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The unintended consequences of decarbonising the built environment: A UK case study

M. Davies[a,*], T. Oreszczyn[b]

[a] The Bartlett School of Graduate Studies, University College London, 14 Upper Woburn Place, London, UK
[b] UCL Energy Institute, University College London, UK

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ABSTRACT

The case for taking action to tackle climate change is now persuasive. It is developed countries that must reduce GHG emissions most and this paper focuses on one such country – the UK. We address issues associated with the decarbonisation of the built environment and the housing stock in particular. We demonstrate the potential for significant unintended consequences and discuss the complexity involved in attempting to understand such processes. We argue the urgent need for the formation of multi- and inter-disciplinary teams with the diverse range of skill sets required to think together and to address these issues. Such teams must involve (at least) Building Physicists, Engineers, Economists, Epidemiologists, Statisticians, Behavioural Scientists, Complexity Scientists and Policy Makers. Without a coordinated and concerted programme of relevant research it is difficult to imagine how the necessary policy will be formulated and implemented effectively without the potential for enormous and irreversible mistakes.

1. Introduction

The growing evidence base for the need to decarbonise is dealt with in the IPCC's Assessment Reports, most recently the 2007 Fourth Assessment Report, which consists of three working group contributions [1–3]. Whilst uncertainties remain in the detail, the case for taking action to tackle climate change is persuasive.

The poorest countries will suffer the greatest consequences of climate change even though they contributed the least to emissions [4]. There are great disparities in Greenhouse Gas (GHG) emissions between regions and countries [5] – see examples in Fig. 1. The 18% of the world's population living in developed countries account for 47% of global CO_2 emissions, whilst the 82% of the world's population living in developing countries account for the remaining 53% [6].

This paper focuses on developed countries i.e. those who must decarbonise the most. We will concentrate on the built environment given its potential for GHG mitigation. However, whilst such potential undoubtedly exists, the challenges are great [7]:

> "While buildings offer the largest share of cost-effective opportunities for GHG mitigation among the sectors examined, achieving a lower carbon future will require very significant efforts to enhance programmes and policies for energy efficiency in buildings and low carbon energy sources well beyond what is happening today."

The resources required will be vast. In the EU alone it is estimated that over the next decade investment in energy-saving building components and equipment will need to be increased by up to €200 billion [8].

The scale of the required mitigation is daunting. The UK government has set itself a legally binding target of reducing GHG emissions by at least 80% by 2050 with five yearly carbon budgets also set between now and 2050 [9]. In the UK the construction industry has the ability to influence over 50% of CO_2 emissions [10] – see Fig. 2.

It can be seen that residential buildings comprise a significant slice of UK emissions. The meeting of the UK targets will thus involve a major refurbishment to close to zero carbon levels of ~25 million dwellings by 2050. This translates to an average refurbishment rate of more than 1 dwelling per minute [10]. Meeting this target will require the rapid development of a new, large-scale, energy efficiency refurbishment industry.

Leaving aside any implementation of local energy solutions, refurbishment of the fabric of homes has the potential to deliver around a 60% reduction in CO_2 emissions [10]. This will involve an estimated expenditure of £200 billion [10] and require the completion of the technically and economically feasible portion of:

- solid wall insulation to 6.4 m homes
- the cavities of between 6.5 million and 8.6 million homes
- full or partial window replacement on up to 6 million homes
- high efficiency boilers to 15.5 million homes
- some or better heating controls to 15 million homes
- full or additional loft insulation in 9–13 million homes.

* Corresponding author.
E-mail address: michael.davies@ucl.ac.uk (M. Davies).

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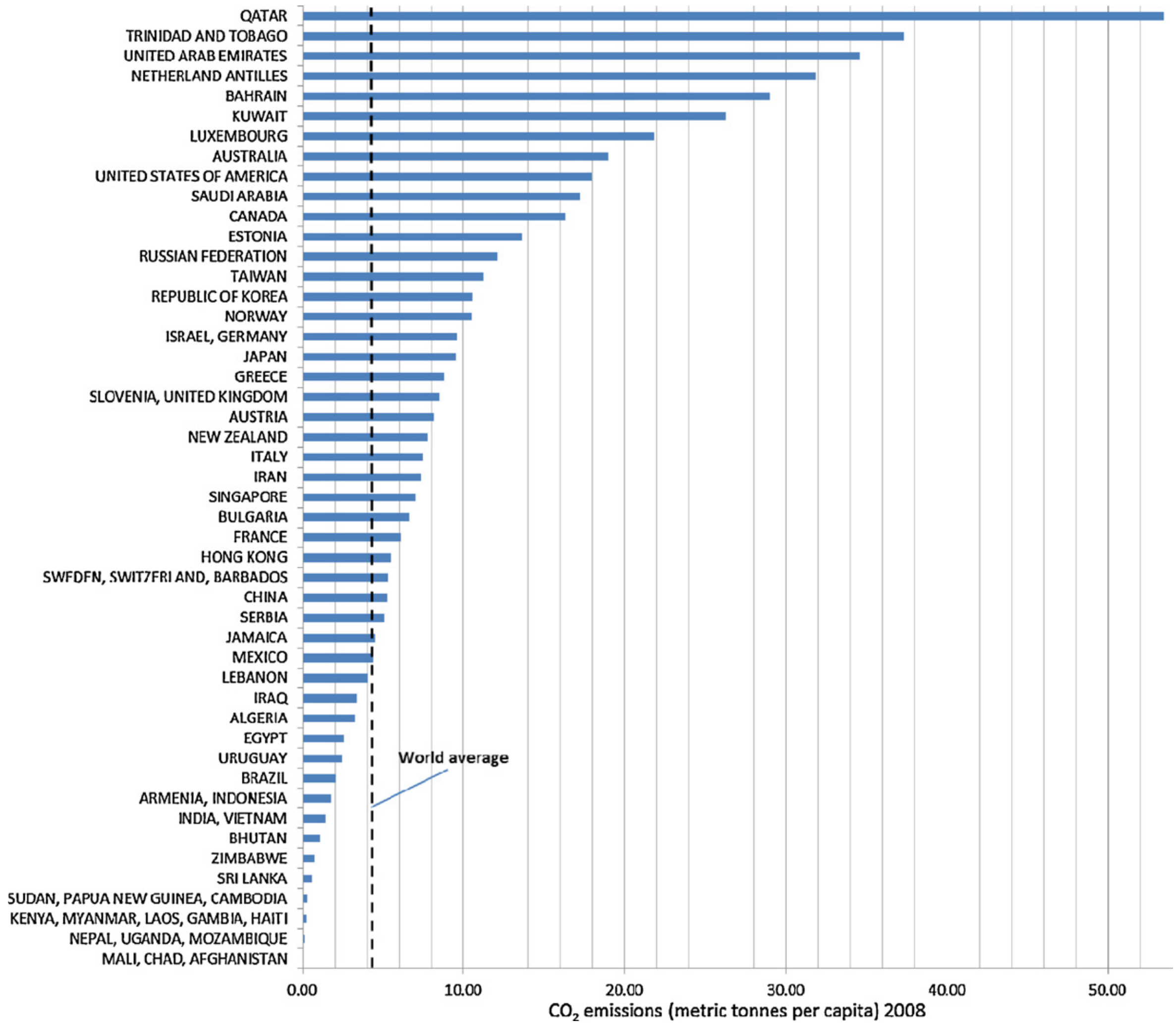

Fig. 1. CO_2 emissions per capita in selected countries and world regions [5].

Although a huge investment, this approach is one of the most cost effective decarbonisation mechanisms – see Fig. 3.

These measures need to be introduced into a very complex UK built stock. This stock is not only diverse in its construction methods which span several centuries but also in ownership (67% owner occupied, 8% private rented, 18% Local Authorities, 7% Registered Social Landlords in 2006) [12].

The current level of energy efficiency of the stock is also very varied with variations even between averages for different dwelling types. For example, the average heat loss for flats is half (170 W/K) that of detached houses (350 W/K) [12]. Many properties have already undergone some energy efficiency refurbishments which are not however, adequate for a 2050 low carbon scenario. Indeed, it may be these properties which result in the greatest and most costly retrofit challenge.

In addition, even within the UK there is significant climatic variation. For example, heating degree days vary by ∼40% across the country [13]. Finally, there is also a very wide range of occupant behaviour and socio economic status to add to this picture of complexity.

However, the real challenge is even greater than this diverse set of contexts implies. Whilst undertaking measures in an attempt to *mitigate* climate change we must also ensure that the same programme *adapts* the built environment appropriately for the range of projected climate change that is unavoidable.

The large-scale and rapid changes are unprecedented and will require one of the largest engineering programmes this century with likely startling societal upheaval. Such a rapid and large scale refurbishment programme has the potential to result in many unintended consequences. Sterman [14] notes:

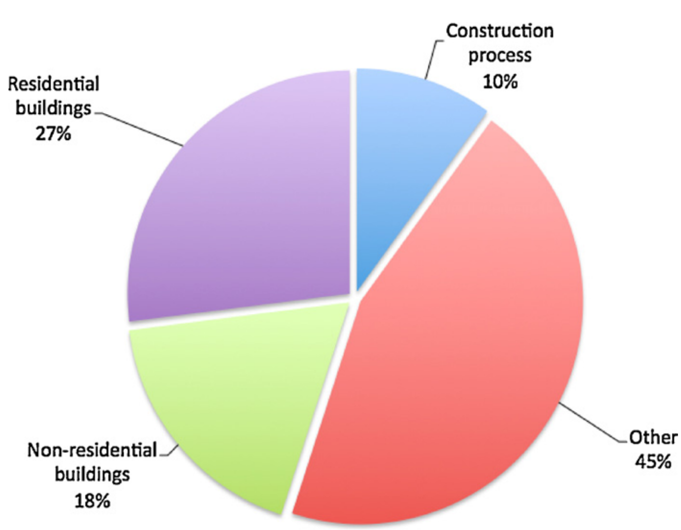

Fig. 2. Proportion of total UK CO_2 emissions that construction can influence [10].

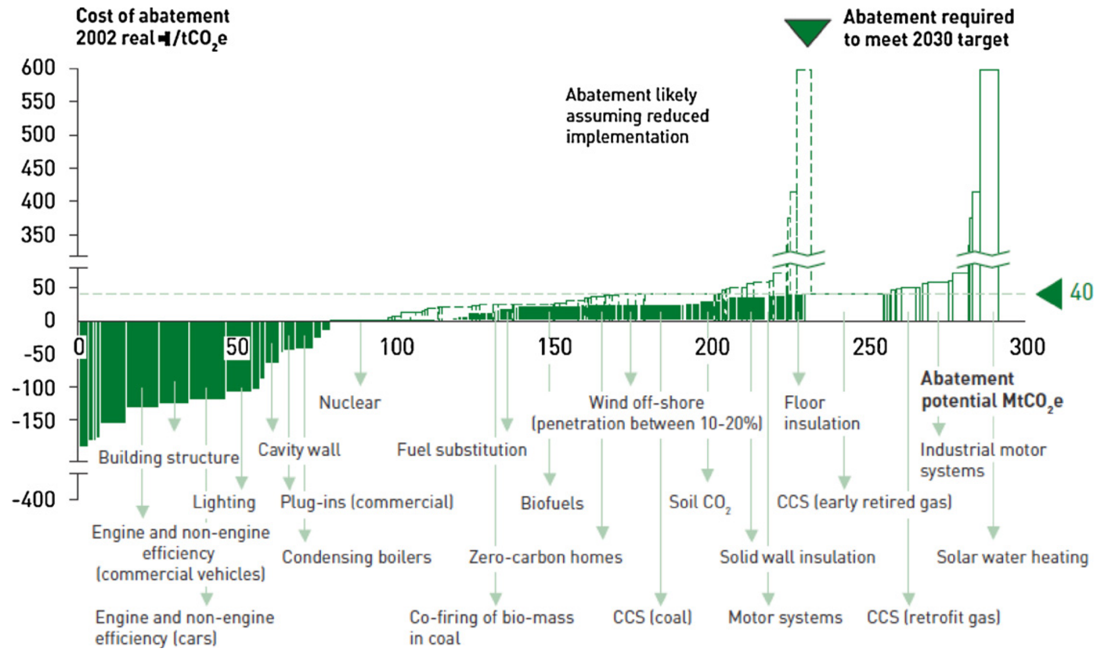

Fig. 3. The 2030 UK cost curve for additional greenhouse gas reduction measures (Source: McKinsey UK cost curve; team analysis [11]).

> "All too often, well-intentioned efforts to solve pressing problems create unanticipated 'side effects'. Our decisions provoke reactions we did not foresee. Today's solutions become tomorrow's problems. The result is policy resistance, the tendency for interventions to be defeated by the response of the system to the intervention itself. From California's failed electricity reforms, to road building programs that create suburban sprawl and actually increase traffic congestion, to pathogens that evolve resistance to antibiotics, our best efforts to solve problems often make them worse."

During a period of large-scale implementation of energy efficient technology it is essential to understand quickly such unintended consequences. In fact, the success of the decarbonisation programme will depend on this.

There is a real danger that in the drive to decarbonise, we will only pause to address the impacts of unintended consequences when they are already apparent and at a large scale i.e. when it is too late. Such possible impacts relate to many areas, for example (i) population health, (ii) the building fabric and contents deteriorating from maladaptation, (iii) economic, social and cultural viability. There is a body of unintended consequences, with varying levels of associated current research and varying recognition in government polices and energy efficiency programmes. Such 'known' unintended consequences include:

1. Indoor Air Quality (IAQ) problems associated with reduced ventilation: for example, particulate matter, radon, VOCs, moisture (resulting in mites and mould) and environmental tobacco smoke in domestic buildings.
2. Higher fuel prices due to increased use of decarbonised supply leading to fuel poverty and associated health effects.
3. Energy efficiency improvements increasing the risk of summertime overheating which can result in impacts on health.
4. Energy efficiency improvements resulting in *increased* GHG emissions due to the 'rebound effect'.
5. Changes to the hygrothermal properties of building fabric resulting from improvements in thermal properties, causing cold bridges, condensation, mould growth and decay.
6. The use of distributed energy technologies moving energy generation into urban areas and hence potentially intensifying the urban heat island.
7. Health and safety issues associated with refurbishment increasing the potential for elevated fire risk.

However, despite being 'known', such issues are, in general, poorly understood. Work in these areas to date has revealed the inherent complexity and daunting challenges associated with tackling them.

Of even greater concern perhaps is the fact that there will certainly be another body of unintended consequences which are currently not anticipated. These (at present) 'unknown' unintended consequences, are, with current ways of thinking in the Built Environment field, not amenable to study. So, how should we proceed? Sterman [14] notes:

> "When we point to outside shocks and side effects to excuse the failure of our policies, we think we are describing a capricious and unpredictable reality. In fact, we are highlighting the limitations of our mental models....What thwarts us is our lack of a meaningful systems thinking capability. That capability requires, but is much more than, the ability to understand complexity, to understand stocks and flows, feedback, and time delays. It requires, but is much more than, the use of formal models and simulations. It requires an unswerving commitment to the highest standards, the rigorous application of the scientific method, and the inquiry skills we need to expose our hidden assumptions and biases."

In order to address such issues we must recognize and acknowledge the potential inadequacy of current models and ways of thinking and work towards the development of new approaches that capture the diverse complexity inherent in addressing the decarbonisation of the complex system that is the built environment.

The field of unintended consequences needs to be studied in a truly multi- and inter-disciplinary manner. We need to focus on this urgent problem, develop appropriate research methods to tackle such issues and help develop effective solutions within the required timescale.

We need to establish ambitious programmes of work will that will be informed both by modern complexity science but also the long-standing body of built environment research.

We must develop a framework that will integrate:

- Reflective interdisciplinary 'conversations'.
- Rigorous new empirical studies coupled with working to access existing large-scale datasets.
- Sophisticated modelling using a wide suite of integrated socio-technical tools. We should acknowledge the potential difficulties associated with such modelling but as Johnson [15] notes:

> "For some socio-technical systems, simulation is the only way we know of investigating their future states.... If you do not trust a carefully executed simulation, you probably have less reason to trust anything else, including the way you currently make decisions."

- Close working with relevant policy makers and planners. This is essential – the decarbonisation programme will essentially be a huge 'experiment' set in place by policy makers and research teams must work alongside them, helping to design and monitor this experiment.
- An acknowledgement and treatment of the spectrum of cultural perspectives within the construction industry.
- Action based research. Conventional science methodologies, although scientifically robust, are both very consuming of time and money and useful for showing *what* does or does not work. However, they are less useful for understanding *why* certain policy instruments do or do not work. Therefore we suggest that 'action based' methods – not commonly used in building science – must form part of the approach. In essence, action research is 'learning by doing' – teams identify a problem, do something to resolve it, see how successful their efforts were, and if necessary, try again.

Via such a multi-faceted approach the research community could make progress in the delivery of a step change in the degree to which our understanding of unintended consequences can inform policy development and implementation. We must focus research on both 'known unintended consequences' as well as 'unknown unintended consequences'.

The challenges that we face in addressing these issues are exemplified if we consider the complexities involved in just two of the areas noted earlier – the possible degradation of IAQ in dwellings and the impact of GHG mitigation policies on the 'fuel poor'.[1]

2. Examples of unintended consequences

2.1. IAQ

When indoor air is polluted, too little ventilation may be insufficient to remove pollutants from indoor sources; but too much, without modification, impairs the effectiveness of the indoor environment to provide protection against outdoor pollution. What is the optimal ventilation rate for buildings in this very common situation? At present, there is still great uncertainty [17] and matters will be further complicated due to decarbonisation strategies.

[1] "A household is said to be in fuel poverty if" *it needs to spend more than 10 per cent of its income on fuel to maintain an adequate level of warmth (usually defined as 21 degrees for the main living area, and 18 degrees for other occupied rooms)"* [16].

For example, the very large-scale installation of 'Mechanical Ventilation with Heat Recovery' systems in the UK, coupled with the very high degree of dwelling air-tightness that are required for the effective use of such systems, may be cause for concern if the systems are installed incorrectly, maintained incorrectly or used incorrectly. It will also be essential to examine suites of policy options which are consistent with achieving the necessary GHG reduction strategies. This is because many of the health impacts of improved control over ventilation as an energy efficiency measure are through changes in the ingress of pollution from outdoors and therefore depend on the changes in other sectors that affect outdoor pollution.

Furthermore, mitigation measures may affect health through a range of pathways, several of which are likely to be as important, if not more important, than the usual exposures. Thus we need to consider a wider array of such pathways than has been attempted previously. A further issue is that to date, too little attention has focused on the underlying assumptions of the models of health impact and the degree to which results are influenced by the structure of the models and the uncertainty in the parameters on which they depend. Finally, a key aspect of any GHG reduction policy is the complex process of understanding the cost of implementing the policy relative to the success that it achieves.

Via several large-scale collaborative projects with multi-disciplinary partners, the Complex Built Environment Systems (CBES) group at University College London (UCL) is contributing to work in this area. In recent work involving the authors, for the UK it was found [18] that a strategy of combined insulation, ventilation, fuel switching, and behavioural changes has the potential – if properly implemented – to avert 5500 premature deaths and save 41 megatonnes of carbon dioxide (CO_2) in one year. A breakdown of the estimated disability-adjusted life years (DALYs) saved per million population is provided in Fig. 4.

Note that these estimated health impacts may be conservative. At the time of the study, it was felt to be impracticable, for example, to make estimates of the impact of changes in exposure to cold and heat due to a lack of reliable evidence.

Building fabric improvements would entail substantially better insulation of walls, windows, floors and roof, whilst improved ventilation would mean reduction of air leakage as well as installation of mechanical ventilation and heat recovery systems in suitable homes. Indoor household fuel pollutants would be reduced by switching all household fossil fuels to electricity, and energy could be saved by reducing thermostat temperatures. The costs associated with such energy efficient refurbishment will be substantial but offset by significant savings in fuel costs.

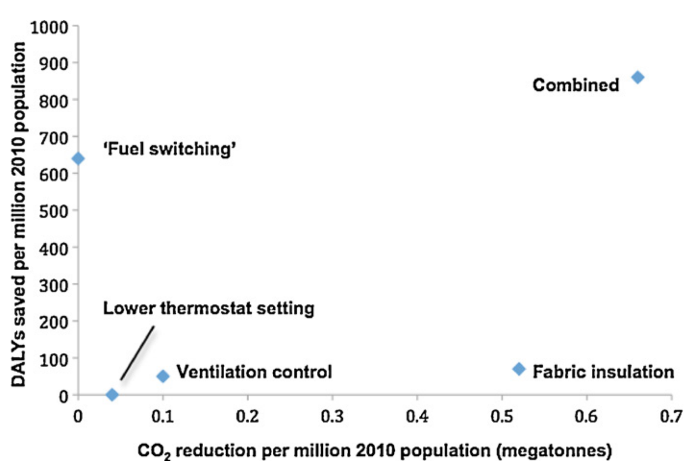

Fig. 4. Estimated effect of the UK household energy scenarios on disability-adjusted life-years saved and reduction of carbon dioxide emissions [18].

However, for such UK housing interventions, the magnitude and even *direction* of health effects depend on how energy efficiency measures are implemented and maintained – this has important policy implications [19]. There is potential for adverse effects in some dwellings arising from such changes owing to (i) increases in indoor pollutant concentrations, including radon and environmental tobacco smoke, if energy efficiency measures reduce ventilation, and (ii) increased penetration of outdoor particle pollutants with higher ventilation rates in dwellings fitted with mechanical ventilation systems unless there is control of external pollution levels or effective filtering of incoming air.

The 'PuRE Intrawise' project in the UK is looking in detail at such issues e.g. [20,21]. Recent work from the project has highlighted, for example, the potential for extremely high levels of PM2.5 exposure in certain dwellings and for certain behavioural patterns. Such work has significant implications for the formulation of a coherent set of Building Regulations relating to GHG emissions and IAQ.

2.2. Fuel poverty

A recent WHO report [22] notes that:

> "A growing body of epidemiological evidence now exists to show links between indoor temperatures and excess winter mortality and morbidity in various European regions, notwithstanding the difficulties of demonstrating direct causality. . ."

Cold indoor temperatures are in part at least related to energy inefficiency. The UK Government has announced plans to establish a framework to enable private firms to offer consumers energy efficiency improvements to their homes at no upfront cost, and recoup payments through a charge in installments on the energy bill – the 'Green Deal' [23].

It might be anticipated therefore that the Green Deal will act to increase indoor temperatures during the heating season and thus have positive health impacts.

However, whilst the Green Deal might enable some altruistic energy efficiency improvements to be undertaken that would otherwise not have been possible due to lack of capital, it seems likely that reliance cannot wholly be placed on such selflessness.

The UK Innovation and Growth Team (IGT) [10] notes:

> "At present a lot of focus is being put on delivery of the Green Deal . . . as a way of engaging customers. However, it is the view of the IGT that a suite of measures that includes regulation, fiscal incentives and penalties will be required in addition to ensure that the scale of refurbishment that is needed is delivered."

It is likely that such a suite of measures will have unintended consequences for the fuel poor. A combination of low household income and penalties such as higher fuel prices will tend to drive more households into fuel poverty with the associated negative impacts on health. Fuel prices are currently rising in the UK and are a very important policy tool for controlling carbon emissions.

It is well known that when energy efficiency measures are introduced, total energy consumption does not fall as much as is often expected. This is in part due to the fact that when improving the energy performance of dwellings a significant element of the improvement can be taken as improved comfort ("comfort taking" or "take back"). This is most likely to occur with the fuel poor and is a beneficial consequence of energy efficiency. This rebound can be controlled by increasing fuel prices at the same time as improving the efficiency of the stock. However, if these measures are not phased correctly significant sectors of the population may move into fuel poverty.

A low carbon future will see a range of different technological improvements introduced to dwellings beyond those measures which directly impact on total domestic energy use e.g. insulation draught stripping, efficient heating and ventilation systems and efficient appliances. These measures will be required to help balance energy supply with demand. For example, the current plan for the UK is to move to renewable and nuclear generated electricity combined with electric space heating using heat pumps in dwellings. This new electricity supply will be far less controllable than conventional fossil fuelled electrical generation and without the storage which is an integral element of fossil fuels. The consequence of this will be that utilities will place a high value on being able to control domestic energy demand via load matching. New smart energy systems will be introduced which involve local thermal storage and local control systems including smart meters. Homes which are prepared to allow such control systems to control appliances such as fridge freezers, space heating systems and water storage temperatures may be offered lower electricity tariffs. These tariffs may be particularly attractive to the fuel poor and yet they may be the least able to afford the smart systems and they may be most vulnerable to any particular unintended consequences of the introduction of such systems.

3. Conclusions

The threat of climate change requires enormous societal transformation, the implementation of which is likely, in part at least, to prove painful. Indeed, the potential for negative unintended consequences is great.

But, action to combat climate change also presents opportunities which could, for example, lead to *improvements* in health. This is the great challenge that faces us now – we must act quickly to establish appropriate and effective ways of working in order to grasp these opportunities and to recognize and minimise unintended consequences.

This paper has discussed how this issue is tremendously complicated and requires a complex systems approach from multi- and inter-disciplinary teams with the diverse range of skill sets required to think together and to address such a problem. Such teams must involve (at least) Building Physicists, Engineers, Economists, Epidemiologists, Statisticians, Behavioural Scientists, Complexity Scientists and Policy Makers. Without a coordinated and concerted programme of relevant research it is difficult to imagine how the necessary policy will be formulated and implemented effectively without the potential for enormous and irreversible mistakes.

Acknowledgments

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