and power.

National building regulations for insulation were introduced in 1965. Since then, standards have been raised over the years, most recently by the *Building Regulations (Amendment) Regulations* SI 1994/1850 (a separate building control system applies to Scotland and Northern Ireland). These amended the *Building Regulations* SI 1991/2768 by expanding the requirement that 'reasonable provision shall be made for the conservation of fuel and power in buildings'. Paragraph L1 of Schedule 1 (England and Wales) specifies that this provision shall be achieved by:[24]

- Limiting the heat loss through the fabric of the building;
- Controlling the operation of the space heating and hot water systems;
- Limiting the heat loss from hot water vessels and hot water service pipe-work;
- Limiting the heat loss from hot water pipes and hot air ducts used for space heating;

- Installing in buildings artificial lighting systems which are designed and constructed to use no more fuel and power than is reasonably practicable in the circumstances and making reasonable provision for controlling such systems.

The latter requirement does not apply to dwellings and some smaller buildings. The five general requirements listed above are supported by *Approved Document L*. This provides detailed guidance on how the building regulations, which apply to new buildings and some conversions can be met. For example, technical information about the thermal performance of different building elements (windows, doors, roof lights etc.) is provided, allowing the calculation of the likely rate of heat loss through the fabric of any building.[1]

The 1994 amending regulations introduced a requirement that newly created dwellings to be provided with an energy rating calculated by the Government's Standard Assessment Procedure (SAP). The procedure takes account of fuel costs, ventilation, fabric heat losses, water heating requirements, internal heat gains (e.g. human body heat, and heat from domestic appliances), and solar gains. The method of calculating this energy rating takes the form of a worksheet, accompanied by a series of tables containing typical data. The latter includes information on the efficiency of different types of heating systems, and estimates of hot water usage as a function of floor area. The SAP rating is expressed on a scale ranging from 1 to 100. A rating of 1 represents a poor standard of energy efficiency while 100 represents a very high standard (reflected in the lowest energy costs).In the context of the Building Regulations, a SAP rating of 60 or below indicates the need for a higher standard of fabric insulation.[1]

2.4 EU Energy Policy: Energy Performance of Buildings Directive

2.4.1 Recommendation

Given that energy efficiency standards in national building codes have been one of the most efficient and cost-effective way of raising energy efficiency in most EU countries, this directive can be very important for future increase in energy efficiency. The effect of it is, however, crucial dependant on the implementation in national legislation. It is important that there is a national debate about the implementation with focus on how to maximise the benefits from the implementation, rather how to have the least changes. In all countries current building codes have relatively low requirements for energy efficiency and renewable energy which leads to higher energy consumption than the cost-effective level. Because most houses are built according to the standards, the users are trapped with these unnecessary high costs. New, stronger building codes can correct this problem, to the benefit of users, the constructors and the environment. Thus, NGOs and relevant stakeholders should push the implementation of the new directive in an ambitious direction, so it will contribute to this.

It is proposed that the limit for renovation of buildings to require current energy efficiency standards is set to renovations that costs above 10% of the value of the building.

2.4.2 Implementation

The directive must be implemented by the end of 2005 with some possibilities for postponing parts of implementation until 2008. Thus, there is little experience with implementation yet. Many European countries have recently updated or are currently updating their energy performance regulations in order to improve energy efficiency of their buildings in line with the requirements of the directive.

The main contents of the Directive are as follows:

- Application and regular updating of minimum standards for energy performance of buildings based on a common methodology for all new buildings and for existing buildings of more than 1000 square meters that are being renovated. The performance will include energy use for heating, ventilation, lighting, as well as the opportunity of heat recovery and local renewable energy supply used in cost-effective ways.

- Common methodology for the preparation of minimum integrated energy performance standards, which Member States will have to adopt for each type of building. This methodology will have to take account of differences in climate and include factors relating to insulation, heating, ventilation, lighting, building orientation, heat recovery, and use of renewable energy sources.
- Certification systems for new and existing buildings: energy performance certificates no more than ten years old, containing advice on how to improve energy performance, will have to be available for all buildings when built, sold or leased. These energy performance certificates, together with information on recommended and actual indoor temperatures, will also be displayed in public buildings and in other types of building frequented by the public.
- Specific checks and assessment of heating and cooling equipment by experts. Member States will have to make arrangements for regular inspection of boilers of a rated output between 20 and 100 kW. Boilers above this threshold must be inspected every two years (gas boilers every four years).

2.4.3 Status

In October 10, 2002 the EU Parliament supported the Commission's proposal with some amendments. Following this, The Commission adopted the final language agreed upon by the Parliament in October. This concluded a year and a half of debate between the Parliament and the Commission. The EU countries have also agreed to the text and adopted it at the energy ministers' meeting November 25. After adoption, the provisions of the directive shall be introduced in national legislation until the end of 2005; though some requirements can be postponed until 2008.

2.5 Fabric Issues

An important aspect of building materials is the building insulation. Insulation consists of materials that minimize the flow of energy through the surfaces of buildings. This includes materials to reduce both conduction and radiation of energy. Without insulation, the energy flow in buildings would be too immense to preserve comfortable conditions via passive means. i.e. ,without the use of mechanical techniques for heating and cooling.

Thermal resistance (R) is a measure of the effectiveness of the insulating material, the larger the "R - value" of a material, the better, Figure 2.2 shows the R - value of most common building materials. For the purpose of calculation of total energy transfer, the reciprocal of the thermal resistance is the "U - value", and is measured in W/^{o}C/m. The smaller the U - value, the larger the thermal resistance.

Thermal Conduction is the process of heat transfer through a material medium in which kinetic energy is transmitted through the material from particle to particle without displacement of the particles. The thermal conductivity of a material depends on its density, the size of the molecules in the material, its electrical conductivity, and its thickness.

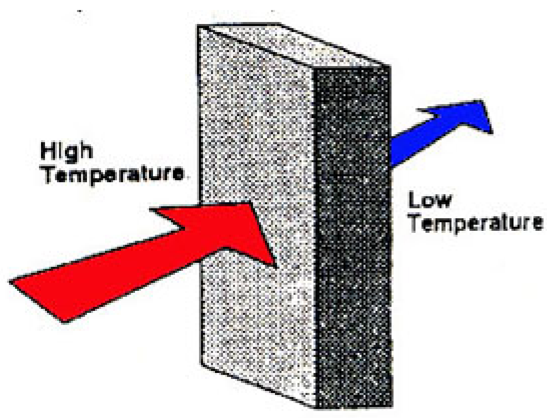


Figure 2.3 *Conduction: is the transfer of energy via a material as faster moving hotter particles collide with slower moving colder particles*

2.5.1 Winter versus Summer R-values

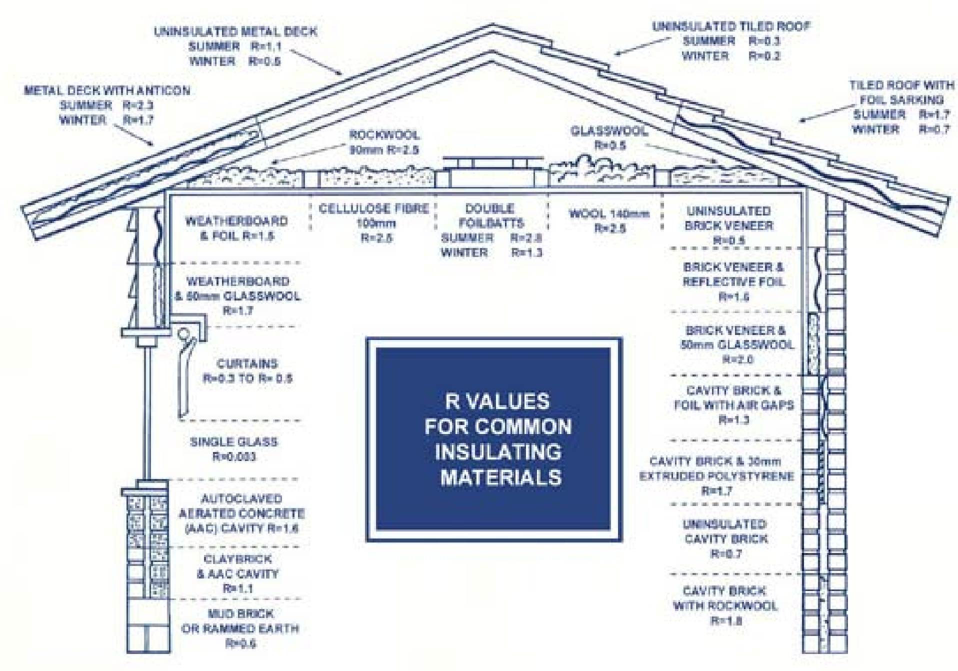


Figure 2.4 *Winter versus summer R values*

(Image from http://www.energy.wa.gov.au)

The difference in R-values are quoted for the same materials in summer and in winter. This is because the total heat transfer depends on whether the energy is flowing into or out of the building. In summer, when it is hotter outside than inside, highly reflective surfaces, such as foil, aluminium paint and light coloured roofing materials will help to reduce the radiant heat gains. In winter, when the inside of the house is warmer, reflecting surfaces on or underneath the roof will do little to prevent energy from being transferred through the ceiling. Any warm air on top of the ceiling is free to escape, and will not provide the same insulating air film thickness as in summer.

Chapter 3: Passive Renewable Technologies

The roles of energy efficiency and energy conservation find the notion that once these issues have been addressed, energy consumption can be further reduced by making use of the available renewable resources that can be applied passively, i.e. by non-mechanical means.

3.1 Building Design

Energy has different grades: the higher the grade, the higher the energy's environmental impact. The key to minimizing the impact of buildings on the environment is to match the right level of energy grade with the needs of the user. Low-grade tasks, such as heating rooms, should be matched with low-grade energy sources like passive solar gain.

Natural daylight, restricting electrical lighting to night- time use, and natural ventilation are just some of the solutions for low-energy building design. Ensuring a building's facade and mechanical systems work together to reduce energy emissions is a key element in achieving the right balance of heat loss and gain.

Low-energy solutions do not mean high costs; they are often cheaper to commission, maintain, and install than other options. A combined approach of conventional design with alternative energy sources not only creates a comfortable environment for building users, but it can make considerable savings as well.

The impact of solar radiation causes changes in the earth’s temperature. As the earth possesses vast heat storing capacity, it takes a long time for it to cool down after sunset, as well as longer time for the temperature to increase after the sun rise. As a result of this phenomenon, higher temperatures are available in the afternoons than mornings although the amount of solar radiation at both times are similar.

Therefore, the design of buildings should be based on a similar concept, in that buildings should be designed to achieve a steady state thermal condition without variations due to changes in the external climate conditions. This procedure involves the integration of thick walls which store heat during the day, preventing the seepage of heat into the interior of the building. During the night, when there is no sunshine, heat stored by the thick walls will be dissipated into the building. In order to achieve thermal comfort by occupants in a building, it is necessary for them to lose amounts of heat which are proportional to the amount generated by physical activities.[23]

3.2 Passive Renewable Energy use in Buildings

Passive solar designs include passive solar heating, cooling, day lighting and natural ventilation.

3.2.1 Passive Solar Energy

The history of making the best use of sunlight through passive techniques dates back to the Romans, where passive techniques were used for spaces such as communal meeting places and the bath house. Such places were designed with large window openings. After the fall of the Roman Empire, the ability to produce large sheets of glass disappeared for at least a millennium. It was not until the end of the seventeenth century that the glass process reappeared in France.

In the eighteenth and nineteenth centuries cities were over crowded and most buildings, including houses were poorly lit. It was not until the late nineteenth century that urban planners investigated the potential of providing better internal conditions. At this time the planners were more concerned about the medical advantages of sunlight after discovering that ultraviolet light kills bacteria. A later realization that ultraviolet light does not penetrate windows, did not change this new-found tradition of allowing access for sunlight into the houses, and this was reinforced by findings that bright light in winter is essential to maintain human hormone balances. Without it people are more likely to develop midwinter depression.[16]

3.2.2 Passive Solar Heating

3.2.2.1 General

In the winter, south facing windows are expected to provide access for the sun's heat while on the other hand insulation against the cold is also necessary. In the summer, in a moderate climate the policy is to admit the sun light and to store the heat. Since most of the day lighting, heating and cooling facilities are on the southern part of the building that is where most of the interior spaces are located.

When designing buildings for passive solar renewable energy, they should incorporate features such as large amounts of windows facing south, to allow maximum solar access. In addition building materials that absorb and gradually release the heat absorbed by the sun should be used in combination with south facing glazing.[2]

An important concept of passive solar design is to match the time when the sun can provide day lighting and heat to a building with those when the building needs heat, this is fairly easy to achieve in domestic buildings, but when it comes to commercial buildings, there are complex demands for heating, cooling, and lighting; therefore their design strategies require computer analysis (e.g. by an energy modeling tool such as ESP-r) by an architect or an engineer.[18]

Design strategy plays an important role, and a building's floor plans should be designed to optimize passive solar heating. For example appropriate glazing in windows and doors, and orientated within 30 degrees of true south.

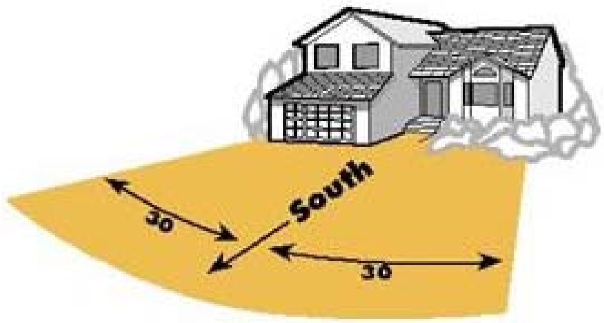


Figure 3.1 *Design strategy: windows and doors should be orientated within 30 degrees of true south*

(Image from http://www.esru.strath.ac.uk)

Because of the solar path, the optimum orientation for direct gain in passive solar buildings is due south. South-facing surfaces do not have to be all along the same wall. For example, clerestory windows can project south sun deep into the back of the building. Both the efficiency of the system and the ability to control shading and summer overheating decline as the surface shifts away from due south.[2]

The basic requirements to optimize the use of passive solar heating in buildings are as follows:

- Buildings should face south with the main orientation of the building within 30^o, buildings located South East will take more advantage of the morning sun, while those located on the South West will benefit more from the late afternoon sun delaying the evening heating period.
- The glazing should be concentrated on the south-side as they are most frequently used and require most heating, so as the living rooms, with little used rooms such as bathrooms on the north
- Responsive zoned heating systems facilitate automatic isolation of areas when and where necessary, thus avoiding the unnecessary heating of unoccupied rooms
- Avoid over shading by other buildings in order to benefit from the mid-winter sun
- Buildings should be thermally massive to avoid overheating in the summer

- The windows should be large enough to provide enough day lighting minimum 15% of a room's floor area (Dept of Environment – Best Practice Programme)
- Buildings should be well insulated to minimize the overall heat loss

3.3 Direct and Indirect Gain Systems

Heating systems are generally classified into two categories, direct and indirect gain systems. Direct gain system utilize collectors to allow light directly into the house, where it is absorbed and converted into heat. Indirect gain systems create intermediate spaces, external to the house, where light is converted to heat, and then the heat is exchanged with the house via intermediate elements. Roof ponds, greenhouses, and trombe walls are all examples of this technique.[18]

However it should be noted that overheating and glare can occur whenever sunlight penetrates directly into a building and this must be addressed through appropriate measures. A "direct-gain" space can overheat in full sunlight and is many times brighter than is required for 'normal' indoor lighting, this can result in glare problems. In late morning and early afternoon, the sun enters through south-facing windows. The low angle allows the sunlight to penetrate deep into the building beyond the normal direct-gain area. If the building and occupied spaces are not designed to control the impact of the sun's penetration, the occupants will experience discomfort from glare. Careful sun-angle analysis and design strategies will ensure that these low sun angles are addressed. For example, light shelves can intercept the sun and diffuse the daylight.[2]

3.3.1 Direct Gain

Direct gain is the simplest approach and usually the most economical to build. Using this technique sunlight enters the building through large areas of south facing glass, it heats the floor and walls directly.

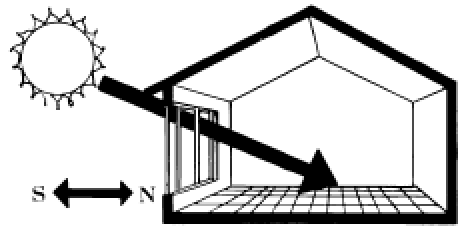


Figure 3.2 *Direct gain solar system*

(Image from www.ncsc.ncsu.edu)

Clerestory windows and skylights are used to increase the amount of sunlight hitting the back area of walls or floors. They can improve the performance of the direct gain system, usually skylights tend to create overheating in the summer and in a climate such as the UK's these may leak if improperly installed or if not well insulated.

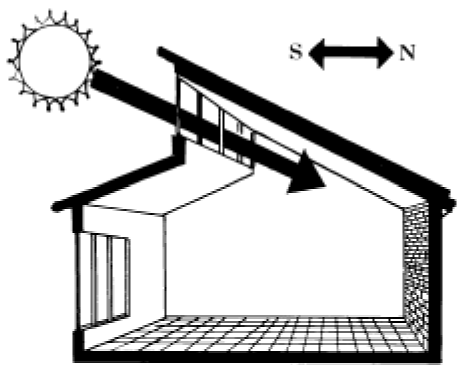


Figure 3.3 *Clerestory windows in a direct gain system let sunlight strike thermal mass on the back wall.*

(Image from www.ncsc.ncsu.edu)

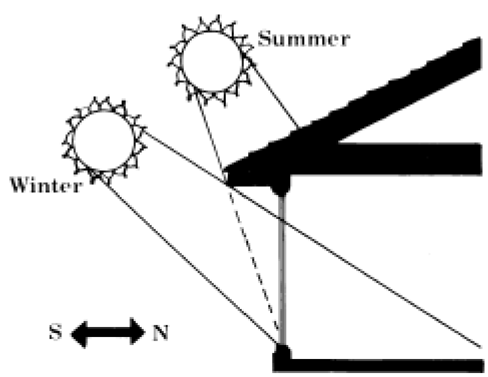


Figure 3.4 *The overhang allows in the winter sun while shading the south facing glass in the summer*

(Image from www.ncsc.ncsu.edu)

In direct gain systems, the amount of south facing glass and thermal storage mass should be balanced for optimum summer, winter and mid season performance. If the windows collect more heat than the floor or walls can absorb, overheating occurs. Therefore shading is required to minimize the heat gain in the summer. There are several choices such as overhangs, awnings, trellises, louvers, solar screens and movable insulation. Nowadays exterior shading is more recommended rather than interior shading because exterior screens and other devices will stop heat before it gets into the building.

In addition, attention to the location and quantity of fabric mass should be made. For example the thermal storage maybe thinner and more widely distributed in the living area than with other passive systems. Covering the thermal storage mass with carpet or other materials will reduce its storage capacity, therefore arranging furnishings is important so as not to interfere with the solar collection, storage and distribution. The table below compares the advantages and disadvantages of various direct gain systems:

Advantages	**Disadvantages**
South facing windows provide natural day lighting and outdoor views	Large amounts of south facing glass can cause problems with glare and privacy
It provides direct heating. There is no need to transfer energy from one area to another	The thermal mass used for heat storage should not be covered by carpet or blocked by furnishings
The number and size of south facing windows can be adjusted to match the space for thermal mass. Clerestory windows can let sunlight fall directly on the back parts of floors or walls used as thermal mass	It can overheat if the windows and thermal mass are not balanced

It is comparatively low in cost to build, since no special room has to be added. The floor, walls, can serve as the storage mass. The solar elements are incorporated into the occupied/living space.	South facing windows need summer shading and a night time isolative covering in winter. Night time insulation can be provided by exterior mounted panels, interior draperies, shutters, pop in panels, or other insulating window treatments
	Furnishings and fabrics exposed to ultraviolet radiation from the sun can degrade or change color.

Table 3.1 *Advantages and Disadvantages of Direct gain Systems*

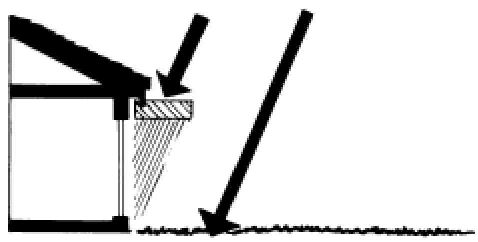


Figure 3.5 *Louvered panels provide shading if the overhang is insufficient*
(Image from www.ncsc.ncsu.edu)

3.3.2 Indirect Gain

In this method the storage mass is located between the south facing glass and the living space. Indirect gain systems use systems such as thermal walls and other types of materials to store collected heat. The common ways of storing mass are a masonry Trombe wall, a water wall of tubes or barrels located several millimeters behind the window.

The brick trombe wall is usually 200-300mm in thickness when compared with direct gain which is usually 100-150mm thick but it is spread out over a larger area. As the sunlight passes via the south facing glass, it is absorbed by the mass of the wall. The wall heats up gradually and releases the heat to the living areas anything from 6 to 8hours later. The time lag between the warming of the mass and releasing of the heat helps to keep temperatures in the living area steady, therefore heating is available in the late afternoon and evening when it is most needed. In a domestic situation this is most useful when the house is unoccupied during the day but occupied at night.

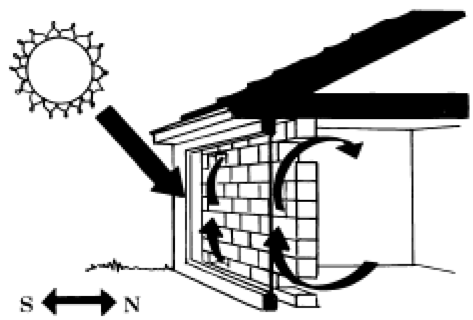


Figure 3.6 *Trombe wall vents circulate heated air to the living area in the day time, meanwhile at night the vents are closed to prevent reverse cycling of heated air.* *(Image from www.ncsc.ncsu.edu)*

The Trombe walls can be vented or un-vented. The vented wall allows heated air to circulate directly to the living area. A vented trombe wall requires night time closing of wall vents, because if not closed the heated air would cycle back to the front of the trombe wall from the living area. Trombe walls have been used less frequently in recent years because of the difficulty in ensuring the proper opening and closing of vents. Research indicates that trombe walls gain more heat during the night. Therefore moveable insulation over the trombe wall will improve its efficiency. The table below lists the advantages and disadvantages of indirect gain systems:

Advantages	Disadvantages
The storage mass is positioned closer to the glass or collection area, which allows for efficient collection of solar energy.	The south facing view and natural daylight is lost. Some trombe walls have been designed with windows set into the wall to compensate.

The floor and wall space of the living area can be used more flexibly since the storage mass is moved next to the south facing glass. This frees the interior space and does not expose furnishings to direct sunlight.	The trombe wall may take up too much wall space in a smaller building.
The thickness and heat storage capacity of the thermal mass heats up gradually and distributes the heat to the living area when it is most required.	Furniture and objects placed against or on the trombe wall affect the efficiency of the trombe wall heating the living area.
	Because the trombe wall heats only the area it is connected to, the cost of labor and materials in its construction may be high relative to the contribution it makes to the overall heating needs of the building.
	Vented trombe walls must be closed at night to prevent reverse cycling of heated air.
	In the summer or on winter days without sunshine, the trombe wall acts as a very poorly insulated wall. Exterior moveable insulation would improve its effect on comfort and energy use.

Table 3.2 *Advantages and Disadvantages of Indirect gain Systems*

The following case studies highlight the use of passive solar energy for heating and daylighting in schools.

3.3.3 Case Studies

3.3.3.a The Wallasey School Case Study

The Wallasey school in Cheshire was constructed in 1961, and the design was stimulated by earlier US and French buildings. The Wallasey school building has the basic features required for passive solar heating and daylighting and it is thus considered as a direct gain design. Some of the features of the school are:

- Thermally heavy weight construction (dense concrete or brickwork). This stores the thermal energy through the day and into the night;
- A large area of south facing glazing to capture the sunlight;
- Thick insulation on the outside of the structure to retain the heat

Figure 3.7 *The Wallasey School in Cheshire, UK*

(Image from Godfrey Boyle, Renewable Energy; Power for a Sustainable Future)

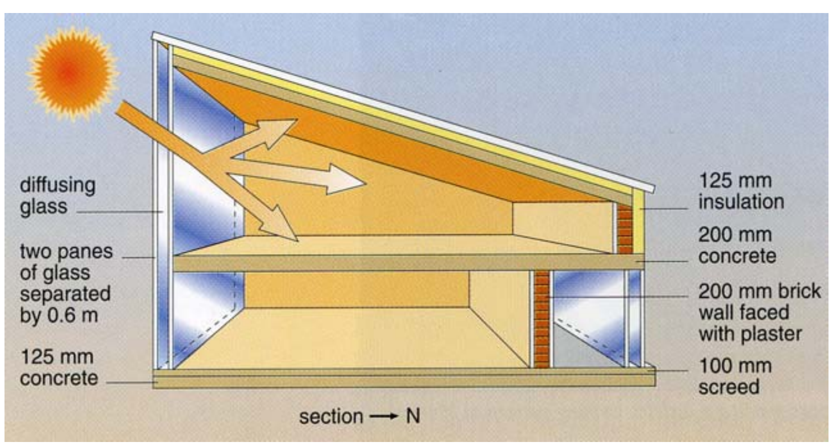


Figure 3.8 *Cross-section of the Wallasey School*

(Image from Godfrey Boyle, Renewable Energy; Power for a Sustainable Future)

After the construction of the school building, it was found that the oil fired heating system was later found to be unnecessary and was removed. Therefore the building was totally heated by a combination of solar energy, light, heat gains from equipment and occupancy of students.[16]

In the majority of schools, energy is supplied in two forms: fossil fuel (gas, oil, coal or LPG) and electricity. In some schools space heating, hot water and some catering appliances are supplied by fossil fuel, although some schools only have access to electricity or use it more extensively. Electricity is used for lighting, electrical equipment and catering. The breakdown for energy consumption is as follows:

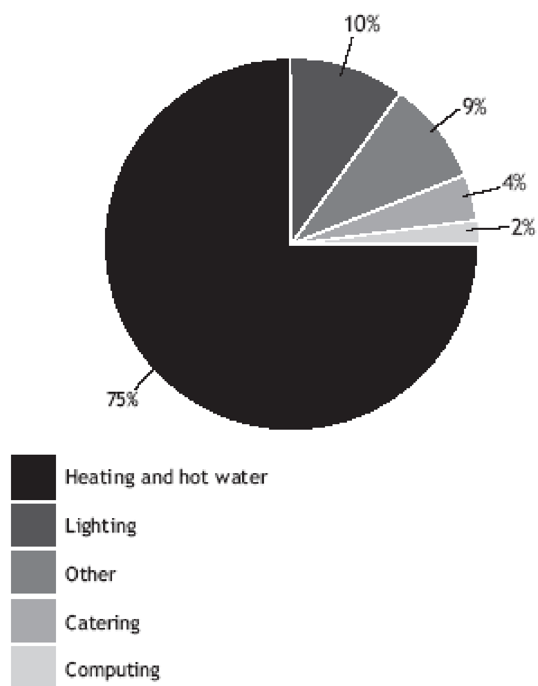


Figure 3.9 *Energy consumption for a typical UK school*

(Image from www.thecarbontrust.co.uk)

Most of the energy consumed in schools is utilized towards heating and hot water. This might result in the school focusing on heating systems. Electricity prices can be as high as 6p/kWh whereas fossil fuel maybe as low as 1p/kWh. Upto 80% of energy consumed in schools is from fossil fuels and this accounts for 40% of the cost. The diagram below shows the cost breakdown for energy use in a typical school. Lighting accounts for almost 50% of electricity costs, with electrical equipment, catering, fans and pumps making up the rest.

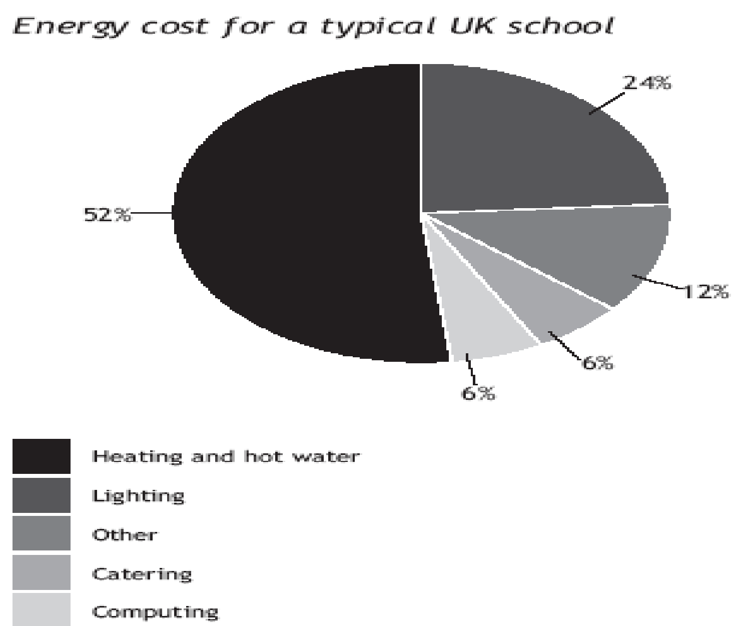


Figure 3.10 *Energy cost for a typical UK school*

Benchmarking allows schools to compare their energy performance with other schools. Most schools are interested in knowing the potential for saving energy and water. Benchmarks are calculated separately for fossil fuel and electricity so that a school can determine performance for each type of energy use. The range of benchmarks available is helpful in determining realistic quantified potential savings. In schools the benchmark is measured in kilowatt/hour (kWh) per m^2 of heated floor space per annum for fossil fuel and electricity. The table below shows the energy benchmarks for a good, typical and poor performing schools.

Energy benchmarks (kWh/m²) for good, typical and poorly performing schools						
Annual Energy (kWh/m²)	Primary School (no pool)		Secondary School (no pool)		Secondary School (with pool)*	
	Fossil Fuel	Electricity	Fossil Fuel	Electricity	Fossil Fuel	Electricity
Good Practice	110	25	117	28	142	29
Typical Practice	157	34	160	36	187	36
Poor Practice	209	47	207	45	233	41

Table 3.3 *Energy benchmarks for a good, typical and poor performing schools*
(Table from Good Practice Guide 057)

The calculation of carbon dioxide CO_2 emissions is possible through the factors available at the table below:

CO_2 emissions by fuel type for the UK		
	kg CO_2/kWh	kg CO_2/litre
Electricity	0.43	
Natural Gas	0.19	
Gas/Diesel Oil	0.25	2.68
Liquid Petroleum Gas (LPG)	0.23	1.65
Renewable Energy	0	0

Table 3.4 *CO_2 emissions by fuel type for UK*
(Table from Good Practice Guide 057)

To calculate a school's carbon dioxide emissions, it is required to multiply the consumption in (kWh) by the CO_2 factor available in table 3.4.

Fuel	Annual kWh		CO_2 factor		Annual kg CO_2
Natural Gas	1,134,000	x	0.19	=	215,460
Electricity	266,000	x	0.43	=	114,380
Total	1,400,000				329,840

Table 3.5 *Calculation of CO_2 emissions*

(Table from Good Practice Guide 057)

3.3.3.b The Pennyland Case Study

The Pennyland estate in Milton Keynes in central England was built in the late 1970s. The design layout is shown in the diagrams below:

Figure 3.11 *Passive solar housing at Pennyland. The view of the south elevation showing the main living rooms having large windows.*

(Image from Godfrey Boyle, Renewable Energy; Power for a Sustainable Future)

Figure 3.12 *The view at the northern side of the buildings has smaller windows.*

(Image from Godfrey Boyle, Renewable Energy; Power for a Sustainable Future)

Figure 3.13 *Plans for the solar housing at Pennyland*

(Image from Godfrey Boyle, Renewable Energy; Power for a Sustainable Future)

An entire estate of these houses was built and they have been monitored since. It is found that the steps (1-5) listed in the diagram below produced houses that consumed almost 50% less gas than that consumed by a normal house built in the previous year, although the extra cost was 2.5% of the overall construction cost but the payback time was four years.

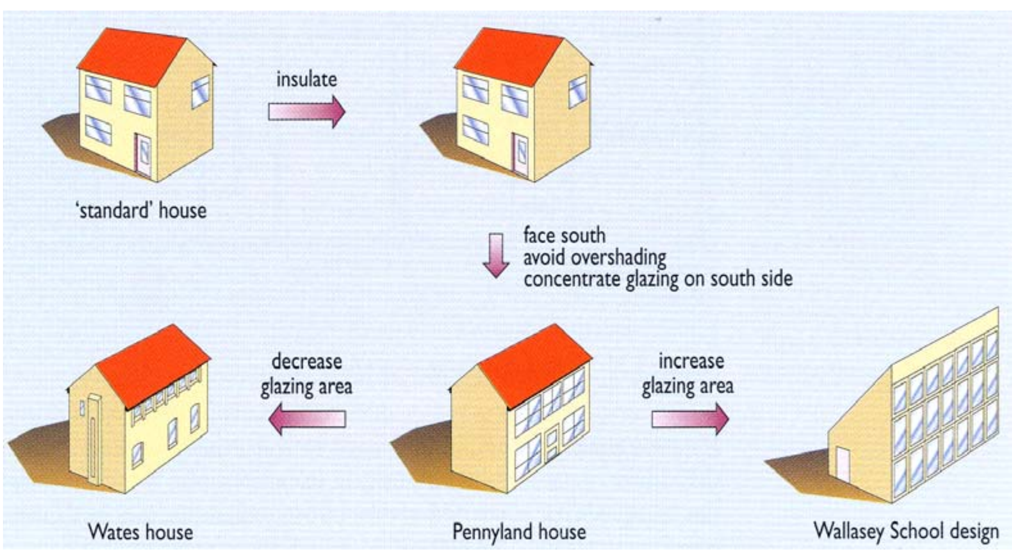


Figure 3.14 *Design steps in low energy housing*

(Image from Godfrey Boyle, Renewable Energy; Power for a Sustainable Future)

When differentiating between the broad and narrow definitions of passive solar heating, it includes all energy saving techniques listed in the steps (1-5). In the narrow sense it covers the parts that are rigidly solar based (3-5).

By applying points (3-5) it helped save more than 500kWh per year on space heating energy. The 500kWh is the difference in energy consumption between a solar and a non-solar house having the same standard of insulation.[16] Meanwhile situated in a low mountain valley, the Wates house is not well located to make use of passive solar heating, but it was intended to be heated and lit by electricity from a wind turbine.

3.4 Passive Solar Cooling

Before the advent of refrigeration technology, people kept cool in buildings by using natural methods e.g.:

- Breezes flowing through windows
- Water evaporating from springs and fountains
- Large amounts of stone and earth to absorb daytime heat.

These ideas were developed over thousands of years as integral parts of building design. Ironically passive cooling is now considered an "alternative" to mechanical cooling that requires complicated refrigeration systems. By employing passive cooling techniques into modern buildings, it is possible to eliminate mechanical cooling or air conditioning or at least to reduce the size and cost of the equipment.[18] Cooling by whatever means is merely the opposite of heating. As such, it involves controlled selected rejection of the incident energy by the collecting apertures. Thermal storage is minimized by heat transfer between storage elements and the ambient heat sinks in the building, such as windows providing ventilation.[2]

Passive cooling techniques can be used to minimize, and in some cases eliminate, mechanical air conditioning requirements in areas where cooling is a dominant problem.

In many cases in modern buildings with high internal gains, thermal comfort in summer means more than simply keeping the indoor air temperature below 24°C, comfort is related mainly to a balance of temperature and humidity.[18]

There are several passive cooling strategies, and they are as follows :

3.4.1 Natural Ventilation

This technique depends mainly on air movement to cool occupants. Window openings on opposite sides of the building enhance cross ventilation driven by breezes. Since natural breezes can not be scheduled, designers often choose to enhance natural ventilation using tall spaces within buildings called stacks or chimneys.

With openings near the top of the stack, warm air can escape, while cooler air enters the building from openings near the ground. Ventilation requires the building to be open during the day to allow air flow.

3.4.2 High Thermal Mass

This technique relies on the ability of materials in the building to absorb heat during the day. Each night the mass releases heat, making it ready to absorb heat again the next day. To be efficient, thermal mass must be exposed to the living spaces. Residential buildings are considered to have average mass when the exposed mass area is equal to the floor area. A slab floor would be an easy way to achieve this in a design. High mass buildings would have up to three square feet of exposed mass for each square foot of floor area. Large masonry fireplaces and interior brick walls are two ways to incorporate high mass.

3.4.3 High Thermal Mass with Night Ventilation

This technique depends on the daily heat storage of thermal mass combined with night ventilation that cools the mass. The building must be closed during the day and opened at night to flush the heat away.

3.4.4 Evaporative Cooling

Evaporative cooling decreases the indoor air temperature by evaporating water. In dry climates, this is commonly done directly in the space. But indirect methods, such as roof ponds, allow evaporative cooling to be used in more temperate climates too.

Ventilation and evaporative cooling are often supplemented with mechanical means, such as fans. They use considerably less energy to maintain comfort compared to refrigeration systems. It is also possible to use these strategies in completely passive systems that require no additional machinery or energy to operate.

The following case study demonstrates both the passive cooling methods and daylighting techniques being adopted at De Montfort University.

3.4.5 Case Studies

3.4.5.1 The Queens Building, De Montfort University Case Study

In 1989 the building stock of De Montfort University's city campus (formerly Leicester Polytechnic) was judged as Inoperable and Unsafe. It was therefore decided to construct a new building for the School of Engineering and Manufacture. The building was named the Queens Building and it provides academic facilities to 1500 students in the School of Engineering and Manufacture.

Figure 3.15 *Side view of the De Montfort University city campus*

(Image from New Practice Case Study 102)

The construction of the building makes visible the structural, acoustic and ventilation techniques employed. The 10,000m^2 structure has three distinctive elements and they are as follows:

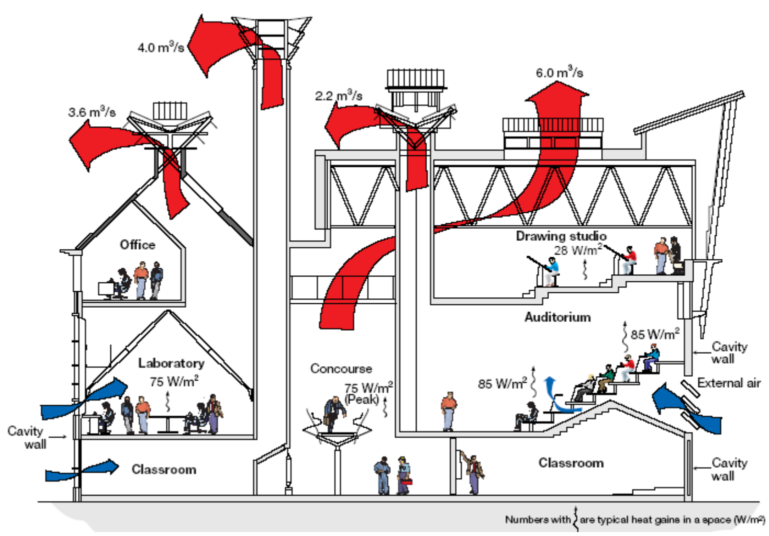


Figure 3.16 *The natural ventilation strategy in the central building*

(Image from New Practice Case Study 102)

3.4.5.1a Central Building

The full height central concourse works as a light-well and a thermal buffer zone for adjoining spaces. The ground floor classrooms and the auditoria are ventilated by distinctive chimneys which act as ventilation stacks, meanwhile laboratories and staff areas on the upper floors are served by rooftop ventilators. Air from the concourse passes via the drawing studios to ridge ventilators, which are glazed and have a northerly orientation to optimize day lighting without solar gain penalties.

Figure 3.17 *The interior of the central building*

(Image from New Practice Case Study 102)

3.4.5.1b Mechanical Laboratories

In order to minimize the noise levels at a nearby terrace of private houses, the naturally ventilated machine hall is flanked on the western façade by a two storey block of specialist laboratories. This as well provides a secondary function for resisting the lateral forces of the traveling gantry crane. These forces are opposed on the east elevation by a series of buttresses. Each buttress is hollow, providing an attenuated fresh air inlet duct, with similarly lined voids over and between ground floor offices supplying air from the west façade. The glazed ridge vents, and the west facing gable windows, which are triple glazed to reduce noise penetration to the outside, ensuring that the machine hall is well day lit.

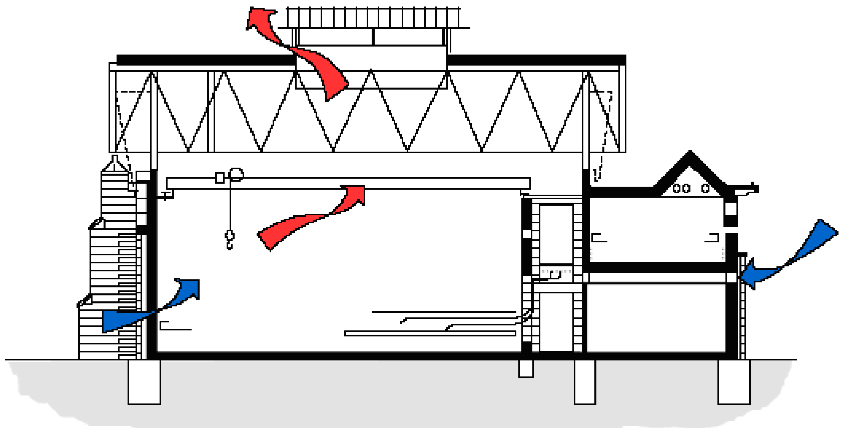


Figure 3.18 *Section through the mechanical laboratories*

(Image from New Practice Case Study 102)

3.4.5.1c Electrical Laboratories

The electrical laboratories are housed in two shallow plan, four storey wings, and so they benefit from cross ventilation and well distributed day lighting. Low-level and high-level opening windows are large enough to provide sufficient ventilation to dissipate the high internal gains from equipment, meanwhile the cantilevered façade minimizes direct solar gain and glare.

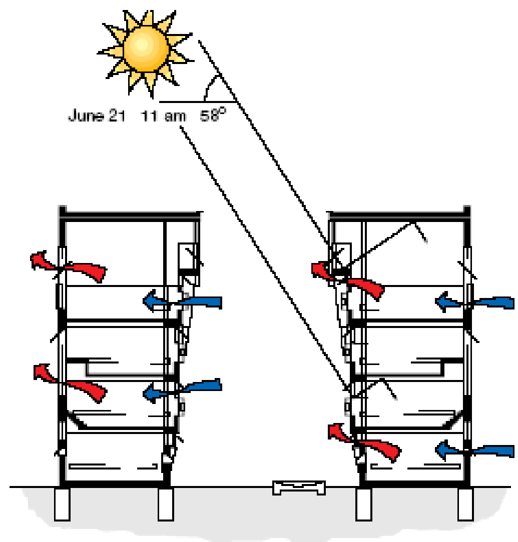


Figure 3.19 *Section through electrical laboratories*

(Image from New Practice Case Study 102)

3.4.5.1d Servicing Strategies

(i) Ventilation

Natural ventilation has been exploited throughout the building. The natural ventilation strategy for the two auditoria is that fresh air enters these areas via plena below the raked wooden floor and directly through the external façade in auditorium 2, and then is exhausted by two 13.3m high chimneys. Meanwhile in the winter the intake air is heated by finned tubes positioned behind the vertical supply grilles. Motorized dampers at the top of the ventilation stacks are adjusted by a building energy management system (BEMS) to maintain room temperatures in the greater part of the building. The auditoria required more sensitive controls with the addition of modulating dampers on the air inlet.

Figure 3.20 *Air enters the auditorium via plena under the raked seating (Image from New Practice Case Study 102)*

The basic requirement when are the auditoria are occupied is for a minimal supply of fresh air, as determined by carbon dioxide (CO_2) sensors, with an increasing air volume to meet the cooling load, provided that the internal temperature exceeds the external temperature. To avoid draughts, the fresh air is heated to a minimum temperature, and stack dampers will close if the temperature in the middle of the stack is sensed to be less than 12^{o}C. Sensors also prevent dampers from opening to more than 50% if there is a risk of entry of wind driven rain.

(ii) Day lighting

Spaces are lit primarily from side windows, which are shaded from direct solar heat gain by deep reveals, overhanging eaves or adjacent parts of the building. A number of small windows is used to provide well distributed daylighting without the penalties of high heat transfer. North lights and roof lights are used extensively to meet the combined needs of stack ventilation and daylighting, while the full height concourse admits daylight into the core of the main building.

3.4.5.2 Building Services

3.4.5.2a Space Heating and Domestic Hot Water

The main heating plant consists of a small $38kW_e$ combined heat and power (CHP) unit, a condensing boiler and two high efficiency boilers, sequenced to fire in that order, provided there is sufficient demand for electricity and heating.

3.4.5.2b Electric Lighting

High efficiency lamps such as compact and T8 linear fluorescents, and high-pressure discharge sources are used to supplement daylighting. During normal working hours, lighting circuit contactors are energized by the BEMS and then controlled locally via manual switches. At other times the BEMS switches off circuits in unoccupied spaces via passive infrared detectors (PIRs).

3.4.5.2c Building Energy Management System (BEMS)

The BEMS controls the heating, lighting and ventilation systems, averaging thermostats in the ten different control zones are ‘set back’ to allow night time cooling in the summer. Numerous additional sensors have been added to the BEMS so as to be used for educational purposes.

3.4.5.2d Energy Use

Energy consumption for the first year of operation based on gross floor area, equated to $114kWh/m^2$ for gas and $43kWh/m^2$ for electricity with a corresponding CO_2 emission of $53kg/m^2$. The avoidance of mechanical ventilation resulted in a significant reduction in use of electricity, although the electric lighting demand could well be lower if the automatic controls were fully operational.

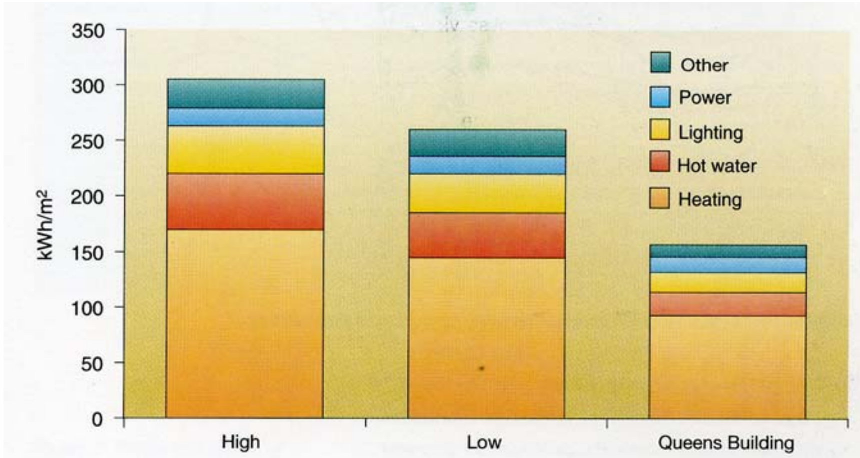


Figure 3.21 *Annual energy consumption compared to DOE's low and high yardsticks (Image from New Practice Case Study 102)*

Although after two years of operation yet there were still outstanding adjustments to be made. The CO_2 detectors are reported not to be functioning properly. Delayed energizing of lighting circuits by the occupancy sensors have resulted in this mode of control being largely overridden. The PIR detectors are thought to be insufficiently sensitive, and feeding their signals back through the BEMS imparts a noticeable delay.

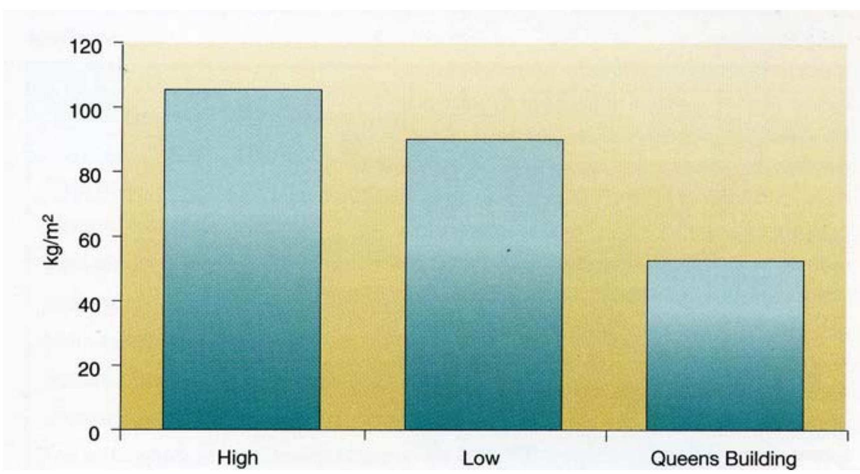


Figure 3.22 *Annual CO_2 emissions compared to DOE's low and high yardsticks (Image from New Practice Case Study 102)*

Meanwhile in the mechanical laboratories, the objective was to replace electric lighting with natural daylighting, but it happens to be unpractical because electric lighting is used whenever heavy machinery is operating on health and safety grounds.

3.4.5.2e Costs

The construction process of the queens building proved to be no more costly (at £855/m²) than a more conventional building. This was a fundamental requirement of the Polytechnic and Colleges Funding Council, because it had to fall within the established cost criteria. The diagram below shows the comparison in costs between a normal engineering building and the queens building.

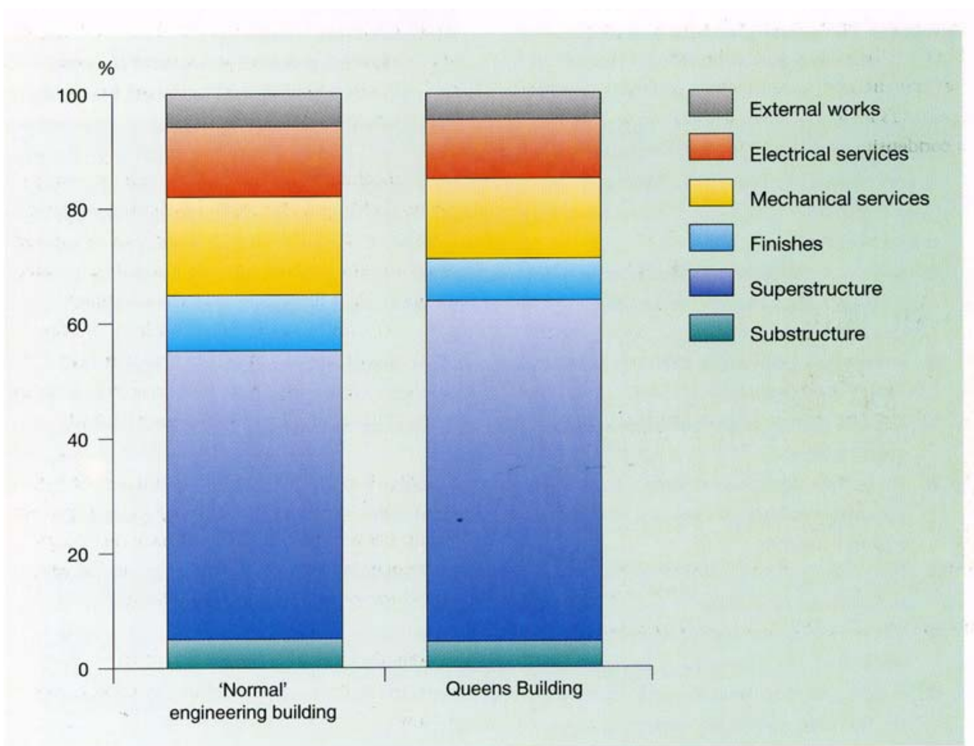


Figure 3.23 *Comparison in costs*

(Image from New Practice Case Study 102)

The passive approach being adopted at the Queens building happens to have provided an acceptable internal environment during its early operation. The problem areas being the result of very conventional openers not being installed. The queens building demonstrates an advance in the 'greening' of both buildings and urban redevelopment.

The building has shown that adopting such a low energy design approach did not conflict with the functional aspects of the facility and has resulted in landmark at no additional costs. The Queens Building is a testimony to what can be achieved in terms of low energy design.

3.5 Day lighting

In most commercial office buildings, lighting can account for up to 30% of the delivered energy use. With the introduction of cheap electricity, in the 19th century natural daylighting was gradually disregarded and most modern office buildings depend primarily on electric lighting.

Figure 3.24 *Mirrors were used to capture daylight in narrow streets in London before World War II*

(Image from Godfrey Boyle, Renewable Energy; Power for a Sustainable Future)

However if properly designed and efficiently integrated with the electric lighting system, daylighting can offer considerable energy savings by offsetting a portion of the electric lighting load up to 25%. A related benefit is the reduction in cooling capacity and use by lowering a significant component of internal gains. In addition to energy savings, day lighting generally improves occupant satisfaction and comfort.[16]

3.5.1 The Stansted Airport Terminal Case Study

Stansted airport is considered one of the most well day lit airports in the world, and also one of the most sustainable designs. Stansted airport is London's third airport, and was completed in 1991 to provide additional air services in the south of England. The construction is mainly comprised of steel, concrete and glass. The main structural elements are painted light grey and the other surfaces are finished in white and the floor is polished grey and white speckled granite.[3]

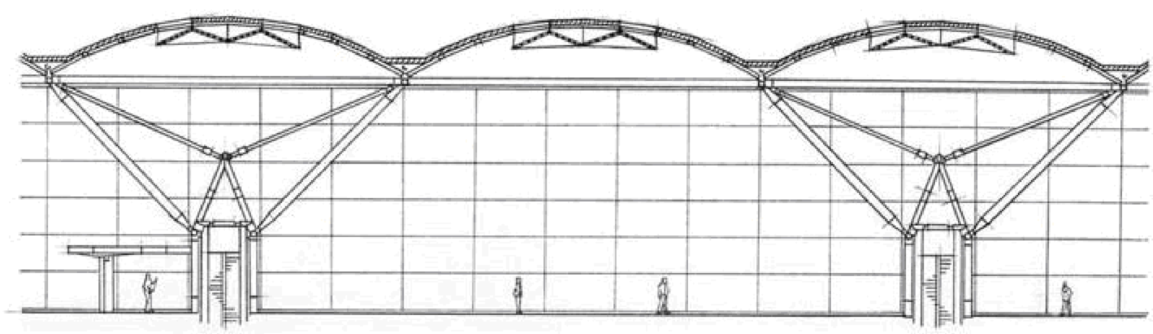


Figure 3.25 *Cross-section through Stansted Airport*

(Image from BRE)

The perimeter of the building, specifically in the entrance and the main public circulation areas, are glazed from the floor level to the underside of the roof structure. In the main entrance area which faces approximately south east, the glass is entirely clear, whereas in the circulation areas there are bands of translucent glass to diffuse direct sunlight, thus reducing direct gain.

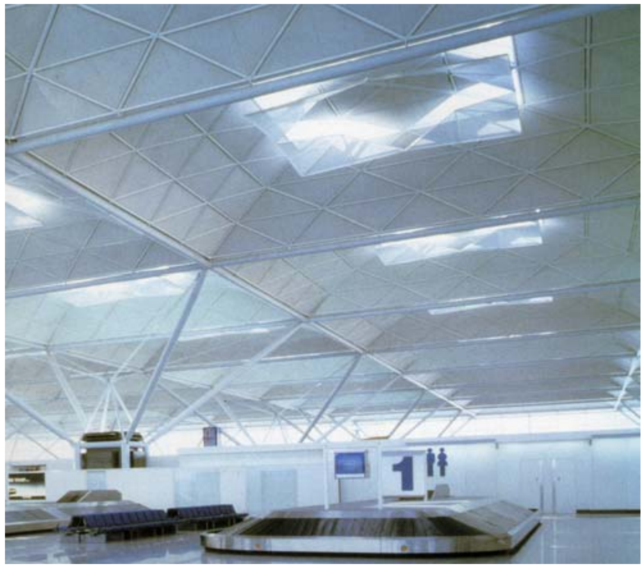


Figure 3.26 *Natural light throughout the terminal*
(Image from BRE)

The roof construction comprises a rectilinear array of shallow, dome-shaped shells with a roof light at the apex of each dome. The triangular roof lights are glazed with clear glass to allow a view of the sky. Below each roof light is a suspended diffuser constructed from perforated metal. This allows sunlight to penetrate the interior and provide diffuse light from the reflecting surfaces.[3]

Figure 3.27 *Roof construction in dome shaped shells allowing a view of the sky*
(Image from BRE)

At the main entry point there is an external canopy formed from the continuation of the roof shells, which provide shade at the passenger drop-off and pick up point. The light pattern and intensity vary according to movement through the building. Natural sunlight is evident throughout the concourse. As well as falling in small patches below each roof light, the daylight reflects to give an overall sense of natural light. Daylight levels are higher at the edges of the building, therefore the resulting effect is one of the visual lightness and on sunny days dappled sunlight provides variety in the light pattern on the floor of the terminal. The dominant impression is of calm efficiency and on bright days this is largely a day lit building for much of the time with no demand for electrical lighting.[3]

Day lighting is a combination of energy conservation and passive solar design. The objective is to make the most benefit from the sunlight. Some other techniques are:

- Roof lights
- Windows with large dimensions allowing sunlight to penetrate inside rooms
- The use of task lighting directly over the workplace, instead of lighting the whole interior of the building
- Shallow plan design, allowing daylight to penetrate rooms and corridors
- Light wells in the centre of the building.[3]

3.5.1.1 The Technology

Daylighting is the efficient use of natural light in order to minimise the need for artificial light in buildings. Daylighting is achieved by control strategies and adapted components which fall mainly into three categories:

- Conduction components - spaces used to guide or distribute light towards the interior of a building
- Pass-through components (e.g. windows) - these allow light to pass from one room or section of a building to another

- Control elements - specially designed to control the way in which light enters through a pass-through component.[4]

The status of these strategies/components are as follows:

- Commercially available: skylights and roof lights; clerestories; automatic controls for blinds and traditional shades; high reflectance paint to improve cavity optics
- In the market: spectrally selective glazing or films; atria
- Development/demonstration: prismatic glazing; tracking light collectors; light pipes and ducts; optical control systems; light shelves and reflectors
- Research: holographic films; chromogenic glasses; electro chromic and directionally transmitting glazing; optical fibres.

The competitive situation in this market is difficult to assess. The major cost element of daylighting design lies in expertise rather than manufactured goods whose real prices are unknown because so many products are still under development.[2]

3.5.1.1a Technical Barriers

The main factors hindering the implementation of daylighting in commercial buildings are:

- lack of information - architects, decision makers and the public tend to be ignorant of the possible benefits of daylighting design; relative efficiencies of different types of scheme are largely un-researched and few studies of the economic aspects are available
- lack of industrial lobbying - there is a strong industrial lobby in favour of artificial lighting from electric utilities and international manufacturers, which has no pro-daylighting equivalent
- lack of legislation to encourage its use - there are few regulations or even codes of practice in place to ensure that daylighting is given due consideration in new design.[2]

3.5.1.1b Market Barriers

Information on products or daylighting design strategies are requested at a very early stage in the designing process. Architects should receive extra training and information packages on these aspects. But as no industrial lobbying exists to promote such passive options, it is dubious it will appear without strong public or State involvement. Information on daylighting is scarce and few economic studies are available.

Ignorance among decision makers, architects and public about benefits and performance of daylighting design leads to reluctance to try the technology which affects the take up rate. Meanwhile there is no particular technical risk is perceived (as there is always a "backup" solution with already installed artificial lighting) but daylighting advantages are not perceived either.[4]

In commercial buildings which are the most interesting market for daylighting, people in charge of investment are rarely those who occupy and manage the building later, they do not benefit from the electricity savings. There is no particular environmental concern that constitutes a barrier to uptake of daylighting design. All passive solar strategies and techniques benefit from positive environmental advantages which should help their future implementation.

3.5.1.1c Financial barriers

The additional costs of passive solar features included in cost calculations vary from zero to 20% and some features such as sunspaces or larger glazed areas are often included as much for their amenity value as for the potential energy savings, so their full costs should not really be included in the calculations.

No particular financial barrier for daylighting solutions exists within private commercial buildings. For State owned buildings, accounting rules do not allow for paying off extra investment costs on subsequent savings.[4]

3.5.1.1d Price distortions

Commercial buildings can benefit from very low electricity tariffs in summer and mid-season periods which do not induce reducing lighting (neither cooling loads).

3.5.1.1e Regulations

Most existing codes and standards do not take lighting and even less daylighting into account. It is only health codes in working places (labour regulation) that indicate the need for quality lighting, suggesting some daylighting options. Enforcement of these texts is not fashionable even though regulation is one of the most effective policy instruments for energy conservation.

3.5.1.1f Other non technical issues

Development of passive solar products: although all the savings outlined above may be made using existing technology, there is considerable potential for even greater savings as new generation products are developed and made widely available like transparent insulation or smart glazing.[3]

Poor lighting can be a major - but often unrecognised - cause of worker dissatisfaction and inefficiency. It can cause workers to make more mistakes or be less productive. Their health can even be affected. It is often forgotten that employees are the major asset and expense of a company: the annual lighting costs per person in an average office can be equivalent to only three to four hours salary. Thus if staff are de-motivated or visually impaired through inadequate working conditions, their productivity will deteriorate.

3.6 Summary

This chapter overviewed passive renewable technologies with case studies provided to highlight the advantages of each technology. In the Wallasey School case study passive solar heating and daylighting strategy is being adopted. It is clear from the design of the building which was inspired by US and French buildings. The school gains its heat through a combination of internal gains ranging from students and equipments to solar energy and daylighting.

Meanwhile the Pennyland case study indicates the importance of insulation and in the design stage to locate large windows facing south in an attempt to gain more sunlight. In this chapter natural ventilation strategies are also being discussed and the Queens Building case study shows the effectiveness of natural ventilation throughout the building. Although the building was declared inoperable and unsafe in 1989. Hence a new building was constructed and named the Queens Building.

The building was ventilated by distinctive chimneys which act as ventilation stacks. Meanwhile in the winter the intake air is heated by finned tubes located behind the vertical supply grilles. On the other hand when it comes to natural daylighting, the Stansted airport terminal proves as a good example of sustainable building design as the dome shaped shells are distinctive in shape and are designed in such a way to gain and utilise the most of sun lighting.

Chapter 4: Integrated 'Active' Renewables & Novel Systems

As discussed in chapter one new buildings offer more options for energy efficiency and new renewable systems being built or installed during the construction stage of the building itself. These systems may involve building materials integrated in the construction or technologies such as local small scale generation such as PV, solar water heating, ducted wind turbines (DWT) and CHP.

4.1 Small Scale Integrated Renewable Technologies

The types of small scale integrated renewable technology appropriate for integration in commercial buildings are discussed in the following sections:

4.1.1 Solar Photovoltaics

Photovoltaic (PV) cells are made of semiconductor materials such as silicon, which is the most commonly used material. When light strikes the material (solar cell), a certain portion of it is absorbed within the cell material. The energy of the absorbed light (photons) is transferred to the semiconductor. This energy knocks electrons loose, allowing them to flow freely. This flow of electrons creates an electrical current, and by placing metal contacts on the top and bottom of the PV cell, this current can be drawn off to use externally to charge a battery, power a device or a, building.

Photovoltaic cells can be utilized individually for small applications, however more power is needed a number of cells are put together to form a module, and modules can also be grouped together to form arrays. In theory arrays can range from a small number of modules to power a building to thousands of modules to power a town.

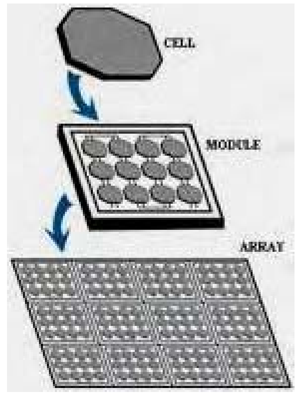


Figure 4.1 *Cells combined to form modules and then onto arrays*

PV is a flexible building material. It can be used for roofs, curtain walls, decorative screens can be embedded in glazing, and can also directly replace other conventional materials in the building fabric. These products can serve the same structural and weather protection purposes as their traditional alternatives, as well as offering the benefit of power generation. PV generates approximately 100 kWh/m^2 depending on the type of PV and system efficiency.

There are several different types of PV panel:

- Monocrystalline PV – this is a single crystal structure and is the simplest type of PV;

- Polycrystalline PV – this uses multiple crystals which makes it simpler and more energy efficient to manufacture;
- Thick-film PV – a film-based PV which is efficient in poor light conditions;
- Thin-film PV – also a film-based PV but very thin, allowing it to be used in complex applications such as curved roofs. It can also resist damage from vandalism.

The UK has lagged significantly behind many other European countries in stimulating PV development. In 2002 the UK Department of Trade and Industry launched a Major Photovoltaics Demonstration Programme, which should result in 3000 domestic roofs and 140 larger non-residential buildings having PV systems installed by 2006. This is an addition to an earlier programme of domestic and Large Scale Field Trials of PV systems, which should result in a minimum of 500 installations on domestic roofs and 18 on large public buildings.[13]

PV arrays can be integrated into the roofs and walls of commercial, institutional and industrial buildings, replacing some the usual wall cladding or roofing materials and minimising the costs of PV systems. Commercial and industrial buildings are normally occupied during daylight hours which correlates with the availability of solar radiation. Therefore the power generated via the PV systems can theoretically minimise the need to purchase power from the grid at the standard commercial tariffs. In other words it is economically feasible to use as much onsite PV power as possible, net metering schemes are adopted by a minority of UK utilities, where the buying and selling prices of electricity are the same, and the consumer pays for the net number of units used. Although net metering is unusual in the UK, it is widely used in other countries such as Germany, Netherlands and Japan.[16]

Figure 4.2 *Britain's first building with PV cladding, a 40kWp system installed in 1995 on the façade of a refurbished computer centre at the University of Northumbria, Newcastle*

(Image from www.nrel.gov)

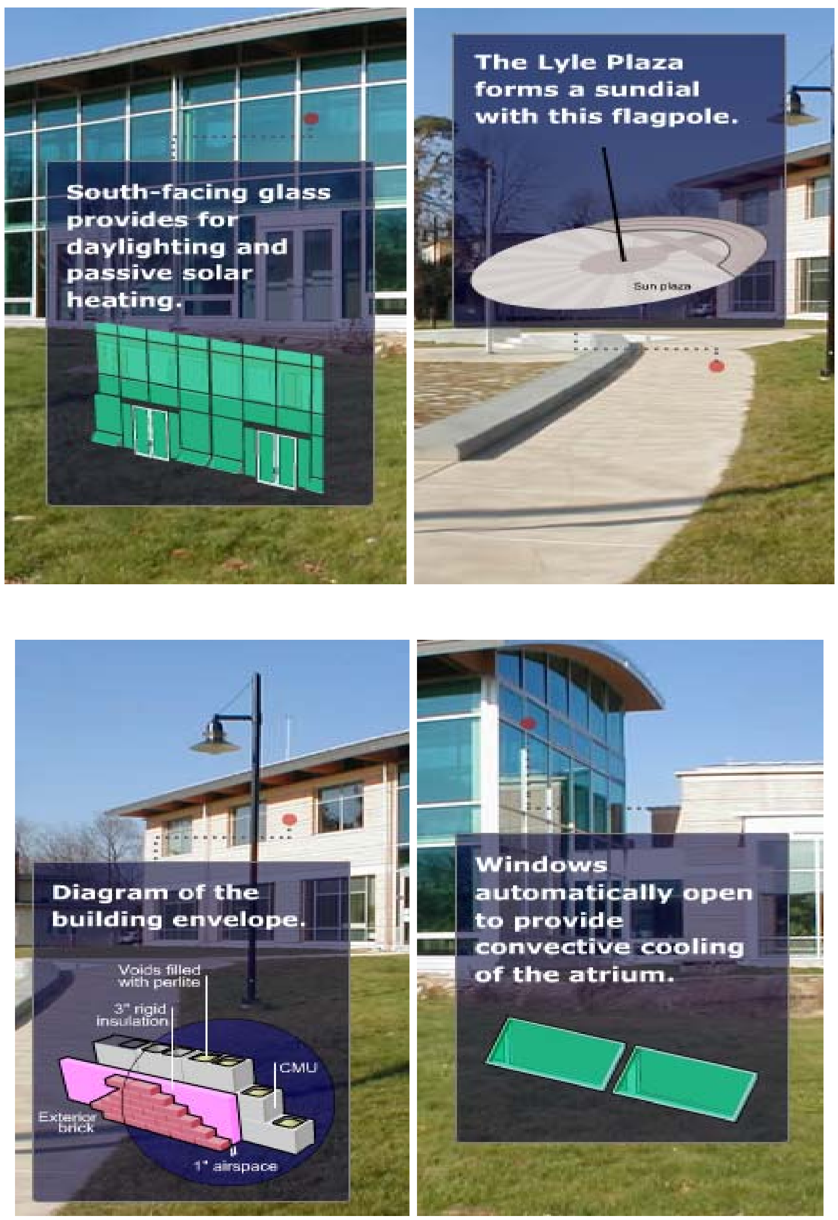
4.1.1.1 The Oberlin College Case Study

The Oberlin college uses a whole-building approach to reduce electrical demand and save money on a roof-integrated photovoltaic system when it built its centre for Environmental Studies. When considering purchasing a photovoltaic system for a commercial building, it is critical to consider the whole building design as it is only cost effective to consider systems such as PV if the overall building design is energy efficient. In other words the PV system is designed to meet the minimum residual load. Whole-building design takes into consideration the building structure and systems as a whole and examines how these systems work best together to save energy and reduce environmental impact.[27]

Figure 4.3 *Side view of Oberlin college building*

(Image from www.nrel.gov/oberlin)

For new construction, as outlined in the previous chapter, energy efficiency and passive solar features incorporated into the building design can have a significant impact on a building's energy consumption. For example, a building that uses natural light will not only reduce electrical consumption for lighting, but will also minimize the amount of heat given off by lighting fixtures, thus, reducing the need for air conditioning.[27]



Even where the need is not eliminated altogether a smaller air-conditioning system will need less electrical power to operate, and therefore, less PV panels will be required for the supply of electricity for cooling the building, thus allowing building owners to get better value from their PV panels. Other technologies that can reduce electrical demand are solar thermal technologies for space and water heating.[27]

On a broader scale, this approach to whole building design could help minimize the amount of energy consumed in the UK by commercial buildings. By creating buildings that consume less energy and have lower power demands, greater robustness of the buildings as well as the power grid is achieved. Other benefits of a whole-building design approach include the potential to:

- Reduce energy use by up to 50%
- Reduce maintenance and capital costs
- Reduce environmental impact

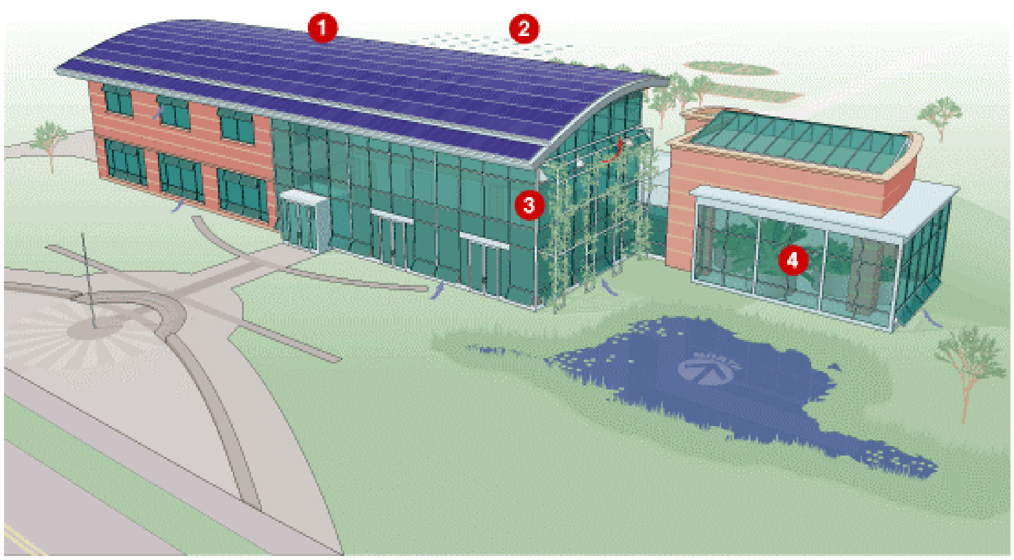


Figure 4.4 *Illustration Key: 1. PV panels 2. Geothermal well field 3. Passive solar design 4. Living machine*

(Image from www.nrel.gov/oberlin)

(i) Building Systems

With over 150 environmental sensors installed throughout the building and landscape, the Oberlin building data monitoring and display system provides a unique opportunity to visualize in real-time the flows of energy and cycling of matter that are required to support the built environment.[27]

(ii) Energy

From local to global scales, most of the environmental problems are linked to the reliance on fossil fuels for energy. Photovoltaic (PV) panels on the roof of the building use renewable energy from the sun to meet a substantial fraction of the building's energy needs. Solar energy production is coupled with energy efficient lighting, heating, and appliances to minimize negative environmental impact. The Oberlin college building has a 60 kilowatt (60-kW) grid-connected PV system to produce a substantial fraction of its energy needs from a renewable source.[27]

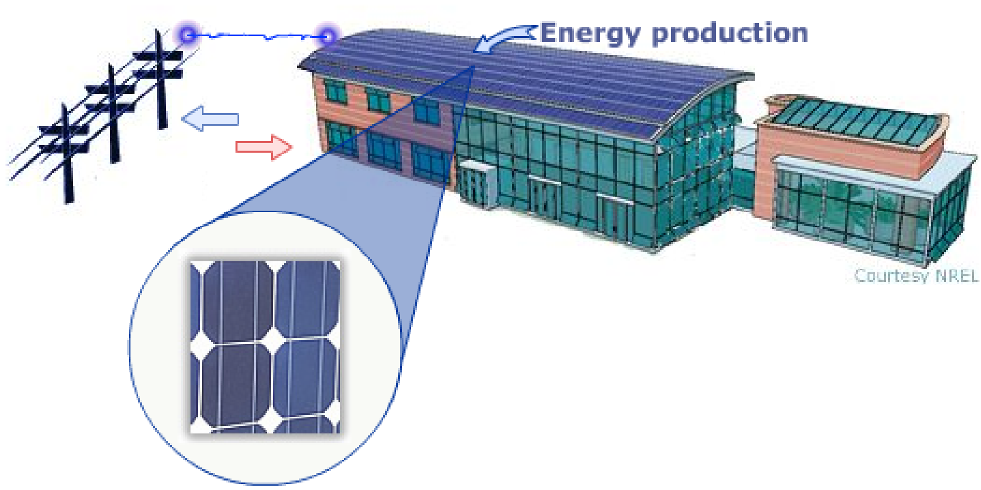


Figure 4.5 *The Oberlin college grid-connected PV system*

(Image from www.nrel.gov/oberlin)

The PV system begins with 690 roof-mounted modules, which use semiconductors to convert solar energy into direct current (DC) electricity. Within the building inverters are then used to convert DC power into the form of alternating current (AC). Compatible with standard building devices, the energy enters the Main Distribution Panel. The panel distributes energy to various parts of the building. Unlike a breaker box, however, which typically divides circuits by areas ("kitchen," "living room," etc.), the panel separates electrical energy flow by end-use (e.g., "lights," "fans," etc.). Extensive energy monitoring equipment takes advantage of the panel's divisions to inform research and to enable optimization of the building energy performance. Finally, when photovoltaic production exceeds the electrical consumption within the building, excess electricity reverses direction through the utility's billing meter and is sold back to the power company.[27]

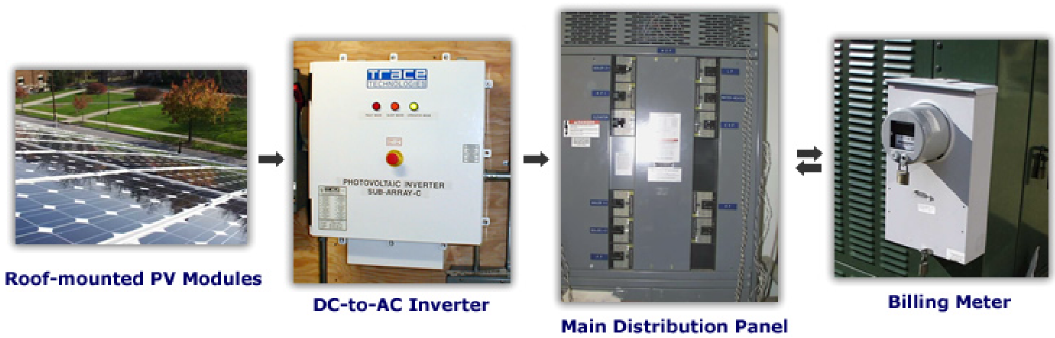


Figure 4.6 *Stages of energy conversion*

(Image from www.nrel.gov/oberlin)

<u>(iii) Indoor Air Quality</u>

Occupied buildings require continuous fresh air to flush out carbon dioxide from respiration and remove toxins off-gassed from materials such as paints, adhesives, carpets, and markers. Ironically, air quality can be problematic in well-insulated and tightly sealed "green" buildings because such practices minimize passive air-exchange ("infiltration"). Using non-toxic materials keeps the air in the Oberlin building relatively toxin free.

(iv) Heat Recovery

Air is actively drawn into the Centre from both the east and west sides of the building by Energy Recovery Ventilators (ERV). Before being sent to spaces inside the building, incoming air comes into contact with outgoing air. The ERV exchanges heat between outgoing and incoming air.[27]

Within the ERV, wheel heats up in warmer air and transfers this heat energy to the cooler air stream. During cooler months, excess heat from outgoing air is transferred to incoming air, thus decreasing the energy needed to heat that air by heat pumps for individual spaces. Similarly, during warmer months, outgoing air is used to cool incoming air before it is sent to condition indoor spaces.

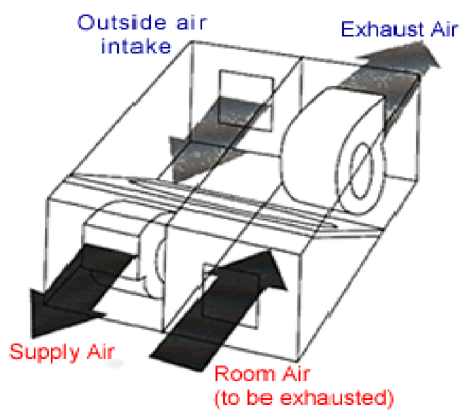


Figure 4.7 *Energy recovery ventilator*

(Image from www.oberlin.edu)

(v) Insulation and Windows

One of the important factors to an energy efficient building is a tight building envelope (exterior surface). This means that the roof, walls, windows and floors are well-insulated to reduce heat conduction and carefully sealed to prevent unwanted air leaks by convection.[27] A tight and well-insulated building requires less energy and smaller mechanical systems in order to achieve comfortable interior conditions. The Oberlin building windows feature are:

- Triple panes for reduced heat loss
- Argon gas interior, as it increases insulation value
- Low emissive coating that reflect unwanted heat
- R-Value of 7
- The R-Value of the standard single or double glazed windows ranges from 1 – 2.5

The table below shows the comparison in R-Values between the Oberlin building and other conventional buildings.[27]

Material	Oberlin Building	Conventional Building
Walls	21	16
Roof	35	19
Whole Building	13	10

Table 4.1 *Comparison in R-Values between Oberlin building and other Conventional buildings*

4.2 Benefits of PV Systems

Photovoltaics have a number of benefits and they are as follows:

- Safe operation
- Simple to operate
- Minimum maintenance and no moving parts
- No emissions and pollution
- Ability to integrate into existing and new buildings
- High dependability, durability and long life (approximately 30+ years)
- Silent operation and no environmental impacts

4.3 Local Energy Generation

4.3.1 Solar Water Heating

There are two main types and both are generally mounted on the south or southwest-facing areas of a building's roof. In some systems, the sun directly heats water that flows through tubes in a flat plat called a solar collector. These tubes circulate the heated water out of the solar collector and down into a holding tank until it is needed. In other systems, an antifreeze solution runs through the tubes instead of water. In colder climates, this type of solution will keep the tubes from freezing. As with the water-based system, the sun heats the liquid and it flows through the tubes down to the holding tank. The heat from the liquid in the tubes is transferred into the water tank and warms the water. In both systems, the liquid in the tubes is then re-circulated back up through the solar collector, where the process begins again.[9]

Solar water heating is a system used for heating water from the sun. There are many uses for hot water in residential and commercial buildings. Below are the two most common: hot water for swimming pools and hot water for indoor use. with a payback of less than two years Solar water heating systems for heating swimming pools are among the most cost effective. These systems are usually mounted on the roof of the building, consisting of plastic tubes usually no more than a quarter inch in diameter, and are coloured black to absorb heat from the sun. The existing pool pump circulates water from the pool, through the solar collector, and then back into the pool.

Medium temperature hot water is used for daily, indoor uses such as bathing, cleaning, and sometimes heating of buildings. There are a variety of solar water heaters that can be used to preheat water for use in buildings:[9]

Passive Systems: these systems rely on water pressure in the main water line or the natural tendency for hot water to rise (thermo siphoning). These systems are among the least costly and have no moving parts that may wear out over time. The simplest system, known as a batch or "breadbox" water heater. Passive systems consist of a collector, usually a glazed box with a metal tank or piping inside which is painted black, and a storage tank which can be an existing water heater.

Active Systems: these type of systems rely on pumps which circulate water or other liquid through a solar collector. The hot water from the solar collector is usually stored in a typical water heater, which functions as a backup system for when the sun is not shining. Although these systems tend to be more expensive, they have higher efficiencies that usually offset the higher first cost.

Residential and commercial building applications that require temperatures below 93°C typically use flat-plate or transpired air collectors, meanwhile those requiring temperatures greater than 93°C use evacuated-tube or concentrating collectors.[9]

Figure 4.8 *Components of an active system in a solar water heater*

4.3.2 Ducted Wind Turbines

The DWT was developed in 1979 by an engineer from Glasgow, the novel objective was for modular application. It was afterwards investigated by the mechanical engineering department at the University of Strathclyde for the integration into the building design. One of the main differences between the DWT and a standard wind turbine is the effect of the aerofoil on the wind turbine. DWT shows the outcome on the flow characteristics around the edge of a building and through the DWT. It can be seen that the pressure on the edge of the building is positive and through the DWT the pressure is negative. The higher the pressure difference the higher the velocity through the turbine blades and thus more power is produced.[11]

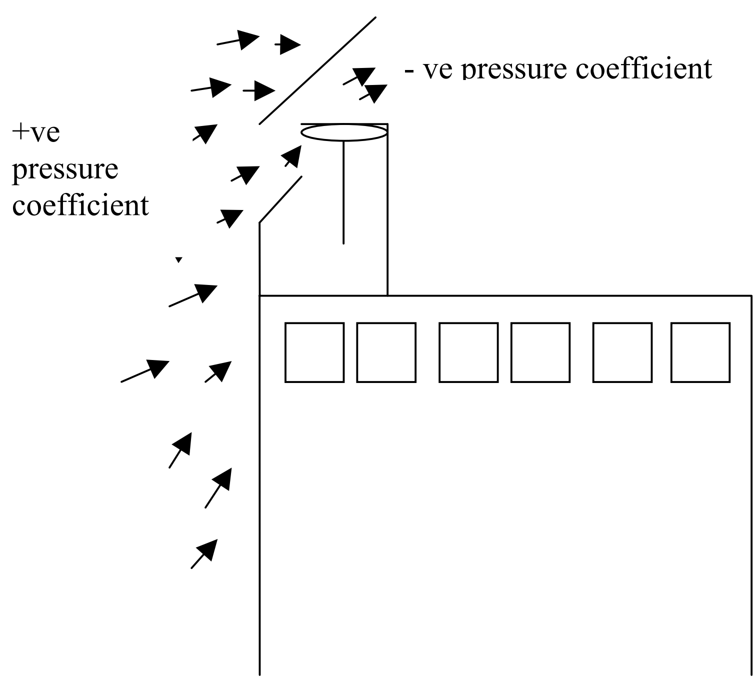


Figure 4.9 *Air flow characteristics around the edge of a building*

(Image from http://www.esru.strath.ac.uk)

Ducted wind turbines are still at an experimental stage but they demonstrate the potential for low power applications. It has undertaken wind tunnel testing and built as a larger prototype for field testing. Results illustrate that the device is best sited at locations with a directional wind regime and can be integrated with larger structures, the ducted wind turbine when tested both in the wind tunnel and out in the field had demonstrated the ability to produce substantial amounts of power, it is also quiet and robust. The construction of the ducted wind turbine other than being robust and contributed towards a quite operation, had a cleverly hidden turbine within the structure to minimize the visual impact if these units were mounted on building rooftops.[11]

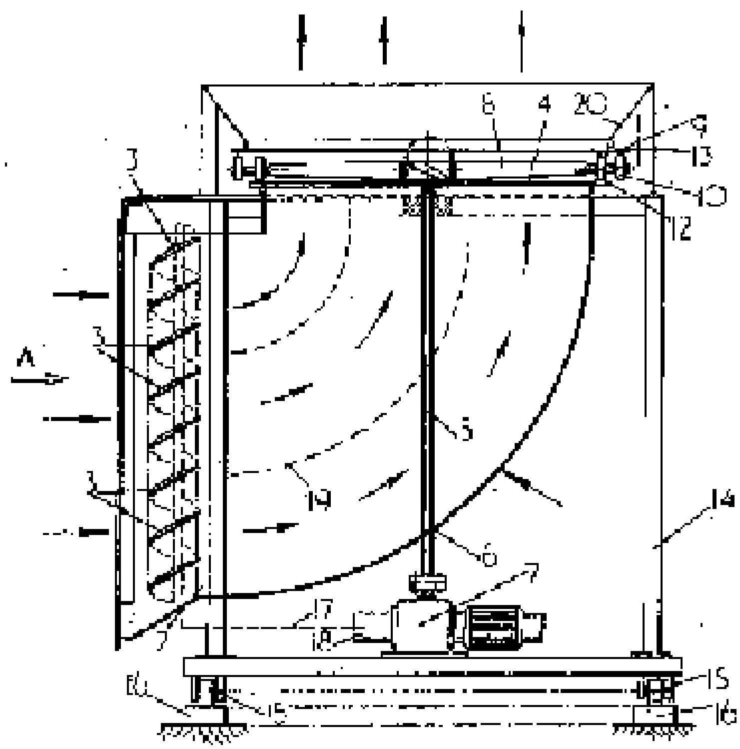


Figure 4.10 *Cross-section through a DWT*

(Image from http://www.esru.strath.ac.uk)

This device is made of easily available/recyclable material e.g. sheet metal/ducting and the location of the generator beneath the ducting does not obstruct air flow as it would for the conventional wind turbines. The case study below demonstrates the use of DWT in buildings.[17]

4.3.2.1 The Lighthouse Case Study

The Lighthouse, was opened by HM Queen Elizabeth in July 1999 and is Scotland's first, dedicated, national centre for architecture and design. The Lighthouse is the renamed, £13 million conversion of Charles Rennie Mackintosh's 1895 Glasgow Herald newspaper office. The Lighthouse vision is to develop the links between design, architecture, and the creative industries, bearing in mind these as interconnected social, educational, economic and cultural issues of concern.

The Lighthouse is operated as a charitable trust, its income is coming from a combination of public and private funds. Out of an annual turnover of £2.5 million, over £2 million is earned income derived from a range of sources, including substantial government grants to promote its Architecture Policy for Scotland and key policy priorities in the economy, lifelong learning, social inclusion and neighbourhood renewal.

The building comprises 1,400 square metres of exhibition space. It shows annually 15-20 exhibitions, many of which are of international stature. The Lighthouse also contains a Charles Rennie Mackintosh interpretation centre and a dedicated education floor extending to 1000 square metres, including workshop, computer laboratory, gallery space and an innovative project called the Urban Learning Space. The Lighthouse also plays a leading role in several key networks including the European Forum on Architecture, The Bureau of European Design Associations and the European Design Forum. It is the lead body on design in Scotland.

The University of Strathclyde in Glasgow was involved in a project to rejuvenate the Lighthouse building in Glasgow. The Energy Systems Research Unit (ESRU) was involved to demonstrate how renewable technology could be utilised. One technology that they decided to utilize was the Ducted Wind Turbine.

It was recognized that renewables could make only a small contribution to the building and so efforts were focused on one small space – the views gallery. A series of energy efficiency and passive technologies were just applied to drive down energy needs and the renewables were deployed to meet the small residual loads.

In this case the DWT is located at the edge of the roof of the building and uses the updraft of the airflow along a building side. The air flows upwards entering the front of the duct, The arrows in the diagram below show the flow through the turbine. The spoiler at the top of the turbine also utilizes a PV module to increase both efficiency and generation opportunities from renewable energy. The DWT is relatively small with a blade diameter of 600mm so they acquire very little visual impact on a building.

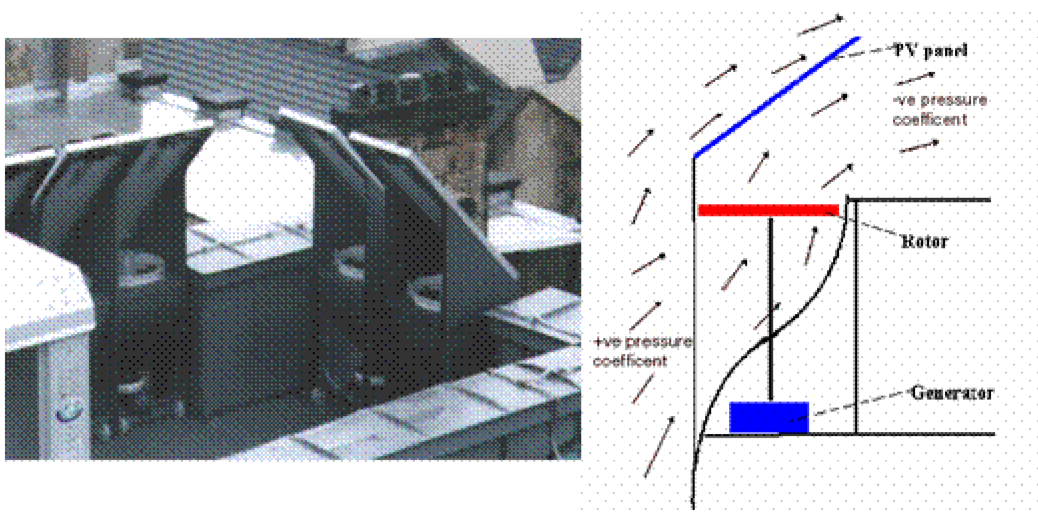


Figure 4.11 *DWT mounted at the roof of the lighthouse*

(Image from http://www.esru.strath.ac.uk)

The DWT is more suited for commercial buildings, office buildings and high rise buildings rather than households because it can easily be incorporated into the design of larger buildings. A ducted wind turbine would produce 530kWh electricity per year. An average installation would consist of 10-ducted turbines, this would capitulate an annual energy production of 5308.56kWh. The installation of a PV on the spoiler would again increase the power output and if the same module from the Urban PV section is used the expected power for a bank of 10 ducted turbines would increase by 722.93kWh to 6031.49kWh per annum, assuming that each ducted turbine has one PV module installed on its spoiler, which covers an area of 0.61596m^2.[11]

Figure 4.12 *A DWT*

(Image from http://www.thecarbontrust.co.uk)

The introduction of ducted wind turbines could result in an annual reduction of carbon dioxide emissions, every kWh of electricity produced from fossil fuels results in 0.97 kg of CO_2.

4.3.3 Combined Heat and Power (CHP)

Combined Heat and Power (CHP) is the onsite generation of electricity and the utilisation of heat which is a by-product of the generation process. The capacity of CHP in buildings has doubled in recent years and now there are over 1,000 installations providing an electrical output of around 400MW. Small scale CHP is now used as the primary source of power and heating in many buildings such as residential buildings, commercial buildings, universities and defence establishments.

Meanwhile under the Kyoto protocol, the UK government is committed to reducing greenhouse gas emissions to 12.5% below 1990 levels by the year 2010, and has set a more stringent internal target to reduce CO_2 emissions by 20% by 2010. The government has therefore set a target to encourage the installation of 10,000MW_e of good quality CHP by 2010 which could produce around 20% of the Kyoto carbon savings target.

CHP installations can convert up to 90% of the energy in the fuel into electrical power and useful heat. This compares very favourably with conventional power generation which has a delivered energy efficiency of approximately 30-45%. CHP installations can run on natural gas, bio-gas or diesel (gas oil). Reliability of CHP is generally good with availability factors of over 90% being common. The range of CHP available for buildings are as follows:

- Micro CHP (up to 5kW_e)
- Small scale (below 2MW_e)
    - Spark ignition engines
    - Micro turbines (30-100kW_e)
    - Small scale gas turbines (typically 500kW_e)
- Large scale (above 2MW_e)
    - Large reciprocating engines
    - Large gas turbines

(a) Micro CHP

There are a small number of micro CHP serving small groups of dwellings and small commercial applications, providing approximately around 5kW_e output and 10-15kW heat. Smaller units of around 1kW_e based on Stirling engines are planned for the market.

(b) Small Scale CHP

This type of CHP is most commonly retrofitted to existing building installations although CHP can be more advantageous in new buildings. Small scale CHP has an electrical output of up to $2MW_e$, and usually available as packaged plant.

(c) Large Scale CHP

Large scale CHP is generally above $2MW_e$ in output. large multi-building installations (e.g. hospitals, universities, etc.) and community heating use either gas turbines or large reciprocating engines, fuelled by either gas or oil. Gas turbines are favored when high grade heat is required for steam raising. Large gas turbines are more complex to maintain, have lower electrical efficiencies and have a poorer efficiency at part load than engine based CHP. Community heating with CHP is a particularly efficient means of supplying large portfolios of domestic and commercial properties.

The following case study discusses how CHP has been used in a large educational facility.

4.3.3.1 The University of Liverpool Case Study

With small scale CHP (<1MW) units have had a successful track record in Europe in a wide range of building applications. Sites with large hot water demand, such as universities, hospitals, hotels, etc. happen to be the most attractive potential markets. In 1986 before the installation of a CHP system at Liverpool University, the university used to purchase all its electricity. The annual electricity consumption was 24,000MWh with a year round average demand of 2.74MW. Meanwhile the instantaneous demand ranged from 2MW to 7MW depending on the seasonal and daily load variations.[25]

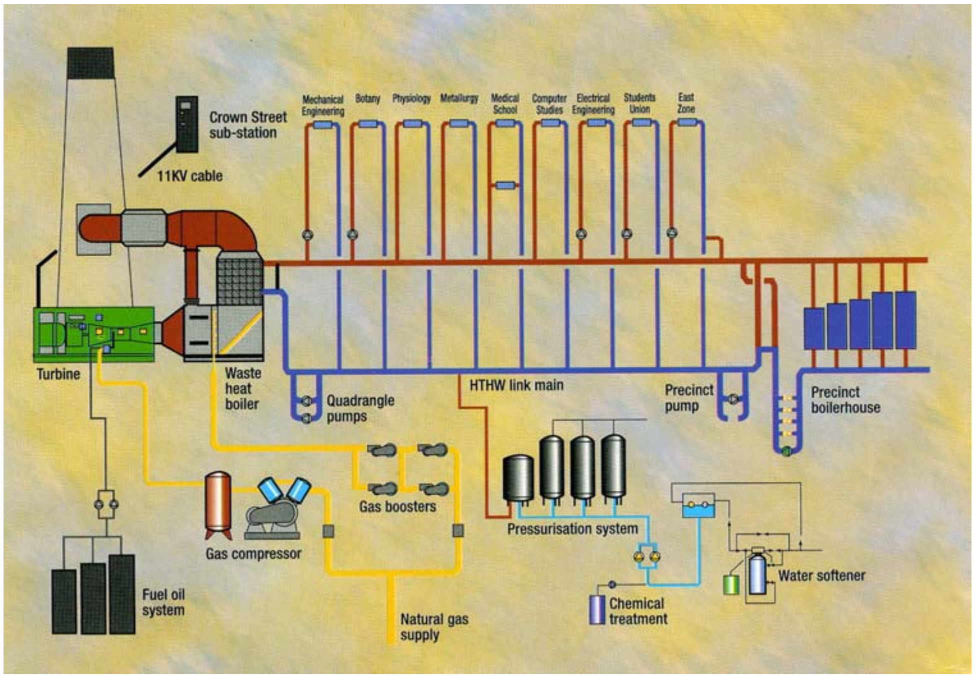


Figure 4.13 *The University of Liverpool CHP scheme*

(Image from Good Practice Case Study 351)

The choice of CHP system, incorporating a gas turbine and supplementary fired heat recovery boiler, was determined by the site's daily and seasonal patterns of heat and power demand. The gas turbine supplies the base electrical load and approximately 60% of the peak daytime demand. The heat recovered from the exhaust gases, supplies the two high-temperature hot water (HTHW) systems, with additional heat input from supplementary firing as required. During the summer months when electricity prices are lowest there is insufficient heat demand to justify operation of the CHP system. It was recognized at the beginning of the project that this would limit CHP operation to 5,000hours/year, meaning a payback period of approximately 5 years.[25]

The CHP system currently adopted by the University of Liverpool is a Centrax CX-350 KB5 gas turbine being rated at 3.65MW$_e$. The turbine is fuelled by natural gas supplied on an interruptible tariff with distillate fuel (gas oil) as the stand-by fuel. Fuel gas at a pressure of 20 bar(g) is delivered to the turbine skid by a two stage reciprocating compressor driven by a 250kW electric motor. Electrical power, produced at 11kV, is fed to the site distribution system. The gas turbine is turned down at times of low site electrical demand, the diagram below shows the exact type of turbine used by the University of Liverpool.[25]

Figure 4.14 *The Centrax CX-350 KB5 gas turbine*

(Image from Good Practice Case Study 351)

The gas turbine exhaust discharges to the heat recovery boiler and is capable of providing 8MW$_e$ of heat to the HTHW system. The ducting between the turbine and the waste heat recovery boiler incorporates a supplementary gas-only burner arrangement which can increase the boiler heat output to 15MW$_e$. By the year 1996 the CHP plant at the University of Liverpool had already operated for a total of 47,000 hours. The annual operating hours ranged from 4,181 to 5,160 with an average of 4,726 hours. The plant is shutdown during the months of June, July and August, when there is insufficient heat load to make the operational more economical.[25]

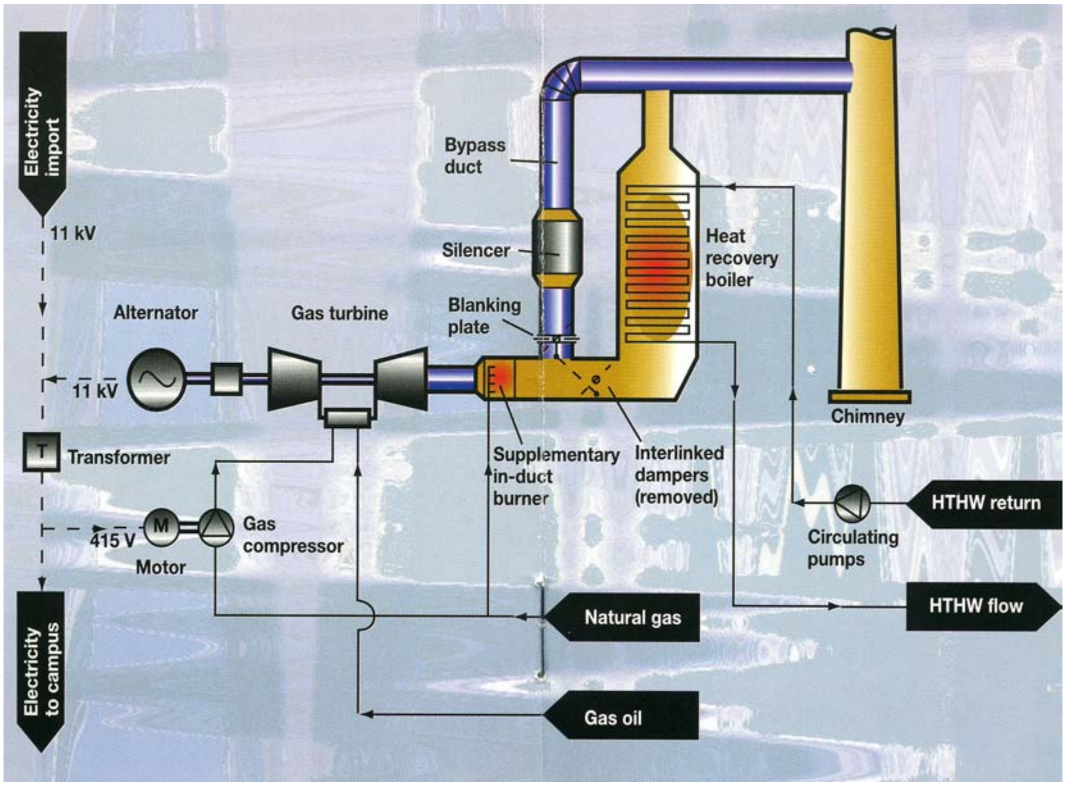


Figure 4.15 *CHP system Gas turbine*

(Image from Good Practice Case Study 351)

During the operational months there have been periods when the lack of heat load prevents full or partial load operation of the CHP unit. This is due to the exhaust by-pass system being fatal due to mechanical problems. Although an average generator output of 2,813kW has been achieved, resulting in a net output of 2,663kW (150kW of electricity is being used by the CHP system). The winter electrical load and generation profiles, with the gas turbine generating 3 to 3.5MW$_e$ throughout a week are the shown in the diagram below:[25]

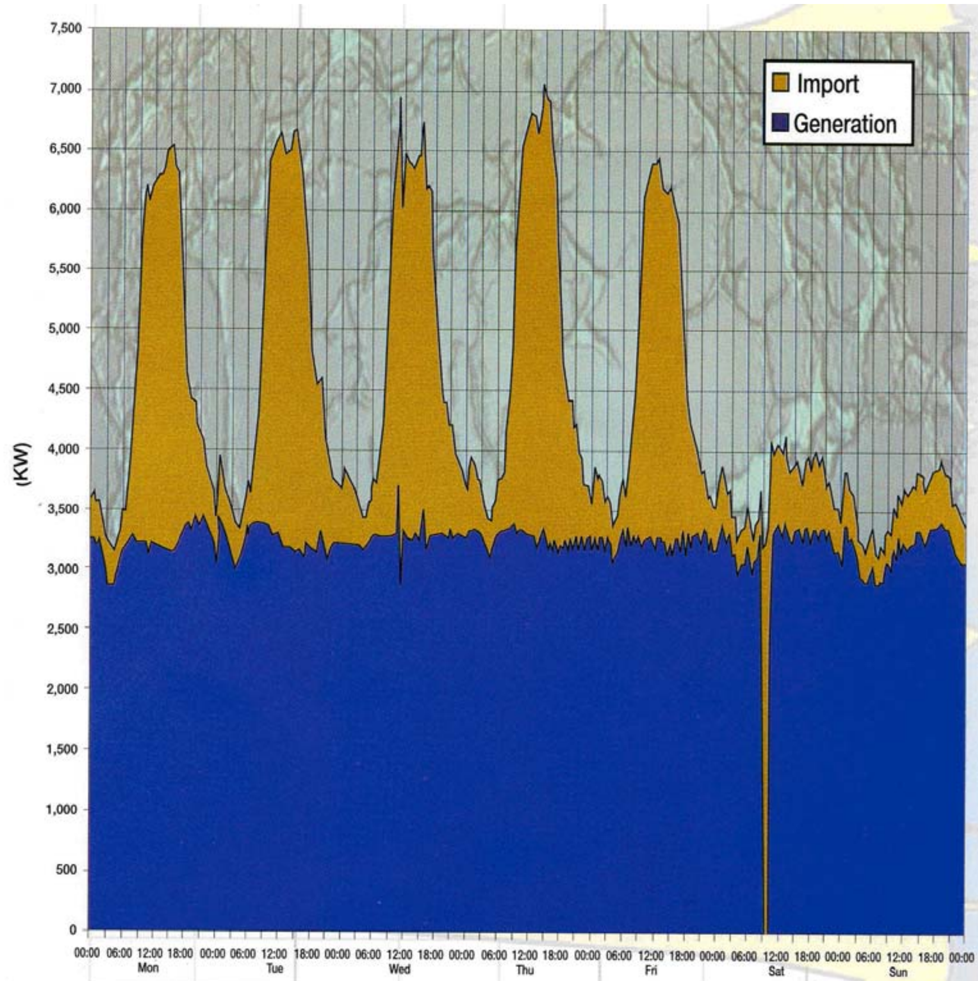


Figure 4.16 *Electrical generation profile throughout a week*

(Image from Good Practice Case Study 351)

The CHP system provides an average of 12.6 GWh/year of electricity. This accounted for 55% of the total site requirement, but due to the growth in demand it now provides only 40% of the electricity used. The CHP plant provides the 32,000MWh/year required by the HTHW system. The average heat output is 6.8MW_e; 95% is provided by heat recovery from the gas turbine exhaust and the remaining 5% by supplementary firing. The CHP system achieved an efficiency of 21%, this is the net electrical power output as a percentage of the total fuel energy input. The overall efficiency of the system was 74.4% and an average heat to power ratio of 2.54:1. Based on the net calorific value the electrical and overall efficiencies are 23.2% and 82.2% respectively.[25]

The CHP system at the University of Liverpool achieved energy cost savings of £433,000/year over the first 5 years of operation. The maintenance of the system during this period averaged £74,000/year equivalent to 0.60p/kWh net electricity generation. However the university saved £33,000/year in avoided maintenance costs for the boilers which were detached. In the last 3 years maintenance costs have been extremely high and this was due to the 30,000 hour overhaul and subsequent problems with the turbine blades. This increased the average cost of CHP system maintenance over the nine years of operation, to £147,000/year (1.16p/kWh).[25]

	Unit cost (p/unit)	Energy use (,000)	Annual cost (£,000)
Gas turbine CHP system			
Natural gas (therms)	22.5	1,803	406
Gas oil (therms)	31.4	211	66
Purchased electricity (kWh)	3.8	13,706	136
Total energy costs			**1,129**
No CHP system			
Natural gas (therms)	22.5	1,500	338
Purchased electricity (kWh)	3.9	25,996	1,014
Total energy costs			**1,562**
Annual energy cost saving from CHP			**433**

Table 4.2 *Mean annual energy use and energy cost savings: 1986-1991*

Note: *Gas price:22.5p/therm = 0.768p/kWh.Gas oil price: 31.4p/therm = 11.36p/litre*

The installed cost of an identical project in 1996 would have been £2.9 million, excluding £0.8 million for the interconnection of the two existing HTHW systems and electricity supplies. A modern CHP system would be able to operate for 5,600 annual full load hours resulting in energy cost savings of approximately £640,000/year at current energy prices. This allows a payback period of 5.5 years after allowing for maintenance costs of 0.6p/kWh.

Last but not least the University of Liverpool invested £1.95 million on the CHP system with a payback period of 5 years, there were cost savings of £392,000/year and the energy costs were reduced by 28%. The CHP system at Liverpool University reduced national primary energy consumption by 97 TJ/year (equivalent to 3,680 tones of coal). Assuming that the replaced electricity was generated by coal-fired power stations without flue gas desulphurization, the CHP system has reduced carbon dioxide and sulphur dioxide emissions by 19,300 tones/year (27%) and 270 tones/year (45%) respectively.[25]

(1.) Benefits of CHP

Combined Heat and Power systems use fuels, both fossil and renewable, to produce electricity or mechanical power and useful thermal energy more efficiently and with low emissions than conventional separate heat and centralized power systems. CHP benefits includes:

- **Environment:** CHP reduces the amount of fuel burned per unit of energy output, and reduces the corresponding emissions of pollutants and greenhouse gases. Reducing NO_x emissions by 0.4 million tons per year and SO_2 emissions by 0.9 millions tons per year.
- **Reliability:** CHP systems located at he point of energy use is considered a form of distributed generation providing reliable electricity and thermal energy. CHP can decrease the impact of grid power outages and on the other hand help minimize congestion on the electric grid by eliminating or decreasing load in areas of high demand.
- **Economic:** The main economic benefit of CHP is the production of power at rates lower than that of the utility's delivered price.
- **Resources:** CHP demands less fuel for a given output, therefore it minimizes the demand for finite natural resources such as natural gas and coal.[25]

(2.) Barriers to Implementing CHP

Although CHP systems have improved in recent years, there are considerable obstacles exist that limit the widespread use of CHP. These obstacles are as follows:

- The market is unaware of the expanded technology developments that increased the potential for local generation of electricity and CHP

- A site by site environmental permitting system that is complex, costly, time consuming and uncertain
- Current regulations do not recognize the overall energy efficiency of CHP or credit the emissions avoided from displaced grid electricity generation
- Many utilities currently charge inequitable backup rates and demand excessive interconnection actions. Utilities are charging unreasonable ‘exit fees’ as part of the utility reorganization to consumers who construct CHP facilities.

Micro and small-scale cogeneration offers solutions for a wide range of applications. Nevertheless, in most of the countries only very few units have been installed so far. This is due to a variety of legislative, economic and technical barriers. The diagram below shows the use of CHP in several types of buildings in other European countries.[14]

Country	Administration Buildings	Agriculture	Commercial buildings	District Heating	Educational buildings	Food industry	Greenhouses	Hospitals	Hotels	Industry	Landfill sites	Military buildings	Residential Buildings	Sewage tanks	Swimming Pools
Austria	x	x	x*	x		x	x	x	x	x					
Belgium		x				x		x						x	x
Bulgaria	x			x		x		x	x	x					x
Estonia	x		x	x	x	x		x	x	x	x				
Germany	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Greece	x	x		x	x	x		x	x						
Latvia		x	x	x		x		x		x	x	x		x	x
Lithuania	x	x	x	x	x	x	x	x	x	x	x			x	
Poland	x			x	x	x		x	x	x	x	x	x	x	x
Slovakia	x			x				x	x	x			x		x
Slovenia		x		x		x		x	x	x	x		x	x	x
Spain	x	x	x	x	x	x		x	x		x		x		x

* especially in combination with cooling applications

Figure 4.17 *CHP in different types of buildings in other European countries*

(3.) Potential for Expanding CHP in Europe

There is a considerable potential for expanding the use of CHP in Europe. Only a minor part of the residential heat demand in EU is covered by district heating. The Accession Countries have a high potential for increasing the share of CHP. In addition there is a considerable potential for small/micro scale CHP in the market for individual boilers in existing as well as new Member States. A further uptake of CHP in Europe will likely be linked to a move towards the use of cleaner and local energy resources, e.g. natural gas, biomass or waste. Thus CHP can help fulfilling also the EU objectives of increasing the fuel diversity and securing supply.[14]

4.4 Summary

This chapter discussed active renewable systems, these systems involve small scale generation through PV, solar water heating, ducted wind turbines and combined heat and power. Each of these technologies has been discussed and demonstrated via case studies such as The Oberlin College case study, The Lighthouse case study and The University of Liverpool of case study. All these case studies highlight the areas of strength of which each technology that made significant impact.

The whole building approach to minimise electrical demand is demonstrated through the Oberlin College case study. This approach to whole building design could help minimise the amount of energy consumed in the UK by commercial buildings.

Chapter 5: Discussion, Conclusion & Future Recommendations

5.1 Discussion

The investigation and case studies provided, demonstrate that there are significant improvements towards sustainable buildings, concentrating on low energy buildings would be of more importance. Through the Kyoto Protocol, the UK is committed to significant reductions greenhouse gas emissions. Meeting these restrictions will impose significant costs on the economy, regardless of the method used to achieve them. A range of options exist including economy wide market based approaches and sector specific regulations. The task for government is to choose those methods that are the most efficient and equitable means to meet the emissions targets.

Understanding of energy use in buildings requires knowing the amounts of energy and of different fuels consumed for various end uses. These data are needed to evaluate the potential effects of energy efficiency improvements. Much less detailed information is available on energy consumption in commercial buildings, which includes different types of buildings and variations of activity within buildings. The diagram below shows the energy consumed by various sectors.

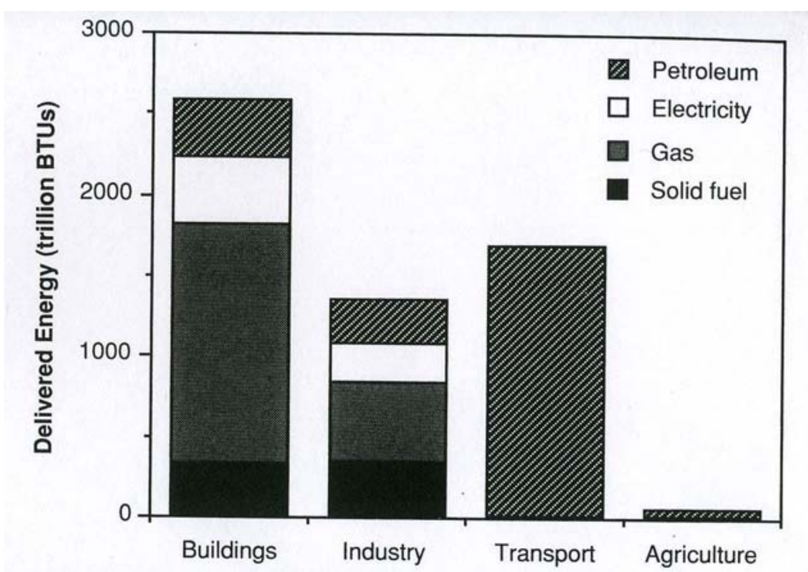


Figure 5.1 *Energy consumed by sector in UK*

(Image from Edward Vine, Drury Crawley, Paul Centolella, Energy Efficiency and the Environment; Forging the link)

Buildings require energy for space heating, water heating, lighting, refrigeration, ventilation and other services. These uses combined with domestic appliances and office equipment, account for about half of total UK demand for energy and a similar proportion of all energy related CO_2 emissions. Improvements to the efficiency with which energy is used in buildings could offer considerable opportunities for reducing those emissions. In the UK, buildings offer many opportunities for improving energy efficiency cost effectively and at no net cost.

Despite the improvements, buildings are still not receiving enough attention as required. With time the UK building regulations have been improved, but could still be much more improved in areas such as ventilation (specifying minimum recovery rate for heat recovery) and insulation. Generally, space heating and water heating account for a lower proportion, and lighting for a higher proportion, of consumption in commercial buildings. In the UK air-conditioning is a significant end use in some types of commercial buildings but a negligible one in dwellings.

Increasing more awareness towards low energy buildings and sustainability in schools, colleges and universities would be a move in the right direction, as it opens the minds of future generations to be more economic and environmentally friendly.

5.2 Conclusion

As most of the case studies in this thesis demonstrate strongly, there is a need to consider energy efficiency before the impact of renewable technologies can be maximised. There are signs that energy efficiency and renewable energy are now being more appreciated and considered by the public. The awareness and the different campaigns helped attract more attention to the issue of the increase of amount in CO_2. Therefore buildings should be designed to optimise energy in use and without compromising performance in terms of, air quality and comfort conditions.

The design and layout of buildings to make the most of the sunlight is considered as environmentally friendly and has implemented great impact on cities and towns. From an engineering point of view, it is considered of much interest and the passive solar techniques have been well received by the occupants.

There is also a great potential to use passive and active renewable energy technologies in buildings and they have the potential to be exploited in:

- Passive solar design
- Photovoltaic cells
- Solar water heating
- Ducted wind turbines
- Combined heat and power (CHP)

Switching to renewables is not a matter of ideology; it can offer a wide range of benefits including:

- Improving 'Green' credentials
- Lowering energy bills
- Introducing the possibility of selling electricity back to the national grid
- Increasing the security of energy supply by minimizing the reliance on fossil fuel

The energy efficiency of a building can be influenced by how the space within the building is utilized. In order to maximize energy efficiency within a building, heat losses within the building envelope must be kept to a minimum. This is achievable via insulation to the roof, walls, windows and floors. Insulation can be improved via joining of units to increase thermal massing and minimize heat loss through exposed walls. Meanwhile on the other hand adequate ventilation without draughts is essential to avoid condensation problems.

When it comes to the rating of energy performance in buildings a strategy for defining energy efficiency is important for successful rating. A strategy should include how to select the energy budget for an energy efficient building as well as how to evaluate the level of low energy and the relative and absolute energy efficiency. The level of amenities must also be considered.

5.3 Recommendations for Future Work

This thesis can be used as a starting point towards more detailed research in the development of energy efficient buildings. Further investigation into renewable technologies such as ducted wind turbines, the comfort levels in different ventilation strategies, the impact of building materials and the opportunity to use recycled building materials into different types of buildings, without affecting the performance of the building could be pursued.

As technologies improve from day to another, there is always room for improvement, the investigation could be further extended to investigate the impact of

5.3.1 Major Recommendations:

- The need for a long term commitment from the Government to promote energy efficiency in buildings
- Better end-use analysis needs to be undertaken in order to know what progress is being made on improving energy efficiency of buildings
- Certification needs to be implemented in parallel with effective information campaigns to explain to the wider public
- The energy certification programme should be designed to help construct and maintain end-use databases to help in the policy analysis

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