School of Engineering and Built Environment

Energy Resources, Generation and Utilisation

Module Code: M2H823551

Task Exercise No: 8

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Section 8: Saving energy: buildings

We now look at how a reduction in energy use can be achieved, first of all in buildings. We will consider the legislation and political drive to create buildings that are carbon neutral. There are a number of measures that can be taken to make any building more energy efficient, but it is also important to design a new building to exploit natural energy resources. The effectiveness of the design can be evaluated by subsequently monitoring energy performance.

The zero energy building

Energy use in a **zero energy building (ZEB)** is minimised and all the energy consumed must originate from a renewable source. However, this does not imply energy rationing or utility independence. Such homes are also referred to as 'zero carbon' or 'carbon neutral', though the latter term more accurately refers to an individual. A 'green building', 'eco building' or 'carbon smart' building will include measures to reduce environmental impact, but not to the extent of achieving zero carbon performance.

Half of the energy used in the UK is within buildings, and the UK government has identified that CO_2 emission reductions in this sector can be readily made. The aspiration is for all non-residential buildings to be zero carbon by 2020 and all new housing to be zero carbon by 2016. Setting these seemingly dramatic targets may not actually have a huge impact because the housing stock is growing by only 1% per annum, and the real problem is with 45% of homes that are over 50 years old and will certainly be energy inefficient. Retrofit measures on existing older residences may therefore be as important as action on new buildings. There is no legal obligation at the moment to construct zero energy buildings, though stamp duty relief is offered as an incentive.

The Scottish Government is considering the recommendations of the Sullivan Report (2007) (**'A Low Carbon Building Standards Strategy for Scotland**') to inform strategy (Fig. 8.1). Neil Jefferson, MD of the National Centre for Excellence in Housing welcomed the report and stated:

'*It is important that we recognise the enormous amount of work which is ahead of us if we are to meet the aspiration of zero carbon homes in less than a decade. We must be realistic about how this can be achieved and it is imperative that consumers be included in the process, not used as guinea pigs for technologies which are not tried, tested and accredited and which may not deliver real benefits for them*'.

There is also EU legislation dating from 2003 (Fig. 8.1). The headline action is that all buildings should have an energy performance certificate (EPC). All the provisions require to be implemented in member states by 2009. However, progress to date has been slow. Though there is much legislation, there is also the barrier that many of the measures required to make a building greener also tend make the building more expensive.

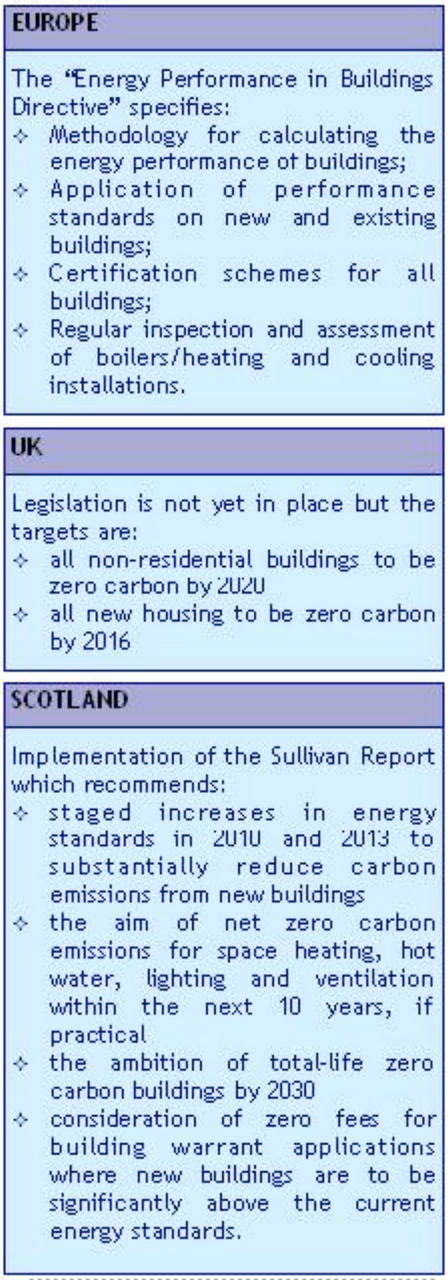

Figure 8.1: The legislation hierarchy - EU directive on the energy performance of buildings (2002/91/EC)

Task 8.1

What is an energy performance certificate ?

Energy-saving measures in the home

There are many different measures that can be taken to limit energy use and eliminate profligacy, but it is first important to assess how energy is currently being used by conducting an **energy audit**. The space heating (and cooling) requirement is the most important consideration because of the amount of energy used for heating. It is desirable to have a thermostat in each room set at a level which is comfortable but not unnecessarily hot. A temperature of 25 ^{o}C is hot, but 18 ^{o}C is tolerable, and there is a big difference in the energy needed to keep the temperature at 18 ^{o}C compared to 25 ^{o}C. As a general rule, about 3% of the total energy used in a building is saved with each degree the temperature is lowered. By experimenting with different settings it should be possible to agree a temperature everyone in the house can accept.

However, a heating system is only needed because heat in the home is eventually lost to the outside. To virtually eliminate heating cost, the rule is pretty simple; as far as possible create a sealed box covered by a thick blanket of insulation. This means closing vents and gaps (though this might not be feasible where cavity circulation is necessary to clear moisture ingress). Since air circulation is needed for comfort (and safety in the case of fires and boilers to clear dangerous products of combustion), hence energy loss becomes inevitable without sophisticated heat reclamation technology (*but see Q 3(d) on the next page*). Nevertheless sensible measures should be taken wherever possible.

Ensure open fires are made efficient, or replace open fires with central heating. Grants are available for the elderly. If there is a choice, install underfloor heating because the circulating water is at a lower temperature than in radiator systems, making the boiler run more efficiently.

Replace older boilers with a **condensing boiler** that incorporates an extra heat exchanger so that the hot exhaust gases lose much of their energy to pre-heat the water in the boiler system. When working at peak efficiency, the water vapour produced in the combustion process condenses back into liquid form releasing the latent heat of vaporisation. You can purchase condensing boilers whether your fuel is mains gas, LPG, or oil. Bear in mind there may be problems with corrosion when the fuel used is oil. Water needs to be hot but never scalding.

For most people, setting the cylinder thermostat at 60 °C is fine for bathing and washing. Heat rises, so 25% of heat can be lost through the roof area. By insulating the roof, much more heat is retained within the property, which can significantly reduce your heating bill. Current building regulations recommend that houses should have 270 mm of loft insulation. There are natural and manufactured materials available, some of which can be installed by the home owner; others require a contractor with specialist equipment for installation. Different materials have different 'U-values' relating to its insulating properties, the lower the U-value the slower the rate of heat loss (ie materials with a low U-value are the best insulators).

As you cannot see cavity wall insulation there is no simple way of checking that it has been done properly. You should use a contractor who will issue a cavity wall guarantee certificate produced by the **Cavity Insulation Guarantee Agency** (CIGA), which covers the work standards and materials used.

Task 8.2

Conduct an audit of how energy is used in your home and how energy use could be reduced. Consider lighting, washing clothes, drying clothes, showers and baths, cooking, cooling, insulation, draughts, type of heating used, temperature of rooms, appliances, glazing. Remember cost is not the issue but energy used, though actions could be grouped by cost.

New building design

When a new building is planned there is an opportunity to incorporate green features into the design. There are a variety of external services available to the architect, but simulation and analysis software tools can be used in-house to calculate the effect of specific design changes on the model and thereby optimise the design. This will also ensure the design conforms with the increasingly tight legislation governing building performance. The building orientation and shape can be altered to accommodate PV arrays or solar hot water, wind turbines can be attached (with due consideration to noise and the effect of vibration) on the structure of the building, and a heat pump may be installed on site. By linking to geographical information systems, weather data, and perhaps data acquired during a site survey, the influence of the microclimate can be factored into the design.

Passive measures can also be adopted to exploit incident sunlight. A passive house will trap solar energy and move the heat about in a natural way to equalise temperature and remove steep thermal gradients. Daylight is used to reduce the need for artificial illumination. Skylights can be used to bring daylight into the centre of rooms when privacy is needed or wall space is limited: Light pipes (or fibre optical bundles) can transmit light from the roof into a dark room.

Buildings can be designed in such a way that glazing faces the full southern sun in winter when energy is most needed. The house should be located away for obstructions. In Scotland, the glass used should have a **high solar heat gain coefficient** (**SHGC**), of the order of 0.75 or higher. This is a measure at how effectively sunlight is converted to internal heat. Overglazing should be avoided: The building will be too hot in summer and too cold in winter. Materials with a high thermal mass should be used for construction and placed in the path of direct sunlight.

Solar collectors (generally solar hot water) are also an economic way of harvesting solar radiation in the UK, and the way they are being incorporated into the building is changing.

Task 8.3

How can different types of glass have such a wide range of properties?

Energy monitoring and non-residential buildings

Energy monitoring in residential buildings often amounts to no more than keeping an eye on the quarterly bills or installing a **smart meter**. This is fine when it is easy to control and limit energy use. However, in a non-residential building, the people with the responsibility for controlling energy use cannot go around switching off lights and turning down the heating. The energy transfer processes in a large building are very complex and environmental parameters such as temperature and air quality should be under the control of an automated **building energy management system (BEMS)**.

The BEMS sensors can also be used to monitor how the building is performing, or a separate network of sensors can be installed. It is important to monitor the temperature and energy performance of a building to check if the building functions according to its design, with any discrepancy feeding into and improving on the design process. Buildings also degrade over time and information from monitoring systems can be used to trigger repairs and improvements.

A building may be continuously monitored with a permanently installed sensor network, or can be periodically surveyed by attaching sensors to the flow and return pipes of the heating system, recording the data captured at regular intervals with a data logger. The data can be processed later with reference to the measured room temperature to understand energy demand as a function of space and time. From this the BEMS may be reconfigured to reduce energy use and improve efficiency.

Non-residential buildings can be more energy efficient than domestic buildings because of their greater size, but are subject to more rigid legislative controls. There are rules governing air quality, temperature, acoustic emissions, and illumination that may be in direct conflict with the desire to reduce energy use. In many cases the design will be more complex because of the additional constraints. **Indoor air quality (IAQ)** is predicted to become an important issue in the future and this should be recognised in current designs.

However, with new non-residential designs, the architect has the opportunity to experiment with medium-scale energy generation measures that would be inappropriate in the design of a residential building: Large ground source heat pumps can be installed; medium-sized wind turbines can be used (20-50 kW) - at these generation capacities turbines become very economic; a micro-CHP running off biomass can be installed; ventilation heat recovery becomes viable; PV panels *may* also be included (see Fig. 3). It becomes necessary to understand the ways new and renewable energy sources can be harnessed in buildings, and modelling must be used effectively to get a credible understanding of how the building will work. These skills are increasingly in demand in architecture and engineering consultancies, building analysis and design consultancies, utilities and regulatory organisations, local and national government, and academia.

Figure 8.3: Whilst solar PV is not currently economic in Scotland, it may become so if the £1 per watt devices being made by Nanosolar *and launched in Dec 2007 are seen to work*

Task 8.4

What is a micro-CHP system? Describe the advantages and disadvantages (think about how energy is wasted as heat whenever electricity is produced by the conversion of heat to work).

Notes

Sensors and transducers

Sensors are devices that map the value of a physical quantity (such as temperature) to an electronic signal level that can be logged or recorded, or used with transducers to enable the environment to be controlled in some way. The signal from a sensor is rarely an ideal representation of the parameter under observation. There are a variety of problems: the signal amplitude may be very low and buried in, or hidden by, the **noise** always present on wires; the output may be non-linear with a complex relationship existing between input and output; the sensing mechanism can be indirect resulting in a capacitance, inductance, or resistance change, and eventually requiring a conversion to voltage; the sensor output may not be repeatable, meaning that it will not always give the same output for the same input.

Real sensors therefore require **signal conditioning**, then **data processing** of the **raw data** in order for the value of the physical quantity to be extrapolated from the electronic output. However, many sensor problems are chronic and cannot be corrected. These are acknowledged by bundling all the effects together as a single error that determines the accuracy of the device. For example, a temperature sensor may have an error of ± 2 ^{o}C. This means that if the sensor reports a temperature of 20 ^{o}C, all we can say for sure is that the *actual*temperature lies somewhere between 18 ^{o}C and 22 ^{o}C.

Many sensors are **analogue**, and the signal is usually converted to **digital** form using an **ADC (analogue-to-digital converter)** so that a microprocessor or microcontroller can be used to monitor and control the system under observation. This is illustrated in the diagram below. Sensors are available to measure wind speed, current voltage, power, energy, speed, acceleration, light intensity, temperature, humidity, pressure, electric field, magnetic fields, radioactivity, and so on. Each parameter may have sensors based on a number of techniques. For example, temperature can be measured by a **thermocouple** (a small voltage generated by the contact of two dissimilar metals or alloys that varies with temperature), a **PRT** (resistance of platinum varies slightly with temperature) or **RTD**, a **thermistor** (resistance of a semiconductor bead varies dramatically and logarithmically with temperature), and a **semiconductor sensor** (described below).

To learn more about sensors, go to the web site www.sensedu.com.

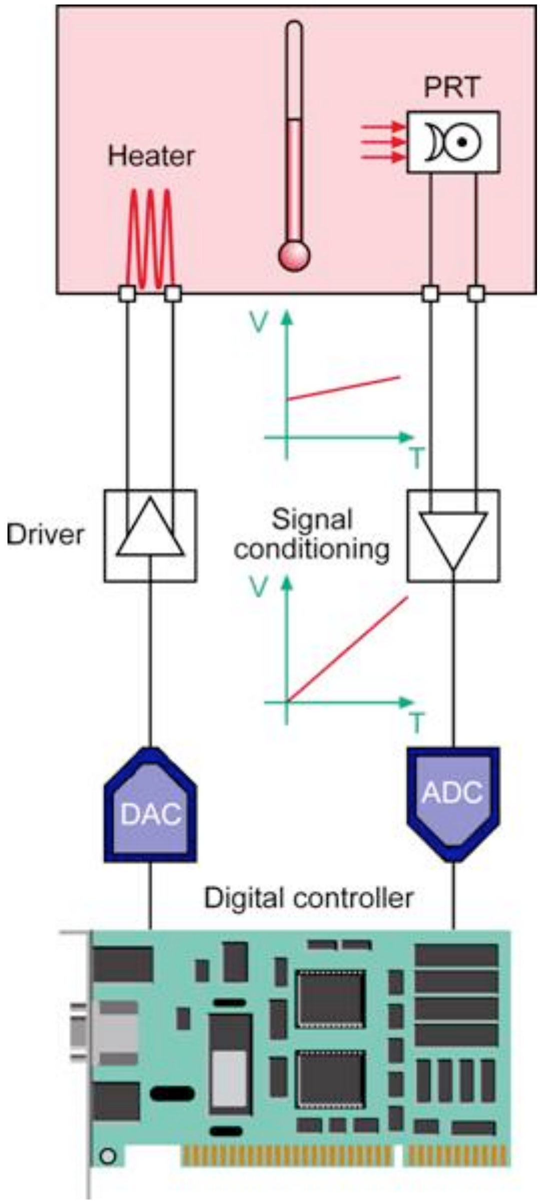

Figure 8.4: A complete control system. A PRT measures the chamber temperature. The signal is modified, converted to digital form and read by a computer or microprocessor. If the temperature is less than required ('set point'), a signal is sent out to switch on an electric heater.

This is a 'closed loop' control because of the feedback path. A **PID** strategy can be used to cope with the delay between supplying heat and the temperature rising.
This could describe the control system of an oven.

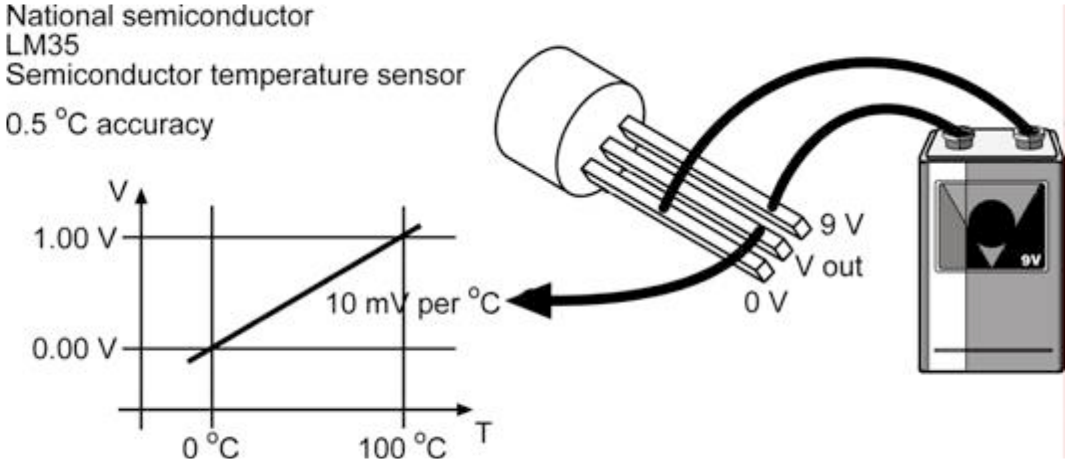

Figure 8.5: If you need a very simple temperature sensor choose the circuit above. The LM35 sensor has linearised the output for you: If the output were 0.51 V, the temperature is 51 ^oC. ***Note: device is not drawn to scale***

Monitoring and control within buildings

A **building energy management system (BEMS)** is common in non-residential buildings. They combine energy-saving control techniques with communication and information systems that allow active management of the building services, with the capability of achieving and sustaining a high level of energy efficiency. However, in many buildings this technology is too complex for users to understand and maintain. As a result, many important elements of the energy system are disconnected from the BEMS, or newly installed systems are not incorporated. This can have a disastrous effect on building efficiency, and we can have the situation of sporadic user intervention, activating override functions and manually turning valves on and off.

A BEMS system is extremely complex and will include a large number of sensors and control algorithms related to the position of the sensors and actuators within the building. The system installer will not spend any more time programming and commissioning a BEMS than is absolutely necessary, with the result that a solution is often produced that is hard to extend and modify, and many functions that should be under convenient user control are not implemented. The customer is often at the mercy of the installer who may charge excessively for maintenance and modifications.

There is a strong case for developing a simple BEMS programming interface that is accessible to the non-expert, and is therefore extensible.

HVAC is another common acronym (**Heating, ventilation and air conditioning**) used in the context of building climate control for comfort and utility. These are the plant used to achieve an acceptable level of air quality, comfort, and illumination, and will generally be under the control of the BEMS.

BEMS software will inevitably become more complex as renewable energy power sources are incorporated into buildings, and heat pumps become routinely installed. To understand the issue with heat pumps (and the paper is a good overview of heat pumps in any case), consult 'Ground-source heat pumps systems and applications' by A.M. Omer, 2006. A typical BEMS system consists of local controllers responsible for a number of 'points'. The points may be inputs (temperature sensors, light sensors, or air quality sensors), or outputs (valves pumps, relays, solenoids). Local zone controllers may be managed by a master device that can, for example, use SMS messaging to report serious problems.

A BEMS system will be expensive to install and implement but can rapidly pay for itself through energy savings. BEMS hardware is often implemented using **PLCs (programmable logic controllers)**.

CBM is **condition based maintenance**. Corrective maintenance means waiting until something goes wrong then fixing it. This can result in lack of service until the problem is resolved. CBM is based on preventative maintenance: Equipment is routinely inspected and serviced in an effort to prevent breakdowns from occurring. The assumption is that before a piece of equipment fails either the cause is visually evident or its behaviour changes in a measurable way. The most obvious symptom of impending mechanical failure is acoustic; the equipment starts making a noise, or the noise changes. Failure in electrical or electronic equipment is often preceded by localised heating or overheating.