The role of built environment energy efficiency in a sustainable UK energy economy

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Abstract

Energy efficiency in the built environment can make significant contributions to a sustainable energy economy. In order to achieve this, greater public awareness of the importance of energy efficiency is required. In the short term, new efficient domestic appliances, building technologies, legislation quantifying building plant performance, and improved building regulations to include installed plant will be required. Continuing these improvements in the longer term is likely to see the adoption of small-scale renewable technologies embedded in the building fabric. Internet-based energy services will see low-cost building energy management and control delivered to the mass market in order that plant can be operated and maintained at optimum performance levels and energy savings quantified. There are many technology options for improved energy performance of the building fabric and energy systems and it's not yet clear which will prove to be the most economic. Therefore, flexibility is needed in legislation and energy-efficiency initiatives.

Introduction

The UK Government has pledged to meet the challenging targets set out by the Royal Commission on Environmental Pollution, which stated that the UK should reduce carbon dioxide (CO_2) emissions to 60% below 1997 levels by 2050 (Royal Commission on Environmental Pollution 2000). In its Energy White Paper (Department of Trade and Industry 2003b), the Government set out potential mechanisms to achieve this challenging target, a cornerstone of which is an increase in energy efficiency. Subsequently the Government published its strategy for energy efficiency. However, the publication was set against a background of increasing energy demand. Left unchecked, this growth in demand could completely derail the UK's aspirations for long-term emissions reductions. The trends in energy consumption are driven by the energy demands of the three main sectors of the economy – transport, power and industry, and the built environment. Since the built environment is the biggest single energy consumer, the challenges of improving efficiency in this sector are the focus of this review.

Energy demands in the built environment sector

In the built environment, the energy consumed by the UK building stock accounts for over 70% of the UK total primary energy consumption. Within this, the domestic sector accounts for 42% of the primary energy consumption, industry 34% and the services sector 23%. The services sector includes the government estate (education, health, administration), retail, hotel and catering, warehouses and offices. The final energy is used for space heating (40%), water heating (13%), lights and appliances (9%), industrial process (15%), and other miscellaneous uses including cooking, motors and drying (Department of Trade and Industry 2003a). The domestic sector is the UK's second largest energy consumer, and energy consumption has increased by 19% since 1990. Domestic electricity consumption has increased by 50% over the same period (Department for Trade and Industry 2003a). The increases in domestic energy consumption have been driven by an increase in the number of households, increasing average internal temperatures and increasing numbers of electrically powered appliances.

The potential for energy efficiency in the built environment

In terms of energy efficiency, the built environment has historically been a poor performer, a state of affairs brought about by a distinct lack of energy awareness in building clients, designers and occupants. Energy performance of buildings is low on the list of design priorities and the installed energy systems are operated and maintained in a way that is not conducive to efficient use of energy. Engendering greater awareness of energy issues is a prime requisite of improving the energy-efficiency record of the built environment.

Energy efficiency when applied to the built environment can contribute greatly to a sustainable energy economy in both the short term (before 2015) and the longer term (up to 2050). Against both of these timeframes, there are a number of challenges to be addressed and technological advances to be deployed. In the short term, one of the key challenges is the delivery of energy-efficiency applications to reduce energy demands. This is dependent on energy-efficient appliances/technology being available, the cost of implementation having clear economic benefits, and users' acceptance of and willingness to implement them.

With regard to the integration of energy-efficient technologies, even at the most basic level many UK buildings are found wanting. For example, 54% of homes have no cavity wall insulation (Utley et al. 2006), while energy-efficient equipment such as heat recovery, heat pumps and daylight responsive lighting are rarities rather than the norm. Technical solutions associated with reducing heat loss from buildings and improving the conversion efficiencies of installed plant are available today and have the potential to reduce energy use and carbon emissions associated with the current UK building stock. For example, a typical UK dwelling's annual carbon footprint is around 7.5 tonnes CO_2, but by upgrading to 'best practice' insulation levels and using currently available efficient systems, lights and appliances, the footprint could, in theory, be reduced to 1.7 tonnes. Where wood fuels and renewable energy opportunities exist, it could be reduced further. A study of a typical local authority housing stock concluded that more than a 50% reduction in the carbon footprint is possible with practical implementation of existing technology and conventional fuels. A further 50% reduction is possible with the adoption of wood fuel for heating (EU RURASU) (Tuohy et al. 2006).

In the non-domestic sector, similar opportunities exist, with many buildings currently operating with poor fabric, inefficient plant, poor controls and low levels of occupant energy awareness. Overheating is common, leading to increased cooling energy demands in hot periods. Improved controls and appropriate use of thermal mass, glazing, shading and ventilation are important to mitigate overheating. The commonly observed situation of windows wide open for cooling while the heating system is running is symptomatic of poor control and in some cases poor fabric.

Improving the energy performance of the built environment is, in part, being stimulated at the local level through development and implementation of Local Agenda 21 policy frameworks (Greater

London Authority 2004). Although not mandatory, a number of local councils have implemented policies either aimed at reducing the energy demands of new buildings or requesting the inclusion of renewable energy technologies as part of local planning requirements. This is evident in London, where planning powers will be used to encourage new non-residential buildings to generate 10% of their predicted energy requirements from clean, renewable energy sources as part of the London Energy Strategy (London Borough of Merton 2003).

Barriers to improved energy efficiency in the built environment

A number of barriers exist to realising potential improvements. The historical low cost of energy made improvement financially unattractive and also drove more profligate use of energy. Billing of fuel does not discriminate in favour of lower energy consumption – if anything, the opposite is the case, where a lower tariff can be triggered by increased fuel use. The observed phenomenon of increased winter indoor temperatures in improved buildings appears to act to reduce heating energy savings as occupants choose comfort improvement over cost saving (although this effect should saturate once all buildings reach comfortable standards and have effective heating and controls). The impact of recent significant increases in energy costs remains to be seen.

For new buildings, the regulatory minimum standards are improving but continue to lag behind the benchmarks (e.g. Passive House (EU CEPHEUS), Swedish Building Regulations (EU SAVE)). The application of the standards to refurbish existing dwellings is not rigorous. The implementation of the EU Energy Performance of Buildings Directive (EPBD) should drive up energy awareness in building designers and occupants. However, one potential issue is the rating of a building's performance against a benchmark building of a similar type. This can lead to a fully serviced and energy-intensive building having a better rating than a less energy-intensive, more passive, equivalent. In general, the current market appears to be mainly focused on highly serviced, energy-intensive buildings and there doesn't yet seem to be a mechanism to drive the focus to more sustainable designs. Even in adaptive buildings where occupants can be comfortable up to 28°C, the indoor temperatures may still be controlled to 21±1°C, with the associated extra energy costs.

The building regulations and standards don't yet require dynamic simulation of the performance of buildings. At the design stage, modelling of performance is often restricted to checking that a building design will meet the minimum criteria possible (i.e. building regulations). This type of modelling doesn't test the performance of a building design in a realistic operational context and has limited value in terms of improving the performance of a building design.

Often low energy performance isn't realised in practice due to poor implementation and maintenance. Problems can occur in the fabric of the building, the controls (at commissioning or due to subsequent faults) and because of a lack of user understanding. Most buildings in the UK do not deploy any energy monitoring beyond recording for billing purposes. Consequently, there is little information with regard to the *in situ* performance of buildings and what information there is often indicates that they perform well short of expectations. There is currently no requirement for an operational energy rating, which would bring actual performance into focus.

Implementing energy efficiency in the built environment

There is the potential for significant upheaval in both the infrastructure for the supply of energy and also in the underlying fuel sources. The built environment relies predominantly on gas as the primary fuel source for space heating, with 77% of homes equipped with gas central heating (Royal Commission on Environmental Pollution 2000). However, dwindling indigenous reserves, uncertainty over the long-term security of foreign supplies along with adverse market conditions have already resulted in significant increases in costs. The continuation of this situation could lead to radical changes in the make-up of the fuels for the domestic sector. For example, high gas prices could rapidly accelerate a drive towards provision of electricity from nuclear, clean coal or renewable resources. The infrastructure for energy supplies could also be radically different by the mid-21st century. Possible scenarios include the decentralisation of electricity production through the micro-grid paradigm and the appearance of a hydrogen economy. All of these upheavals will influence the type of plant found within buildings and will have an impact on energy performance.

To minimise third-party influences on delivering step changes in driving efficiency into the built environment, a clear strategy for improving energy efficiency needs to be promoted. This involves driving down the demands of buildings through efficient appliances and fabric measures, the use of passive technologies where possible, and then the consideration of energy-efficient supply technologies. Finally, monitoring and analysis of operational energy use is required.

Embedding energy efficiency into the built environment is a challenging design task due to the complex interactions between building materials, environmental conditioning systems, control systems, climate and human factors (i.e. the effect of the building occupants on the performance of the building). The most appropriate means to deal with this complexity at the design stage is the use of detailed modelling tools, which are able to verify that comfortable temperatures and adequate ventilation are maintained with minimum energy demands. However, at present, these are infrequently applied in the design process (Crawley and Lawrie 1997), even though studies into the use of detailed simulation in building design have proved that its application leads to better buildings, reducing energy consumption and also improving the quality of the indoor environment for the building occupant (Energy Technology Support Unit 1998). Further, detailed tools have proven themselves robust enough to deal with the challenges posed by the integration of new and non-standard technologies (e.g. fuel cells, micro-combined heat and power (CHP)) into building designs. So the issue with regard to modelling is not the development of new modelling tools and techniques (although enhancements to user interfaces and inter-operability, in particular, are needed); rather, it is the integration of detailed tools into the design process (McElroy et al. 1997). Recent legislative changes, particularly the launch of the EPBD and the UK's implementation of the Directive through revised building regulations, have set specific whole-building performance targets and introduced proof of compliance prior to construction. This requires building performance to be adequately assessed prior to construction, encouraging the use of modelling (albeit in a limited way) to become a component of the design process.

The need to increase public awareness of the future role of energy efficiency is crucial to achieving user understanding and acceptance. The types of people that should be targeted include the general public/consumer, procurement managers, building stock managers, maintenance managers and business managers. The challenges here are to develop mechanisms for the effective engagement of those individuals and to implement these mechanisms as a matter of urgency.

Technology-focused advances

The most immediate means of improving energy efficiency in buildings is to improve the quality of the building fabric and to improve energy awareness. However, in well-insulated, well-run buildings, these options are not available. Instead, technology-focused solutions need to be adopted. These fall into two categories:

- **Passive technologies** like advanced glazings and solar thermal collectors make use of sunlight to provide heat and light and the movement of air to provide ventilation.
- There is a huge range of **active technologies** that could be deployed in buildings ranging from variable speed drives on fans and pumps through to advanced, active glazing and facades.

Some of the most promising technologies with regard to energy efficiency are detailed below:

- **Heat pumps** are a potential heat source for the domestic sector as they can be used to directly replace most existing heating systems (e.g. gas and electricity) and have been shown to produce significant carbon savings. For example, ground-source heat pumps can operate with a coefficient of performance of around 4 (Berntsson 2002). This means that for four units of useful heat supplied, one unit of electricity is consumed. Further, as their primary fuel is electricity, heat pumps are well matched with future energy scenarios in which natural gas supplies become less secure and there is significant growth in electrical supplies from distributed/embedded renewables and/or nuclear power. In such cases, heat pumps have an advantage over other energy-efficient heat sources requiring natural gas such as fuel cells or micro-CHP.

- **Monitoring and control via internet-enabled energy services.** This requires low-cost sensors installed at the demand site to monitor environmental conditions e.g. temperature, humidity, air quality etc. occupancy and appliance/plant status and running conditions. Data collected is either processed and enacted on locally or transmitted via the internet to a central service provider who enacts the energy services signed up for (Clarke et al. 2002). In this case, services include efficient operations of plant or equipment depending on load conditions sensed. Plant condition monitoring can also be facilitated via real-time monitoring and historical data stored in the databases. The main challenges for the development and uptake of this technology are (a) the development of a range of low-cost radio-frequency (RF) sensors/actuators to enable services to be enacted; (b) the wider uptake of broadband internet so that economies of scale can be realised with a suitable market size; and (c) wider public promotion of facilities and services available in order to gain public acceptance.

- **Electrical appliances.** These consist of energy-efficient lighting, white goods, home entertainment systems, etc. In the case of white goods uptake, incentives and information schemes are already in place to increase public awareness via an energy labelling scheme. The challenge is to translate this awareness into the energy and financial benefits to be accrued when choosing such appliances over a conventional product. Future challenges relate to the development of integrated smart controls within appliances to ensure that appliance operation and control is beneficial to efficient energy usage. It's likely that this will be facilitated via the deployment of internet-enabled energy services, where appliance status and demands are monitored and the appropriate control actions are implemented remotely by a third-party energy service provider using internet-enabled protocols.

- **Building integrated renewables.** These technologies produce thermal and/or electrical power locally within the building to minimise the demand placed on the main energy supply infrastructure; and, in the case of electricity, to use this within the plant located in the building to avoid exporting to the electricity network. Renewable technologies, such as advanced glazing systems for daylight utilisation and solar thermal power delivery, could contribute to a significant reduction in building lighting and space/water heating demands (Born et al. 2001). For UK applications, photovoltaic and encased wind turbine technologies are complementary in that they compensate for each other's seasonal variation in electricity production in order to maintain electrical power delivery throughout the year. Although advanced glazings, photovoltaic and wind power technologies are mature, the challenges facing us are: (a) developing an understanding of system performance when integrated within the building fabric; (b) understanding the performance interactions when multiple technology types are applied to the building; (c) educating building design professionals in system configuration to optimise performance in different building sizes, shapes and locations; and (d) specifying appropriate technologies for the type of buildings being supplied, the plant within and the time and duration of operation.

Conclusions

Energy efficiency has the potential to contribute to substantial energy savings in the built environment in both the short and longer term. The challenges are first and foremost to develop a culture of energy awareness in building owners, designers and occupiers, and to provide the means to support improved energy efficiency within the design and operation of buildings. Further, any energy-efficient solutions must be robust enough to accommodate possible radical changes in the fuel supply and energy infrastructure.

Energy-efficient technologies in many instances are mature, although future technological developments are expected to enter the market. However, the efficient option is generally more expensive when compared to the conventional technology and is marketed as such. There is also a marked lack of skilled installers of new technologies and this needs to be urgently addressed.

Longer-term measures for improving efficiency are likely to see the integration of renewable technologies into the building fabric, although it's important to remember that, before these are considered, energy demands must be minimised and passive methods utilised as far as possible. The development of 'best practice' guidance and standards is required to enable building designers to ensure the technologies selected are optimal for the building operations. Advanced integrated building simulation has the capability to deliver this.

Future internet-enabled energy services have the potential to deliver low-cost building energy management capabilities for the mass market and to monitor and control plant operations for optimal performance. This will require the development of low-cost generic RF sensors and actuators, and the growth of companies offering energy services.

Widespread monitoring and analysis of operational energy use of buildings is required, with perhaps the development of the equivalent of an MOT for buildings and their systems.

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