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Technologies to achieve demand reduction and microgeneration in buildings ☆

Mark Hinnells *

University of Oxford, Environmental Change Institute, Oxford University Centre for the Environment, South Parks Road, Oxford OX1 3QY, UK

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ABSTRACT

Buildings account for almost half of UK carbon dioxide emissions, and energy demand in buildings continues to grow. In the context of economic growth, population growth, increasing demand for homes and commercial floor space, and increasing demand for energy services, energy use and probably carbon emissions look set to continue to increase unless there is significant change. This paper outlines enabling technologies that may permit a step-change reduction in energy demand from buildings through the application of next-generation information metering and control, energy-efficiency products and microgeneration. It covers both residential and non-residential buildings. This wide approach has been adopted because technologies and trends tend to migrate from one building sector to another, as, for example, IT has moved from offices into homes and lighting trends from offices and retail into homes. It covers technologies that can be used in new build or major refurbishment. Much of the need for change involves the better use of known technology, and some involves changing behaviour. Some behaviour depends on new technologies such as metering. Understanding how technological innovations are taken up (e.g. stock turnover issues, as well as how technical change occurs) and the economics of new technologies is as important as the technologies themselves.

1. Introduction

1.1. Scope

Given the imperatives of climate change, a massive technological change is needed in the way we heat, light and perform a range of tasks in our buildings. This paper outlines basic needs and opportunities in enabling technologies for step-change demand reduction in buildings through the application of next-generation information metering and control, energy-efficiency products and microgeneration.[1] The paper covers both residential and non-residential buildings (offices, retail, warehousing and public sector buildings such as education and healthcare). This wide approach has been adopted because technologies and trends tend to migrate from one building sector to another (e.g. IT, which has moved from offices into homes and lighting trends moving from offices and retail into homes). It covers technologies that can be used in new build or major refurbishment.

1.2. International context

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change included an entire chapter (Levine et al., 2007) on mitigation measures in buildings. The authors present the results of a survey of the global literature, in which there is high agreement and much evidence of the low-cost potential for carbon emissions reduction in 2020. But there is much uncertainty about higher levels of and longer-term potential for savings. There needs to be much more development if improvements in the reduction of carbon emissions are not to be wiped out by increases in services, leaving levels of global carbon emissions from buildings close to where they were in 2004 (Fig. 1).

The need for the change to be global in nature (accounting for variations in climate, levels of economic development, and local traditions and cultures) therefore requires international collaboration. In terms of research and policy co-ordination, there are several mechanisms, though these arguably fall short of the level of activity and urgency required. The International Energy Agency

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* Tel.: +44 1865 285164; fax: +44 1865 275850.
E-mail address: mark.hinnells@ouce.ox.ac.uk

[1] Although the term 'microgeneration' has become more common, the term 'low- and zero-carbon technologies' is preferred. Microgeneration creates the impression of electricity generation technologies, whereas much carbon saving is from the generation of heat with lower carbon. Microgeneration tends to imply an upper limit of 50 or 100 kW, whereas any technology up to several MW has significant benefits where it provides low-carbon heat and or electricity to a building, site or community.

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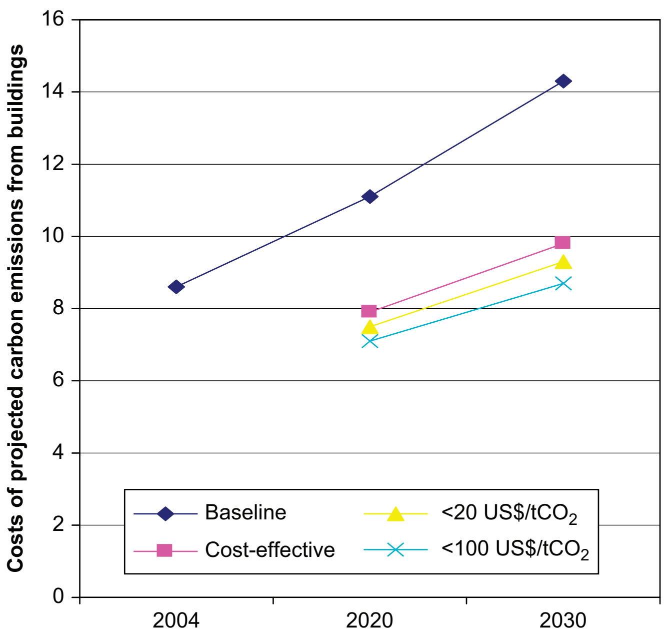

Fig. 1. Costs of projected carbon emissions from buildings (source: Levine et al., 2007).

has a range of technology agreements on aspects of energy use in buildings (www.iea.org/textbase/techno/index.asp). Key among these are on energy conservation and demand side management. At the EU level, the Intelligent Energy programme has funded much work in buildings (www.ec.europa.eu/energy/intelligent/index_en.html). The EU COST programme has set up a new network on Strategies for a Low Carbon Urban Built Environment (www.lcube.eu.com/). The remainder of this paper looks in more detail at issues pertinent to the UK.

1.3. The extent of change needed in the UK

Buildings account for almost half of UK CO_2 emissions, with residential buildings representing 29% of UK CO_2 emissions and non-residential 19%. To achieve the Energy White Paper objective of a 60% reduction in CO_2 by 2050 requires something like a 2% per annum compound reduction in carbon.

Despite efficiency improvements, total energy use has been rising in the residential sector by around 1% per annum and in non-residential buildings by 0.4% per annum since 1970 (with any reductions in carbon achieved only through fuel switching). In other words, there is still significant unmet demand for energy services. Often, improvements in efficiency are taken to be improvements in service and not as reduced consumption (the so-called 'takeback' or 'rebound' effect (Sorrell, 2007). Without significant changes, such trends could make a 2050 reduction target very challenging.

In homes, standards of comfort are changing with time and with increasing wealth. In the residential sector, analysis by the Environmental Change Institute (www.eci.ox.ac.uk/research/energy/bmt.php; Boardman et al., 2005) shows family size is declining (from 3 persons per dwelling in 1960, to perhaps 2.1 in 2050) at the same time population is increasing. Therefore, according to the same Environmental Change Institute study, the total number of homes is increasing (from 24 million to 32 million or more by 2050 and, since homes are not getting smaller, this equates to more space per person. Since 1970, there has been a large increase in the proportion of detached homes in the stock (from 10% to 22% in 2005, to an estimated 25% in 2050), and with more external wall space comes a higher heat loss. In addition, levels of thermal comfort (warmth) are increasing, as are demands for hot water consumption and electricity in lights and appliances.

Overall demand for commercial space is also closely related to population trends. In 1977, there were 23.3 m^2 of commercial floorspace per person. By 2005, this was down to 21.6 m^2. It could be expected to decline further, with changes in industrial structure, increasing costs of real estate and pressure on planning consent. Nonetheless, the relationship with population is a useful basis for projections of the overall level of the stock, since population projections are available up to 2050, given relatively well-understood drivers of birth rates, life expectancy and net migration. In addition to increasing space demands, space is used at increasingly higher occupancy densities, and energy is being demanded for longer periods (e.g. longer opening hours, and IT and lighting systems operating even when buildings are not occupied). A key trend in commercial space is the rapidly increasing demand for energy in ICT applications. There is a trend to outsource data management to independent organisations to ensure security of operation (including controlled conditions, power supply security and physical security. This is driving a massive increase in data centres (Hinnells et al., 2008a).

Management of commercial space is often not helpful to the management of energy consumption. According to Key and Law (2005), around 66% of retail, 63% of offices and 24% of industrial property by value is owned by investors. The proportion of stock owned by investors is increasing as owner–occupiers look to sell and leaseback space, in order to release capital to invest in core business activities. The split between landlord and tenant is often dysfunctional in energy terms, with neither party incentivised to invest in change. Significant policy change may drive a process of 'greening' commercial lease structures (Hinnells et al., 2008b).

The opportunity to achieve energy and carbon emissions reductions depends substantially on when old equipment can be replaced with new. Historically, turnover rates have been determined by end of economic life of equipment or an asset. The fabric of a building may exist largely unaltered for many decades, heating systems may last for 10–20 years, although many other systems are upgraded more frequently. For example, lights and appliances are commonly changed every 5–15 years. However, policy changes may accelerate turnover rates, and key opportunities to drive change include changes of owner or tenant or changes in use.

1.4. The role of behaviour and technology

Reducing energy use in, and carbon emissions from, the building sector is likely to require a mixture of technological advances, enhanced uptake of existing technologies and behavioural changes by individuals. Some technologies require further development before they have the desired energy-saving/low-carbon or low-cost characteristics. However, many of the key technologies are already at a commercial stage and the focus needs to be on establishing the conditions for widespread deployment.

An all-pervasive approach to technology adoption in the built environment will be critical because of the wide range of disciplines involved, from procurement processes to methods of construction, regulatory actions, new service models, buyer behaviour understanding, and technology advancement like the design of super-efficient appliances. As well as research and development, new technologies need widespread demonstration and improvement before displacing incumbent technologies and becoming mainstream.

2. The major priorities

Buildings exist to provide human comfort and security, within which a range of activities associated with normal living can be carried out. To provide comfort requires a combination of appropriate temperature control, humidity control and air quality (including avoiding the build-up of CO_2). Depending on the climate, internal spaces can require heating or cooling, humidification or dehumidification, and replenishment of fresh air. The thermal balance is particularly important. Buildings gain heat from solar infiltration, occupants, lighting, equipment and hot water, with any deficit between gains and desired temperatures made up by a heating system. Buildings lose heat by ventilation of warm air, and through the fabric of the building. Increasingly, activities associated with normal living use electrical energy and therefore heat gain to buildings is increasing, and in many commercial buildings, more than half the total carbon emissions can be produced by appliances and equipment.

A number of areas of research are important:

- metering and control systems
- technologies that maintain thermally comfortable and productive conditions, e.g. an appropriate balance of insulation and ventilation, façades including elements such as smart glass, shading and daylighting as appropriate, control systems, innovative insulation products and new forms of construction
- technologies that provide heating, cooling and/or electricity with a lower carbon content or zero carbon compared to conventional sources (e.g. micro combined heat and power (CHP), solar photovoltaic (PV) power, etc.)
- appliances or equipment that convert energy (usually but not always electricity) into specific end-use functions more efficiently (e.g. low-energy refrigeration and lighting). At the same time as exploring technologies to reduce consumption, awareness is needed of technologies that may dramatically increase consumption, e.g. the development of data centres.

Changes in emissions factors outside the sector (e.g. low-carbon-network-supplied electricity from large-scale renewables) are an important source of additional carbon reduction, but outside the scope of this paper (Table 1).

2.1. Metering and control

A range of smart metering systems are under development and trial in the UK (Department for Business, Enterprise and Regulatory Reform: www.berr.gov.uk/energy/environment/smart-metering/index.html). Smart meters ensure timely and accurate bills instead of estimated readings. They can tell people about their energy use through either linked display units or other ways, such as through the internet or television. They can have an impact on behaviour, through informing consumers of their usage patterns, for example, in comparison to similar households or businesses.

Building energy management systems cover a range of technologies, from closed-loop (relatively dumb) control to systems for individual buildings or groups of buildings that use computers for monitoring, data storage and communication. Systems such as those developed by CISCO (2005), enable all energy-using devices to be Internet Protocol (IP) enabled, so a centrally located facility can manage many buildings remotely. With energy meters and temperature, occupancy and lighting sensors connected to a building energy management system, faults can be detected using automated fault detection software. IP connection could enable not only buildings but entire networks to be connected together in a smart grid, facilitating embedded generation.

2.2. Fabric measures

The building shell includes: smart façades, intelligent buildings, new insulating materials, high-performance windows, thermal mass, shading, etc.

Within the highly conservative building industry, construction methods tend to change slowly. Building fabric systems that are produced in controlled conditions to tighter tolerances and quickly assembled on site may replace traditional 'brick and block' forms of construction for residential and non-residential buildings. New forms of construction (known commonly as 'modern methods of construction') are under development but better research into the effectiveness of modern methods of construction and better communication tools will be important to move these technologies forward. Using off-site construction to improve tolerances, optimise performance characteristics, and reduce construction waste could reduce construction time and construction costs. The net environmental benefit will depend on other issues, for example, lifetime, capacity for reuse or recycling, and assessment of the benefit of thermal mass in heating and cooling.

A smart façade adapts itself to the environment and climate, for example, by balancing the need for light with the impact of heat radiation in order to avoid overheating. Such approaches offer significant energy savings under particular conditions, but much research is needed to identify the most appropriate and cost-effective application of technologies.

One of the greatest challenges to upgrading the existing building stock will be improving the insulation of solid walls. At present, both internal and external systems are costly and can in certain situations (e.g. character property) be perceived to have aesthetic and other disadvantages. However, they can allow dramatic transformation of a building's appearance as well. Greater investment in research development and demonstration is needed in order to find out whether more advanced materials could produce more cost-effective and aesthetically acceptable insulation options.

2.3. Heating ventilation and air conditioning

Heating ventilation and air conditioning with significantly lower carbon implies moving away from conventional heat-only gas or direct-electric heating, and away from electric chillers, towards systems that make use of passive sources, renewables (sun, wind, biomass, etc.), or waste heat from power generation (CHP and possibly cooling), in that order of priority. A number of studies have come to broadly similar conclusions on the potential for microgeneration-based technologies (Boardman et al., 2005; Department of Trade and Industry, 2005; Environmental Change Institute: www.eci.ox.ac.uk/research/energy/bmt.php). Having said this, all too often the contribution of passive renewable systems (solar gain, passive cooling technologies and optimising use of daylight for lighting) are almost universally overlooked in policy design and need to be elevated to a principal, rather than a cinderella, role in delivering lower-carbon buildings.

Technical improvements in performance or cost reduction would radically transform a number of active renewable technologies. PV solar cells are currently a very expensive way of generating electricity. Nevertheless, if the price per kWh generated can be brought down, they have a large potential to produce low-carbon electricity in all buildings. The price of generating electricity from PV continues to fall as production volumes

Table 1
Technologies for reduced energy consumption in buildings

	Technologies on the market with the potential for higher uptake	New technologies with both market and technical barriers	Behaviour change
Metering and billing systems	• Smart metering	• Back-to-base smart metering automated feedback mechanisms	• Feedback processes • Time-of-day pricing
Production of electricity	• PV panels • Building-integrated wind generation	• Solar thermal plus a heat engine • Energy storage	
Heat gain or loss through building fabric and faç ades	• Building fabric materials with insulating qualities • Triple glazing • External shades and shutters	• Modern methods of construction • Smart facades • Phase-change materials • New materials and nanotechnology	• Workforce skills
Heat loss through ventilation	• Airtight buildings with mechanical ventilation and heat recovery • Passive (stack effect) ventilation	• Software for ventilation design feedback	• Workforce skills
Heating and hot water (often in conjunction with production of electricity)	• Control systems • Thermal mass, shading and orientation to manage solar gain • Solar thermal heating • Heat pumps • Thermal storage systems	• Stirling engine CHP • Fuel cell CHP • Anaerobic digestion of wastes and pyrolysis often at community scale • Biomass heating • Improved heat storage, e.g. vacuum insulation and phase-change thermal storage	• Interactive heating services linked to actual occupancy and/or seasonal comfort expectations
Space cooling	• Thermal mass, shading and orientation to manage solar gain	• Solar-thermal-driven cooling • Phase-change storage of coolth • Reverse-cycle heat pumps • Software for ventilation design feedback	
Lighting	• Fluorescent lighting, including compact lamps • Occupancy sensors • Better use of daylight (lightpipes, reflected light, etc.)	• Light-emitting diode (LED) and organic light-emitting diode (OLED) lighting • Software for daylighting design feedback	• Turning lights off
Refrigeration	• Absorption refrigeration using heat from CHP	• Absorption cooling using heat from solar thermal • Vacuum-insulated panels	• Avoiding features such as frost-free or through-the-door dispensers
Cooking	Gas or microwave cooking (rather than electric resistance heating)		
IT, communications and home entertainment	• LED screen technology	• New screen technologies (e.g. OLED) • solid-state power supplies (standby $<0.1\,W$) • fuel cells and solar PV power supplies	• Turning devices off standby
Washing and drying	• Gas tumble dryers		• Lower-temperature washes
Miscellaneous	• New products avoiding profligacy, e.g. through mandatory energy labelling of all goods	• Solid-state power supplies (standby $<0.1\,W$)	• Avoiding proliferation of standby consumption

increase; the efficiency of the basic cells continues to improve; alternatives to silicon cells are developed; cheaper substrates are developed (e.g. thin-film polymers rather than glass, or conventional tiling materials); and as costs come down through the use of concentrators (to focus more light on a smaller area of PV). (Issues associated with PV are identified in Photovoltaic Technologies Boreland and Bagnall.)

There is potential for heat pumps, including both ground- and air-source. A number of air-source heat pumps have recently begun to appear in the UK market, and cost improvements as well as improvements in co-efficient of performance could potentially see them achieving high levels of penetration. While they do not achieve the same high efficiencies as ground-source heat pumps, they are less disruptive to install. Heat pumps can be run in reverse mode to provide cooling, often at high levels of efficiency (for example, extracting space heat within a building, or providing water heating).

Large improvements can be made in solar thermal technologies. Producing hot water at higher temperatures plus improved thermal store for heat or coolth (e.g. through phase change) could see solar thermal providing significant space heating and space cooling as well as hot water provision.

Building-integrated wind generation would become much more cost-effective, with improvements in efficiency as well as reductions in cost. While very small machines are of debatable value, mid-range machines (5–50 kW) appropriately sited and installed (e.g. as part of new-build and high-rise developments) could provide a significant contribution.

CHP is the production of electricity and use of waste heat generated in the process of producing the electricity. A number of engines or prime movers can be used as the basis of CHP in buildings or networks, and micro-CHP at the house level (including Stirling engine, reciprocating engine, and fuel cell CHP). There is a great opportunity for the development and commercialisation of a range of fuel processing technologies, including biomass gasification, anaerobic digestion of wastes, and pyrolysis (to produce a synthetic gas for combustion), particularly at smaller scales more appropriate to community-based CHP provision. (A range of issues need development and these have been identified in a separate paper—Combined Heat and Power in Buildings, Hinnells.)

Fuel cells offer high electrical efficiency, but when used in combined cycle with gas turbines (at larger sizes), electrical efficiencies may approach 70%. Smaller devices too, such as 1–2 kW higher-temperature fuel cells may also be able to use gas derived from very small digesters running on household waste. (Issues associated with fuel cells are included in Hydrogen Fuel Cells: a vision of our energy future (Edwards et al.))

2.4. Lights and equipment

This section covers both domestic appliances and non-domestic equipment, including office equipment, commercial cooking equipment, refrigeration, etc. In the domestic sector, lighting and refrigeration account for the major savings potential, and electronics is the major growth risk. Taking the domestic and non-domestic sectors together, lighting, refrigeration, IT and home entertainment account for 36% of UK electricity (based on analysis by the Environmental Change Institute: www.eci.ox.ac.uk/research/energy/bmt.php).

2.4.1. Lighting

Lighting in domestic and commercial sectors accounts for around 16% of all UK electricity demand. Lighting energy use can be reduced by 75–90% compared to conventional practice through: (i) use of daylighting with occupancy and daylight sensors for electric lighting; (ii) use of the most efficient lighting devices available; and (iii) appropriate use of ambient and task lighting.

Use of daylighting requires rethinking of architectural processes. Turnbull and Loisos (2000) found that, rather than involving lighting consultants from the very beginning, architects typically make a number of irreversible decisions (e.g. about layout) at an early stage of building design that adversely impact on daylighting, then pass on their work to the lighting consultants and electrical engineers to do the lighting design. As a result, the lighting system becomes, de facto, strictly an electrical design.

More efficient products will become available. Whilst incandescent technologies produce up to about 20 lumens per Watt (lm/W), LEDs already achieve up to 100 lm/W and are broadly comparable with fluorescent technologies for energy performance. They also carry benefits in terms of life time and controllability of the light source. However, LEDs are still at the early stage of development for higher lumens per watt, and in terms of commercialisation. LEDs offer an opportunity to rethink the whole process of providing lighting services to buildings, particularly when paired with renewable electricity and storage technologies that operate more effectively at lower voltages and using direct current. Challenges include:

- increasing the lumens per Watt from LEDs to 150–200 lm/W
- retaining the characteristics of the lamp (colour, brightness, etc.), throughout its life
- developing a portfolio of controls and fittings appropriate to the technology
- developing new systems for the provision of light in residential and non-residential buildings.

It is likely that LEDs will see earlier application in high-value environments like hotels, retail and prestige offices before being more generally applied in housing. It may also be that LEDs penetrate new-build applications (where fittings and control systems can be installed from the start) in a different way to the general refurbishment market.

2.4.2. Appliances and equipment

A particular end use where efficiency improvements could be achieved is refrigeration (both domestic and commercial). Together these sectors account for 8% of UK electricity. Using known technologies, consumption of new domestic refrigeration devices fell by more than 35% between 1997 and 2004 (CECED, 2004). The stock will take 15–20 years to turn over, and further savings are available. A similar order of savings are available in commercial refrigeration (Schäppi et al., 2005). To go significantly further in either sector requires new technologies. A key element of the potential for energy saving is from vacuum-insulated panels (VIPs) replacing foam insulation. VIPs are a technology that can reduce energy losses by 75–80% compared to conventional blown foam insulation for the same thickness of material. VIPs require innovative production methods and new concepts in design. In a price-sensitive market, there is little incentive for a manufacturer to produce a model much more efficient than the rest of the pack. The impact on the product distribution chain is unknown. For example, how resistant to damage are the panels? What happens to the insulation value if the vacuum is lost? What is the impact on failure rates, profitability and consumer perception? What is life expectancy? Tackling these issues would be easier in high-value, low-volume products (e.g. medical or refrigerated transport) and would cascade learning through to the lower-value, high-volume domestic refrigeration market and even the domestic water storage heater market. If VIPs were developed, they could see use in a range of other end uses—ovens, hot water storage, building insulation, etc.

Home and office IT and home entertainment systems (taken together) account for 9% of UK electricity consumption.

In the home, there is a significant historical and projected increase in ownership of 'always on' devices or devices with standby, with a proliferation of batteries and chargers. Transformer-based power supplies currently consume 1–7 W, but solid-state power supplies with losses of 0.1 W are possible. In the home, television, phones and computers are tending to merge. Increasingly, televisions have writeable storage (currently DVDs), together with software capability for games playing. Home entertainment products and PCs are likely to come together as a single group. At the same time, phones are merging with portable computers, and even—with the advent of 3G—with televisions. Televisions are merging with PCs, with new USB-based freeview devices for PCs giving access to all digital television channels. So while main televisions are getting larger, second televisions could be portable or even pocket devices. The whole area of communications is merging. In practice, this is happening quickly, and significant change could be seen before 2010.

Fuel cells may power a range of residential and commercial mobile devices such as phones, MP3 players, PDAs and laptops in the next few years, and a number of companies are developing prototypes. The input fuel would therefore be gas rather than electricity, with much lower carbon emissions. In due course, PV may make a comeback for small electronic goods if efficiency improves (from 6% to 20% and even 50%), and if costs come down (e.g. moving away from silicon-based technologies and using polymers rather than glass as a substrate). PV will require back-up power sources either in the form of a battery or fuel cell, with both technologies making significant technical progress.

In the commercial environment, the major issue is the enormous growth in data centres. With demand for data doubling approximately every 5 years (taking up expensive space in town centre locations) and data now so central to commercial operations, companies are contracting out data management to data centres, equipped to provide both power security and data security. Data centre energy demand, and therefore carbon emissions, is becoming such an issue that they are being seen as 'the new aviation'.

3. Diffusion of technology within the building stock

Having the right technology at the right price is not sufficient to ensure that efficient or low-carbon solutions are adopted to their maximum potential. Far from it. Very few efficient technologies have been installed at anywhere near 100% of potential. There is room for greater installation of everything from loft insulation and cavity wall insulation to new and better windows and district heating. Some of these technologies can be upgraded as part of the normal replacement cycle for equipment and appliances (e.g. double or triple glazing, efficient washing machines), whereas others can be installed at any point as an efficiency improvement (e.g. roof or wall insulation), and still others only as part of an area improvement strategy (district heating). The policy strategies that would lead to greater uptake of these technologies have been presented in detail in work by the Environmental Change Institute (www.eci.ox.ac.uk/research/energy/bmt.php; Boardman et al., 2005). Many technologies would be developed in one sector and would diffuse across the economy. In many cases, the household sector may be the last to benefit fully, for instance, with LED lighting.

In addition to technology-based research and development, further work is needed on a range of issues. These include how technological innovation happens (building, for instance, on Hinnells and Boardman, 2008), and what affects the uptake of technologies for both the new build and refurbishment of existing buildings. Policy to promote uptake needs to be evidence-based. Many of the industries involved (e.g. the building industry and the appliances industry) are low-technology, with little investment in innovation, and are risk-averse. They do not (yet) perceive a market for innovative low-energy products.

What are the impacts of changing the socio-technical system? The move from central generation to microgeneration and smart metering may make consumers much more interested in how they consume energy. Research suggests that people who install microgeneration devices also reduce energy use.

The economics of new technologies and techniques needs further understanding, including, for example, the impact of increasing volumes on the cost of various measures. There is a substantial literature on technology learning or experience curves (e.g. International Energy Agency, 2000) which has been applied predominantly to large-scale power supply, very little to microgeneration (other than PV), and very little to energy efficiency. Very high levels of uptake could reduce capital costs significantly. The impact on the cost of a whole-building approach (rather than measure by measure) needs to be understood. At present, cost-effectiveness calculations assume piecemeal measures and show many measures to be expensive. If several measures are undertaken concurrently, cost savings can be achieved. Changing energy prices will impact on cost-effectiveness. A long-term forward view may require us to work on the assumption that energy prices are very much higher than they are now, given growing demands in developing nations and constraints on supply and on the amount of carbon we can emit into the atmosphere. And finally, the criteria for investment need to be revisited. Currently, Government (e.g. through decisions on building regulations and grant programmes) uses a similar benchmark for payback in energy efficiency in buildings as in plant and machinery. However, the economics of investing in different asset classes are profoundly varied. A motor, air-conditioning unit or car has a limited life, and measures must pay back within the life of the asset. However, buildings have a long life and are appreciating in value, not depreciating to zero. In addition, there is reason to suppose that rental or resale value will be linked to energy rating (an assertion that will need validating by research once the energy label for buildings is introduced). If this relationship is proven, savings from energy efficiency in buildings may need to cover only interest payments and not capital repayments.

Policy to encourage new technologies interact with some of the themes above. So, for example, many technologies have the potential for substantial application in buildings but, because of the diffuse nature of the industry, research and development opportunities are difficult to facilitate. Investment in trialling new technologies has the potential to deliver large-scale environmental change. A number of measures may encourage carbon literacy (including widespread labels, more widespread carbon trading schemes, including personal carbon allowances). In the right market framework, energy service companies (ESCos) could finance investment on the customers' side of the meter in preference to building new large power projects. Policy to support ESCos has been explored by many, for example, the UK Energy Research Council and the Sustainable Development Commission (2005). Policy can remove the worst products from the market. The EU Energy Efficiency Action plan lays out 14 product groups where regulation could be introduced (European Commission: www.ec.europa.eu/energy/action_plan_energy_efficiency/index_en.htm). Globally, more than 200 minimum standards are in place (Collaborative Labeling and Appliance Standards Program: www.clasponline.org/index.php).

There are many human issues to consider. For example, how do consumers identify which actions to take and why? What impact would smart metering and billing have in different market segments? What new business models or service models may be needed? What are the training needs for the workforce?

4. Capabilities assessment

The UK has perceived itself as having a strong research base on buildings. This perceived pre-eminence (if it ever existed) is diminishing rapidly. For example, the quality of our new build is poor relative to some European markets, and the incentive to innovate in new or in the refurbishment of buildings and associated equipment is low, if not non-existent.

It is timely for the UK to take stock of its building research focus and consider the role of the market in parallel to the examination of individual technologies. Research that captures the drivers for industry and/or consumer adoption of technologies is as important as improving technologies. Closer relationships between technology research and technology deployment could facilitate faster environmental change.

5. Conclusions

Buildings account for almost half of the UK's CO_2, and energy demand has been growing for several decades. In the context of economic growth, population growth and smaller household size, this looks set to continue, without significant change. New technology is required and needs to include better building shells, microgeneration, and more efficient appliances and equipment (especially lighting, refrigeration, information technology and home entertainment). Much of the need for change is in better use of known technology, and some relates to behaviour. Some behaviour depends on new technologies (e.g. metering).

Understanding how technological innovations are taken up and the economics of new technologies over long time periods (with higher energy prices and lower equipment prices from technology learning) is as important as the technologies themselves. The right decision-making framework for consumers is essential to the delivery of change. This would include information (e.g. labels), incentives (e.g. The Governments proposals for the Carbon Reduction Commitment) and know-how and access to capital (e.g. Energy Services Companies or ESCos). Such a framework can be underpinned by regulation (e.g. the Energy-Using Products Directive) to remove the worst products from the market. There is a significant challenge in integrating the engineering and technology issues appropriately with the behavioural, economic and policy issues.

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