

THE BUILT ENVIRONMENT

Fit for a sustainable, energy-efficient and climate-resilient world

M.J. Kelly
 Department of Engineering,
 University of Cambridge

Introduction

Given that for the first time in history we have now had a decade of global wide-bandwidth communications – so that no-one has the excuse of being ignorant of other people’s problems – what has come to the fore in global discourse, both popular and among political leaders? The answer is a litany of Malthusian issues: overpopulation, resource depletion, environmental degradation, climate change, the downsides both of poverty and of affluence, etc. We could add the global financial chaos to this list! These concerns are heightened by the increasing information from sensing systems of the perturbations caused to our global ecosystems by the actions of mankind.

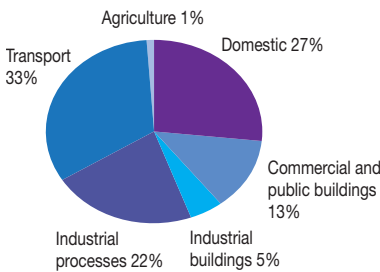
The world as a whole faces a particular triple challenge over the next few decades. The developed world is already consuming resources in an absolutely unsustainable manner, while the developing world is degrading its local environment just to produce sufficient food. Peak oil will come one day (it already has for the major Western countries), and there are no known and practical alternatives ready to replace the growing shortfall at the appropriate scale: much greater energy efficiency will become a necessity. The preliminary data on future climates exists, and most future scenarios point to more extreme weather events. Buildings are responsible for over one third of global energy consumption, through heating air and water and the use of appliances. The ECS (Energy efficiency, Climate resilience, Sustainability of consumption) triple challenge will in large part be met or missed by what happens to our global built environment over the coming decades.

With specific reference to the United Kingdom, 45 per cent of today’s energy consumption occurs within existing buildings, and 87 per cent of those buildings will still be present and operating as about 70 per cent of the building stock in 2050. Our homes are responsible for over 27 per cent of all our energy consumption today (Figure 1).

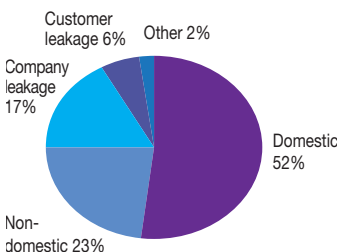
It is estimated that it would require three planet earths to source global consumption in a sustainable manner, if everyone in the world were to share our current lifestyle in the UK. For three to four years now, we have been net importers of energy. Over the last 30 years, since we have had the North Sea as our gasometer, we have run down our ability to store natural gas. We are particularly susceptible to spot price fluctuations, and our energy security is in the hands of foreign countries. Great improvements in energy efficiency are essential if we are to regain our energy independence. If we are to mitigate the worst of future climates, and adapt to the

Figure 1
 The built environment has a significant impact on emissions and water consumption.

Carbon emissions from energy use in buildings account for 45% of UK emissions



Water use in homes accounts for over half of public water consumption



inevitable future climates, our existing buildings will need a serious makeover, and our new buildings will need to be constructed to standards higher than are contemplated today – they will have to be ‘carbon negative’.

If one were to consider the retrofitting of the existing built environment over the next three to four decades, so that it becomes fit for purpose, as a single civil engineering project it would be the largest ever contemplated in the history of the world, and for the UK in particular. This way of thinking – including strong lessons for what can and cannot and should and should not be done – will be explored further below.

It is essential to consider the closely interrelated nature of these challenges as they apply to buildings: the measures needed to address one challenge will play their full role in addressing the other two. An agnostic on the current need for deep interventions to mitigate climate change can still be concerned about energy security now, and sustainable consumption in the near future.

The UK housing stock

Domestic buildings

There are 22 million homes in the UK and about 5 million non-domestic buildings. About 7 million homes were built before 1900. (In the 1800s, many workers brought home a bag of coal, and in the 1960s energy was cheap. Unlike Scandinavia or the Mediterranean, our climate is moderate, and thermal insulation to keep heat in or out was never an important design issue). Building in the UK peaked at 410,000 per year in 1968 (Figure 2), but was down to 141,000 per year in 2000, very similar to the number in 1900.

In recent years it has dropped again because of the financial crisis, while the government has a policy of trying to have 200,000 built per year. This is of the order of 1 per cent growth a year. The life of our homes is very long: only about one house is demolished for every ten new ones built. Semi-detached housing at 4.9 million is 31 per cent of total stock, followed by low-rise flats and detached houses. The UK has been an urban society for some time, and the population in urban areas increased

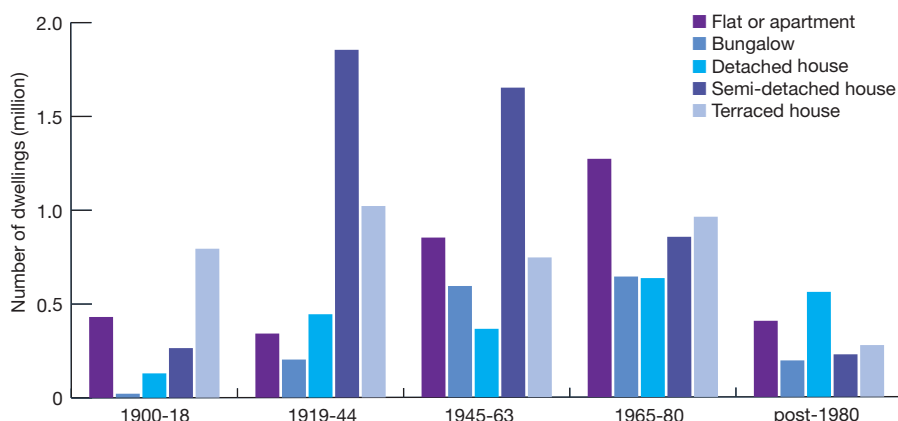


Figure 2
Profile of housing stock
in England.



Arlingstone/Wikimedia commons

from 77 per cent to 89 per cent of the total during the 20th century. In France this ratio grew from 59 per cent to 74 per cent in the period 1954 to 1990 alone. The UK is an outlier in Europe, with 68 per cent of homes in owner occupation (up from 10 per cent in 1900), while private rental dropped from 89 per cent to 10 per cent in the 20th century. By 1999, 17 per cent of all homes were rented from local authorities and 5 per cent from housing associations, although the balance between the two has been shifting towards associations as a result of legislation. These statistics form the backdrop of ownership against which the practical policies for meeting the triple challenge must be couched.

The UK non-domestic stock

The approximately 5 million non-domestic buildings are a rather more heterogeneous collection, but there are major sectors: hotels, hospitals, retail outlets, office blocks, warehousing and factories (for both light and heavy industry). As a group they are newer than homes, and in practice they receive a makeover on a more frequent basis than do homes.

Housing improvement in the periods 1990-2005 and 2005-2020

Between 1990 and 2005, the carbon emissions from domestic buildings dropped by a net 4 per cent from 154 million tonnes of carbon dioxide equivalent to 147 million. During that period there was a 10 per cent increase in house numbers, a 4 per cent increase in population, and a sharp rise from a very low base in the electricity consumed by electronic appliances for IT and entertainment (e.g. computers and plasma screens). The reduction in CO₂ emissions might have been 10 per cent or more without these countervailing factors. This net reduction came, in the main, from the recorded steady progress in measures to improve the thermal envelope in houses. We consider the following basket of interventions: installing 75 millimetres or more of loft insulation, double glazing more than 60 per cent of the windows by area, draught-proofing over 60 per cent of rooms by volume, and installing cavity wall insulation where appropriate. The house condition survey shows that about 35 per cent of all houses already had this standard of insulation and were already capturing the energy-saving benefits in 1990, and this figure rose to about 65 per cent by 2005. At the current rate of installation, these measure will be exhausted by 2015, and they have a strictly limited capacity to drive further deep reductions in CO₂ emissions from our homes, even if we increase the depth of loft insulation and take the 60 per cent figures above to 100 per cent. When we note that the 2008 Climate Change Bill sets a 24 per cent reduction target by 2022, we can see that the building sector is going to have to work on its existing stock to achieve *six* times the net reduction in carbon emissions in the current 15-year period, and we are already 30 per cent through this second period! We have indicated a limited capacity of the thermal envelope to contribute, unless there is a major R&D project to bring forward new thermal insulation materials and products with new and more effective means of installation. This factor *six* sets the scale of the challenge that faces us for housing, let alone any other part of the national infrastructure – non-domestic buildings, energy supplies, transport, etc. It is clear that current policy thinking is far too timid: the saturation of even 250 millimetres of loft insulation, and the completion of double glazing, draught proofing and cavity wall insulation measures only buys us a few years to get more radical interventions ready for roll-out.

Measures to 2050

There are four ways in principle by which the operation of domestic and other buildings can contribute their full share of an 80 per cent reduction in carbon emissions, improve energy efficiency and move towards sustainable consumption, and they are all needed:

1. New measures to improve the thermal envelope of buildings – materials, installation processes, controls, etc.
2. Decarbonizing the grid and other sources of energy.
3. Improving the energy efficiency of appliances.
4. Changes in personal attitudes and behaviour concerning profligate energy consumption.

Of these, only the second is widely accepted in the public debate, and measures are being taken in relation to renewable sources of energy, a nuclear rebuilding programme and a renewal of a more efficient grid. There are concerns about whether lights will go out within a decade as a reward for past dithering on the big decisions. Any actual crisis will sharpen the debate about energy efficiency. About 5 per cent of all electricity in the USA (and UK) is consumed by IT, especially for cooling hardware. Domestic cooking and lighting consume about 10 per cent of domestic electricity.

Behaviour change is well documented as a cause of high energy consumption in buildings. In an era of cheap energy, our concept of comfort has evolved over the last 40 years. Those over 60 now can remember houses where only one room was heated at any time. Whole houses are now routinely heated, and the ambient temperature has risen from 17°C to 22°C. Public buildings are controlled to a temperature of typically 22±2°C all year round, and even in winter, the morning blast of energy from 0600 to 1000h is followed after 1200h with chilling of the air for the rest of the day to remain within the specified bounds. At Eland House in London, the headquarters of the Department for Communities and Local Government, a small move to maintaining the temperature at 21±2°C in winter and 23±2°C in summer is anticipated to reduce the heating bill by 9 per cent and the cooling bill by 5 per cent. Mr Koisume, Prime Minister of Japan, in 2005 ordered that no public buildings should be cooled below 28°C or heated above 22°C. This has led to a revised dress code ('cool biz', where men do not wear jackets or ties in summer). What evidence I have seen points at most to a 2 per cent drop-off in the efficiency of call-centre operators working under this wider temperature regime in Tokyo. Redefining the acceptable levels of comfort at work and at home will be one of the major areas for meeting the interim carbon reduction targets for 2020.

The noble efforts of a few to green their homes at great personal cost in terms of money and time are all very well, but they are not role models for the whole of society. If we think that we might have at most two chances to make a major intervention to any given home between now and 2050, we must scale up over the next few years to a steady state of 1 million houses per annum being subject to a whole house intervention. One will see energy, water, waste and air systems being upgraded to be more efficient. Anything less will not get us to where we want to be. This is about double what is estimated to occur at present in terms of renovation, a much more limited and simpler activity. Do we have the capacity to grow the sector to what is needed?



Mandy Barrow/www.woodlands-junior.kent.sch.uk

The building sector

The real problem is that there is no retrofit market for buildings. The renovation market, such as it exists, is totally balkanized with small firms or single traders offering limited services. Reality TV shows depict examples of poor workmanship when some interventions are undertaken. There are many suppliers of different products with no large market leaders. The many small players are keen to play a role, but all are looking for clear leadership: none are willing to risk their own businesses by going out alone and ahead on the green agenda while others continue to cut corners on products, services and prices.

There is a further structural problem that needs fixing. In recent years, much public and some private money has been committed to R&D towards solving the problems of energy inefficiency, climate change and sustainability. Funding agencies can be assured of a route to market of successful R&D in nuclear rebuild, renewable energy, and carbon capture and storage. Someone bidding to research on new external cladding materials cannot get the support from big players that do not exist, and that bidder is at a disadvantage. Indeed there are some novel technologies sitting on the shelf for want of a clear order for 10⁶ pieces that would justify the tooling-up for manufacture. Until there is a retrofit market, the gap between rhetoric and appropriate action at scale will continue to widen.

The new building sector is better off, with demanding targets of zero-carbon new buildings by 2016 and 2018. The new materials and products are likely to be closely coupled to new methods of construction that will not be applicable to retrofitting the existing buildings, which are constrained by older methods of construction and were designed in an era of cheaper energy.

Suggestions for national action

Given the responsibility for building regulations and codes, and for planning, there have been five areas where I, as Chief Scientific Advisor at the Department for Communities and Local Government, was urging action of my civil servant colleagues to move in getting the existing building stock to play its full roll in seeing off the triple challenge. The common theme is to appreciate the scale of the problem and start working towards measures that solve the problems at the right scale.

1. If the further and higher education sectors would volunteer (or be tasked) and be funded to get their own estates to the 2050 targets for carbon emission reductions, with the concomitant increase in energy efficiency and a move towards sustainable consumption by 2035, they could show the rest of the country the way. Their buildings are proxies for private dwellings, public buildings, offices and factories. Some of the brightest minds in engineering and psychology are on campus, and if the higher/further education sectors cannot succeed, who else can we expect to succeed? (Large corporations will probably get there, but their building stock is a small subset in number and type, compared with the whole.) The students, who are the leaders of tomorrow, can be inspired to participate. The skilled personnel needed for the transformation of existing buildings can be recruited and trained within these education sectors. There are over 100 universities and over 400 further education colleges, and at least one



Mandy Barrow/www.woodlands-junior.kent.sch.uk

within 30 miles of every citizen in England. The scale of the sector is big enough to engage the building sector in bringing new products and services to market. Having universities in the lead of efforts to 'save the planet' is a natural and timely extension of their recently acquired role as engines of local economic growth, and is a possible source of large philanthropic funding to supplement the public sector and fees-based income. Knowledge exchange is a core skill of academics, so they can be articulate advocates of what works and critics of what fails in the journey towards a new national built infrastructure. Many universities are doing experiments at present, and though they are not to the scale needed to impact the whole country, they could be directed to that position.

2. The public sector building stock could be retrofitted to a schedule and scale that could create and drive a retrofit market. Between them, the health, education, defence, social housing and local government sectors spend of the order of £10 billion per annum on renovation. By working together and specifying aggressive improvements in the performance of future thermal materials, products and installation processes, and better and more efficient appliances, the public sector could use their financial muscle to create and drive the retrofit market, just as the California legislature drove the market for the reduction in vehicle emissions from the mid-1980s. In ten years, the individual home owner would find only superior-performance products on the market and at competitive prices. There could even be council tax surcharges incurred by inferior quality work.
3. Central government ambitions for the nation are actually delivered at a local level within local authorities. Few universities, companies, local authorities or other bodies who espouse their green credentials have any vision that extends beyond 2015. I would like to see model trajectories developed at the local authority level that will tell us how Cambridge, Manchester or London are going to work in each of the eight five-year periods from 2010 to 2050 to meet the 2050 targets and the interim targets. There is no need to rush at everything indiscriminately. Some model trajectories, engineering equivalents of the economic arguments of Stern, would add immensely to the quality of policy formation and action plans. We do not want to imitate the first-generation biofuels actions which have made matters worse on several fronts, with little or no carbon savings and unwarranted disruptions to other aspects of civilized life. One factor that might come to the fore is the relatively greater effectiveness of some energy-efficiency measures if they are undertaken at a community level, or at some stage involving several households. Another is how one might cope if there are radical changes to the supply of energy: if, in 20 years from now, natural gas is regarded as too precious to be used as a heating fuel and is then reserved to be an industrial feedstock, how will the UK move smoothly on a national scale to other forms of energy? It is individual actions, integrated at the local authority level, that will most effectively capture the problems and opportunities over the next 40 years.
4. Over the last four decades, public attitudes and behaviour have changed with respect to wearing seatbelts in cars, not drinking and driving and not smoking in public confined spaces. We have to reach a position where the profligate use



BG-Williams/UNEP

of any form of energy is considered deeply antisocial, and personal behaviour tends to exploit any technology interventions rather than circumvent them. A commonly accepted redefinition of comfort at home and at work is an essential first ingredient, taking a steer from, and extending, the Japanese initiative.

5. The planning system in the UK is premised on the basis that applicants have to show that they are not offending local plans. This will have to change to a more permissive regime if the carbon reduction targets are to be met. With 15 per cent of buildings in the Southwest being either listed or in conservation areas, wherein most current methods of saving energy (solar panels on roofs, double glazing, external cladding, etc) are not allowed, we can admit defeat now. With the advent of horizontal rains as a part of future extremes of climate, such buildings will be defenceless and subject to accelerated ruin, exactly what is not intended by current legislation. We will not want the National Trust having to hand over buildings to English Heritage, which has a wider experience of handling ruins! We are going to have to change for the sake of our heritage. More widely, concerned citizens should be met on the presumption of permission for a wide range of approved energy-efficiency measures.

The scientific and technical challenges

The pursuit of clean energy sources is well rehearsed in public discourse. If someone could see the way to treble the capacity of the grid and supply it with clean electricity for (say) £1 trillion by 2035, the debates might be over. However, the engineering challenges suggest that this could not be delivered in time. Under such circumstances, every little bit helps a little, but every large bit helps more.

Materials of much greater thermal insulation (per unit thickness) must become available in quantity, having accompanying properties of mechanical and other stability and durability, and ease of application to both the interior and exterior walls of our buildings, including floors.

Better heat exchangers can reduce waste when air and water leave buildings. Civilized people can live with much less than half our present daily consumption of water – at present 50 per cent of UK water consumption is for domestic purposes (Figure 2), and the natural environment would improve if we drew less water from aquifers and rivers.

An IT revolution applied to the simplification of building controls could make deep inroads into energy consumption in buildings if carried through with new conventions on comfort. If more of our tasks could be undertaken virtually rather than physically, a smaller environmental impact might follow.

A major drive to reduce the energy consumption of appliances should put much greater emphasis on the appliances themselves, to reduce their energy needs rather than exhort users to use them more sparingly. Normally off, rather than normally on standby, is one early move.

For the R&D community, a new emphasis on the urgency of exploitation will be needed. The linkages between ultimate end-users and initial researchers will need to



L. Prosser/UNEP

Available figures show annual energy use of buildings decreased by 0.7 per cent between November 2004 and 2006.

There was an overall increase of 1.1 per cent in carbon emissions in that period.

Over that period there were increases of:

- 67 per cent in photovoltaic installations
- 23-36 per cent for small wind turbines
- 21-24 per cent for small hydro schemes
- 150 per cent for ground-source heat pumps
- 140 per cent for biomass installations

Use of recycled material in construction increased 21-23 per cent by value and 20-22 per cent by mass.

Figure 3

The scale of the adaptation challenge.

Sustainability: Communities and
Local Government report to
Parliament, 2006.

be tighter than in the past. When sums of the order of £1 billion are devoted to UK programmes such as the Energy Technologies Institute, or Living with Environmental Change, those committing such sums are entitled to expect more than the outputs of 1,000 independent £1 million programmes, but rather to be able to answer, within a decade, what difference such investment has actually made to the nation in practical change. The intermediary organizations that perform the linkages will come to play an ever more important role. The Haldane principle leaves it to the scientists to decide what programmes to fund out of the public funding of science. Where a challenge to the nation can be considered at hand, the relative ease in implementation, and the likely impact at the large scale of implementation, will become a much greater determinant of how scarce R&D resources are deployed.

The government scorecard

A plethora of measures are being issued by many individual departments of central government to tackle aspects of energy efficiency, climate change and sustainable consumption. Not many of these measures are noted to be tackling all three challenges simultaneously (Figure 3).

Few measures are accompanied by a robust analysis of exactly what savings are to be achieved per measure and by when and exactly how. It is stated that 3,000 windmills will be put up in the North Sea by 2020 (i.e. one every day from now till then), but the commitment is not accompanied by the facts that (i) it takes of the order of a week to take such a windmill from shore on a specially design boat, to erect the windmill and return for another, and (ii) there are only 60 days a year when the sea is calm enough to erect windmills. We need 42 special boats to guarantee success or seven erection barges and a flotilla of ships to keep them supplied with new windmills.

A notable exception is the Department of Energy and Climate Change's 'UK Low Carbon Economy Transition Plan' of July 2009, which is still an economic analysis (see below), but it is the first with a clear contingency provision that will ensure that overall targets for 2020 and 2050 carbon emissions will be met. The analytical annex to this report does not include the word 'engineering' even once. The presentation is typified by the following paragraph:



B Dungee/UNEP

Reducing overall energy demand can potentially be very cost-effective. However, there are real and practical constraints to what may be achievable on the ground. These include:

- *The scale of change we are all prepared to see in the way our homes look and are built.*
- *The physical constraints and engineering challenges in moving to new technologies, such as installing large numbers of ground- and air-source heat pumps, or setting up district heating systems.*
- *The commercial and lifestyle changes businesses and people are willing to make.*

There are a number of targets for 2010 which were set earlier in the decade (e.g. under the Kyoto Protocol) that have been met by serendipity. One would not propose a collapse of the Russian industry to enable that country to meet its emission targets, any more than we should rely on the tail end of the ‘dash for gas’ to achieve emissions saving that should have come from more aggressive action within the building sector. Short-term government targets to curb emissions from within its own estate are being missed: this is because those issuing the targets had no detailed appreciation of the civil engineering needed to accomplish them. The languages of Whitehall and Westminster are first economics, second social science, and third the law, with science and then engineering coming later, and this will remain the core of the problem. It is arguable that the MPs involved did not fully appreciate the commitment Parliament was making when the Climate Change Committee was set up and its targets were subsequently accepted. This brings me to the last major point.

The big civil engineering project

Let us regard the retrofit of the existing built environment and of the national infrastructure (transport, energy, waste, water, etc) as a single but complex civil engineering project that is scheduled to be completed to the specification of an 80 per cent carbon emission reduction for the national society and economy by 2050, starting from where we are now. What are the implications for the legal system, society and the economy that follow from this view? Where we might come up against difficulties, it will then be incumbent on the engineers to lay down the *de minimis* requirements for achieving the objective, and then for all the others to make the necessary adjustments and provisions! Rather than have economics drive what can be done, as is the current mindset in Whitehall, we will end up having the global and national economies being driven for some decades by what must be done! Is there the will or urgency at scale?

The first decision will be the extent of the decarbonized provision of electricity in 2050. Clearly if there was a credible proposition to decarbonize the grid and quadruple its capacity by 2050, we would need to do nothing other than switch everything to electricity, starting with all ground transportation. A much bigger, sustainable and decarbonized UK electricity grid is not on the horizon. We should take the ambitions of the sector and assume that they get 80 per cent of the way to their target of providing electricity that is 80 per cent decarbonized, and work from there.

The next set of decisions will include the phasing of major works in terms of what can be deferred in the confident anticipation of superior technologies deployed at

scale in a known future window. We might choose certain areas of the country at risk in terms of future climate (e.g. the buildings and infrastructure on flood plains) as vanguards and pilot exemplars from which lessons learned can be incorporated as other areas come in behind. Alternatively, we might consider these places at risk as too important for making mistakes, and choose other localities for the pilots.

A comprehensive plan of works could then be accompanied by a more detailed analysis of the resources required and the sustainability of that consumption. Manpower requirements can also be extracted. A range of options in the project plan are probably possible, and these could be costed, so that forward budget profiles could be established.

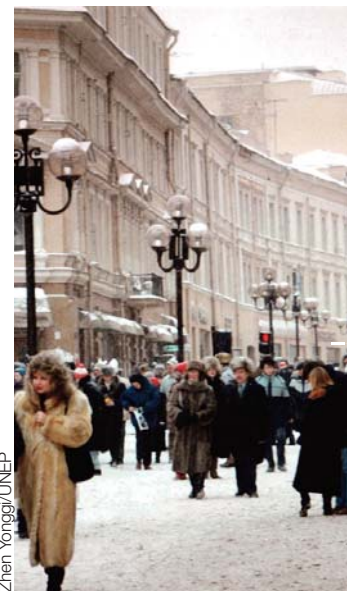
This sort of work happens at a smaller scale in all large civil engineering companies, and it would be strongly in the national interest to have such work carried out to help frame the public debate. Taking a single-project view of meeting the triple challenge would learn lessons from the Manhattan project, where a technical outcome was needed in an urgent timeframe and resources were marshalled to guarantee success without any subsequent evidence of profligacy.

Just do it

Rather than be paralysed by ever more analysis of the triple challenges, there is a strong case to be made at the local level to just get on and do something about it. After all, the present infrastructure in Birmingham was established by Joseph Chamberlain as mayor – he just got on with it. Firstly, imagine a local authority working out exactly what it would do with some £1 billion to improve its locality in terms of energy efficiency, climate resilience and sustainability of consumption. The key questions will be: What will it cost to reduce our local carbon emissions etc robustly to 60 per cent of 1990 levels in the next decade without compromising our ability to get to a more than 80 per cent reduction by 2050? How would spending be divided between buildings and (transport, energy and waste) infrastructure to get the deepest cuts in emissions? What is the appropriate balance of investment between mitigation and adaptation to future climates? What should be deferred so as to get much more effective action a decade hence, and what is left that should be started now? Secondly, how could we arrange for an acceptable return on a long-term investment – energy savings, council taxes, communal transport income...? If there are satisfactory answers to both kinds of question, and the second will be harder at present, then we could approach the pension funds or other long-term investors. The people joining pension schemes now will draw their pension in the 2050s, and they should expect their contributions to be invested in part to ensure that the world is a better place than it would be if business as usual continued in the intervening period. There is the pragmatic challenge for a local green community that cuts through all the analysis in Whitehall! If the numbers do not add up, then it will be a matter of further public discourse until they do!

The European context

Worldwide energy consumption within buildings represents about 35 per cent of all energy used. In the EU, buildings in Scandinavia and Iberia were designed and built from the outset with due considerations for extreme weather. During neither of the



Zhen Yongqi/UNEP

peak UK building periods in 1860-1900 and 1945-65 was energy efficiency a major issue – during earlier times many workers got a regular bag of coal and in later times energy was cheap. The very heterogeneity of the housing stock in the EU, especially in terms of energy efficiency, is represented in the range of targets and measures being implemented (see <http://www.eceee.org/>). In part because of imaginative schemes for financing up-front investment and recovering the costs over time in energy savings, the German retrofit project seems further advanced, and the supply chain is now well established. One area where EU-scale endeavour may prove effective is in the establishment of an EU-wide decarbonized electricity grid.

In conclusion

I know of no previous era where a global problem, or in our case now a set of global problems, have come to the fore with a timeline of three to four decades for making serious inroads. Whereas in 1900 half of UK public expenditure was on defence, by 2000 half of public expenditure was on health and welfare. The cost to retrofit just our homes will be of the order of £1 trillion (at ~£50,000 for each of 22 million homes over the next 40 years), with a comparable sum spent on renewing the infrastructure of energy, water, waste and other supplies and disposals. Even one year ago, such sums would have been considered daunting, but £1 trillion then entered the public consciousness to prevent a collapse of the banking system! If we soon see a six-fold increase in the rate of improvement of energy consumption of buildings in the current 15 years to 2020, compared with the period 1990-2005 above, we may continue with the heightened sense of urgency. If not, the cries for a Manhattan style project, or the move by non-democratic bodies to launch geo-engineering projects, will gather force. The stakes are very high, and climate change is not even the most pressing.

Author's note

Much of this chapter I have come to appreciate during a three-year (2006-9) part-time secondment to be Chief Scientific Adviser to the Department for Communities and Local Government, the department that owns the relationship of central government with all the local authorities, and has responsibility for the building regulations and for planning. The figures quoted here come from a myriad of sources.