Title

100 unintended consequences of policies to improve the energy efficiency of the UK housing stock

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Abstract

As a major sector contributing to the UK's greenhouse gas (GHG) emissions, housing is an important focus of Government policies to mitigate climate change. Current policy promotes the application of a variety of energy efficiency measures to a diverse building stock, which will likely lead to a wide range of unintended consequences. We have undertaken a scoping review identifying more than 100 unintended consequences impacting building fabric, population health and the environment, thus highlighting the urgent need for Government and society to reconsider its approach. Many impacts are connected in complex relationships. Some are negative, others possibly co-benefits for other objectives. While there are likely to be unavoidable trade-offs between different domains affected and the emissions reduction policy, a more integrated approach to decision making could ensure co-benefits are optimised, negative impacts reduced and trade-offs are dealt with explicitly. Integrative methods can capture this complexity and support a dynamic understanding of the effects of policies over time, bringing together different kinds of knowledge in an improved decision-making process. We suggest that participatory systems dynamics (PSD) with multi/inter-disciplinary stakeholders is likely to offer a useful route forward, supporting cross-sectorial policy optimisation that places reducing housing GHG emissions alongside other housing policy goals.

Introduction

European and domestic legislation motivated by (GHG) reduction concerns aims to substantially improve energy efficiency in both new and existing UK homes in the coming decades [1]. Existing dwellings are likely to represent 70 - 80% of the 2050 stock [2, 3]. Through a number of policy mechanisms [4], these existing dwellings are likely to undergo extensive retrofitting with a range of measures that will increase air tightness, insulation, glazing improvements and the efficiency of heating systems in order to help meet the UK's ambitious GHG reduction targets (80% of 1990 emissions by 2050) [5]. The summary of relevant legislation and national policy in Table 1 demonstrates the Government's approach to GHG reduction involving the housing sector; with policies seeking to improve energy efficiency, reduce the carbon intensity of energy generation and change the energy related behaviour of building occupants [4, 6].

Table 1 Summary of primary UK legislation, policies and incentives currently used to promote the decarbonisation of the housing stock.

Legislation	**Description**
Climate Change Act 2008	Requires emissions reductions of 80% by 2050, introduces legally binding carbon budgets and sets a legal framework for climate change adaptation.
Energy Bill 2012	Electricity Market Reform including predictable incentives for investment in low-carbon generation (Contracts for Difference) and ensuring adequate supply (Capacity Market).
Building Regulations and associated technical guidance	Includes legislative requirements for energy efficiency and GHG emissions from new buildings as well as requirements for retrofitting existing buildings.
Policies and Incentives	**Description**
Renewables Obligation	Requirement for electricity suppliers to source an increasing proportion of electricity from eligible renewable sources or pay a penalty. Suppliers buy certificates from generators and present them to the regulator or buy-out their obligation.
The Green Deal	The main national incentive for retrofitting existing dwellings, includes a loan scheme covering loft and external wall insulation (including solid and cavity walls); boiler upgrade or replacement with heat pump; renewable energy generation (solar panels or wind turbines); double glazing and draught proofing. Expected financial savings must be equal to, or greater than, the costs. Loans are attached to property utility bills.
Energy Company Obligation (ECO)	Requirement for Energy Companies to fund energy efficiency improvements under three obligations: (i) provision of insulation to low income households in specific target areas; (ii) provision of heating and insulation for beneficiaries in private tenure and (iii) installation of less cost effective measures not meeting the financial savings requirement of the Green Deal (e.g. solid wall

	insulation). Energy companies are expected to respond to these obligations by increasing energy prices.
Feed-in Tariff (FITS)	Guaranteed payment from electricity suppliers for surplus electricity from small-scale (less than 5MW), low-carbon generation – under review.
Domestic Renewable Heat Incentive (RHI)	Proposed future extension of the non-domestic RHI to houses, providing financial support for installation of eligible technologies (e.g. biomass boilers, ground source heat pumps, solar thermal).

The need to consider the linkages that exist between buildings, human wellbeing, local and wider societal, and environmental impacts when forming these policies has been noted previously [7]. In this paper, with a focus on housing, we aim to illustrate the complex nature and range of possible unintended consequences arising from policy framing and implementation that is limited to a focus on climate change mitigation. This initial scoping study makes no claims to be a systematic review - rather we aimed to exemplify and categorise the broad range of possible unintended consequences that may arise as a result of proposed energy efficiency measures. We further suggest the need for a broader approach to policy decisions that integrates multiple objectives about housing and includes consideration of a wider range of outcomes and involves multiple stakeholders in decision-making so that co-benefits may be optimised, negative impacts reduced and trade-offs made more explicit.

Methods

Definition of Unintended Consequences

For the purpose of this study, unintended consequences were defined as outcomes that arise unintentionally as a result of policy, development or implementation. Multiple direct and indirect consequences can occur. They can be broadly grouped into two categories: (i) an unexpected benefit or negative effect (or a combination of both), which may occur in addition to the desired effect of the policy or action; (ii) an effect contrary to the original intention that undermines the intention and even makes the problem worse [8]. The complex interdependence of many of the consequences is discussed in detail below.

Framework

In the absence of a specific structure for the potential relationships between housing, people and nature, we used a broad exploratory framework (Figure 1) to define domains of possible consequences [9].

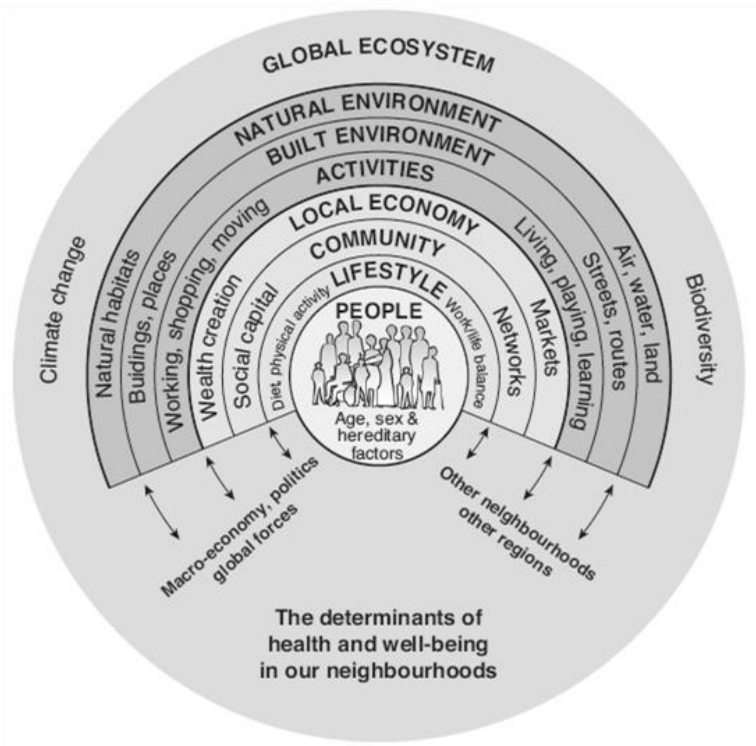

Figure 1 Holistic framework of health and wellbeing [9] adapted from [10]

This framework was originally designed to illustrate the relationships between health and wellbeing in neighbourhoods and the physical, social and economic environment, but we considered it a valuable holistic model. It provided a useful structure that directed the areas for literature search by revealing the multiple domains of consequences of policies to improve energy efficiency.

Search Methods

We used the framework described above to undertake a scoping search of the literature across the following disciplines: building physics; construction technology and practices; health and wellbeing; and social sciences. We searched the following electronic databases: Web of knowledge (including citation reports which were further investigated via Scopus); Google Scholar; Index of Theses; Science Direct; Social Science Research Network and PubMed. Grey literature investigated included the Open Grey data base, European Union and UK Government legislative and policy documents, technical data sheets and specifications, published textbooks, reports from NGO's involved in the retrofitting process, recognised websites (for example from construction organisations) and newspaper articles. We used the grey literature to identify further peer-reviewed studies.

Using the framework domains, an initial set of keywords were developed for each energy efficiency intervention and further used in combination with outcomes relevant to that intervention, for example human health. An example is shown below in Table 2. The full range of search terms are shown in the web appendices accompanying this study, available at http://bit.ly/HEW-100-unintended-consequences. Additional terms and combinations revealed by the literature search were also investigated.

Table 2 Example of keywords used in the literature search

Policy Impact	Initial Keywords	Domain combination	Additional Revealed terms
airtightness	permeability, airflow, air change rate, indoor air, indoor air quality, airtight	health, well-being, consequence	mental health, physical health, psychological well-being, child development

The impacts of the range of interventions on dwellings were considered independently so as reveal the pathways of their individual consequences. Themes emerged from the literature which lead to specific interventions being investigated including: increasing airtightness, purpose provided ventilation (PPV); insulation (including double glazing) and impacts related specifically to ‘traditional built’ structures as opposed to new builds due to their constructional differences [11]. Additional areas of investigation include the implications of the policy funding structure under the Green Deal; the UK Coalition Government’s flagship carbon emission reduction policy for domestic properties [4], as well as the potential effects of changes to design, construction and manufacturing processes that may result from current policy.

Selection Criteria and Analysis

The search was limited to studies in English published from 1990-2013. We included studies that made a direct connection between an intervention to reduce GHG emissions from, or improve the energy efficiency of, dwellings and an impact on one or more domains described in the framework above. Studies that failed to meet these criteria were considered not relevant to the scoping review and were rejected. We used the findings of included studies to group and characterise described relationships between interventions and outcomes. We tabulated these relationships, summarising the short pathways described in the studies between the impacts on buildings, people and the natural environment. Where there was unresolved debate about the direction of effects of an intervention on an outcome, we included both theories. Although we placed greater emphasis on systematic reviews of particular effects of interventions on housing our aim was not to assess the quality of the evidence, nor to report on relative effect sizes or the strength of relationships.

Results

We identified nearly 1600 potentially relevant studies. Of these, 436 had content relevant to this study, and of these 206 met the inclusion criteria. 119 unintended consequences were highlighted, representing the impacts related to the application of the investigated energy efficiency policy measures. However, many individual consequences further impact on multiple domains resulting in a total of 196 possible outcomes reported across the studies. The papers reported impacts across many of the domains identified by our framework (figure1) including the built environment, life style, and activities, community, local economy, the natural environment and the wider global ecosystem. We also identified some intervention effects that did not fit well within the holistic framework, including new legal ramifications and impacts on household-level economics. These have been included in the results and indicate potential future additions to the framework.

The included studies described the effects of interventions that could be categorised as impacts associated with:

- increasing dwelling airtightness;
- replacing uncontrolled ventilation with purpose provided ventilation;
- insulating properties and raising indoor temperatures

A further set of unintended consequences have been reported that relate to current options for funding interventions and to the way that such interventions are being implemented. Within these categories, many studies also explored the particular impacts on older/traditional houses compared with more modern ones due to their constructional differences. The term ‘traditional’ is generally used to define a structure built prior to 1919 with solid walls constructed with moisture-permeable materials [11, 12]. Such buildings are estimated to represent almost a quarter of the current UK housing stock. They have specific issues different from the rest of the built stock for example; heat loss and moisture movement in solid walls [11, 12]. Both current regulations and the Green Deal and related policies do not take these differences into account when applying efficient technologies [11], although work is currently underway to address some of these issues.

Due to the substantial range of consequences uncovered, it has not been possible to capture individual impacts in any depth within this article. However, the following sections demonstrate the level of detail that exists for some known consequences.

Impacts associated with increasing dwelling airtightness

Studies described the airtightness impacts of a range of measures including for example; draft-proofing, the provision of double glazing, insulation of loft spaces and the filling of cavity walls. For these interventions a range of both positive and negative impacts on a range of domains were described. Increases in airtightness of dwellings should result in reduced ventilation heat loss through lowered air change rates potentially leading to reduced energy consumption and GHG emissions [13]. The quieter environment created by these measures can have further impacts, such as a more peaceful atmosphere and the accompanying sense of security, which has a positive impact on mental health and psychological wellbeing [14, 15]. Improvements in child development in the spheres of physical, social and emotion health as well as behavioural outcomes are reported [16]. These positive impacts have been attributed to the 'reduction' in noise [17]; conversely it has been emphasized that the 'absence' of sound (e.g. sounds from nature) may lead to negative mental health impacts [15, 17]. For some individuals this can lead to anxiety from both real and perceived threats [18] and a possible sense of isolation and disconnection having further impacts on social cohesion. Increased window opening to compensate for lack of natural sounds could lead to increases in ventilation heat loss working against GHG emission reduction [19].

External sealing of the building envelope to increase airtightness was found to have the additional benefit of making properties more watertight and is recommended as a climate change adaptation measure thereby reducing possible future impacts from excess rainfall and the likelihood of water damage and mould/rot risk [20]. However, other authors have described links between lower air change rates and a rise in relative humidity (RH), leading to increases in house dust mites, mould, severity of asthma and allergies [21, 22] and in fabric decay in existing properties, particularly traditional buildings [11]. Further rises in RH are produced when clothes are dried indoors and have been linked to increased exposure to microbiological pathogens and infectious diseases [23]. In new builds, with tighter construction drying out times for ‘wet trades’ are extended leading to higher RH over a prolonged period during initial occupancy [24].

Other changes in indoor air quality have also been identified as a further consequence of the lower air change rates, beyond those associated with increased humidity. Whilst a reduction in pollutants from external sources such as $PM_{2.5}$ which has known negative health impacts is noted [5], an increase in exposure to indoor sourced pollutants such as $PM_{2.5}$, volatile organic compounds (VOCs) and environmental tobacco smoke (ETS) may occur [5, 25, 26] There is also emerging evidence for a population-wide increase in cancer risk from increased exposure to radon indoors (an airborne pollutant known to be carcinogenic [13, 27].

These relationships between increasing airtightness and human and environmental wellbeing are summarised in Table 3; which demonstrates the method used to map the pathways described between interventions and individual unintended consequences.

Table 3 Examples of unintended consequences arising from the application of energy efficiency measures; airtightness

A	B	C	D	E	F	G	H
No	**Policy Impact on Buildings**			**Impacts on People/ Nature**		+/-	**Reference**
				Unintended Consequence	**Domain**		
1	Airtightness		Quieter Environment	Peace/Wellbeing / Security	Mental Health Psychological Well Being	+	[14, 15] **D,E,F**
2	Airtightness		Quieter Environment	Isolation/ Disconnection	Mental Health Psychological Well Being	_	[18] **D,E,F**
3	Airtightness		Quieter Environment	Anxiety: real and perceived threats	Psychological Well Being	_	[18] **D,E,F**
4	Airtightness		Quieter Environment	Reduction in Noise	Mental Health	+	[15, 17] **D,E,F**
5	Airtightness		Quieter Environment	Absence of sound	Mental Health	_	[15, 17] **D,E,F**
6	Airtightness		Quieter Environment	Improvements in physical health; social, emotional, and behavioural outcomes	Child Development	+	[16] **D,E,F**
7	Airtightness	Lower air change rate	Increased RH Timber decay	Increase in HDM and mould, severity of asthma and allergies.	Physical Health	_	[21,22] **B,C,D,E,F**
8	Airtightness	Lower air change rate	Increased RH Clothes drying issues	Increase in and exposure to microbiological pathogens. And infectious diseases	Physical Health	_	[22, 23] **B,C,D,E,F**
9	Airtightness	Lower air change rate	Drying out times (wet trades) Increased RH	Mould-microbiological growth	Physical Health	_	[24] **B,C,D,E,F**
10	Airtightness	Lower air change rate	Changes in indoor air quality (IQA)	Increased exposure to indoor sourced pollutants. Decrease in external sourced pollutants (e.g. $PM_{2.5}$).	Physical Health	+/-	[5, 25, 26] **B,C,D,E,F**
11	Airtightness	Additionally More water tight	Prevention of impacts from excess rainfall	Mitigation benefits, less water damage, mould risk	Physical Health	+	[20] **B,C,D,E,F**

As illustrated in Table 3, some interventions have a cascade of consequences from their direct effects on the building to effects on human wellbeing and the environment (nature). Columns B-D represents the flow of impacts caused by the application of airtightness policy on buildings. The resulting unintended consequences are seen in columns E and the domain affected in column F. Column G shows the direction of the impact; whether positive, negative or both. Column H shows the literature source and whether this refers to the whole flow or an aspect of it by indicating the columns to which the literature source refers.

A full version of this table with all the unintended consequences described in the included studies and additional references used are available at http://bit.ly/HEW-100-unintended-consequences.

A more complete consideration of the complex inter-relationship between airtightness and its unintended consequences is shown in Figure 2, illustrating the limitations of considering each impact pathway in isolation. The level of complexity seen raises a number of issues which are dealt with under the *Summary of impacts* and *Discussion* sections below.

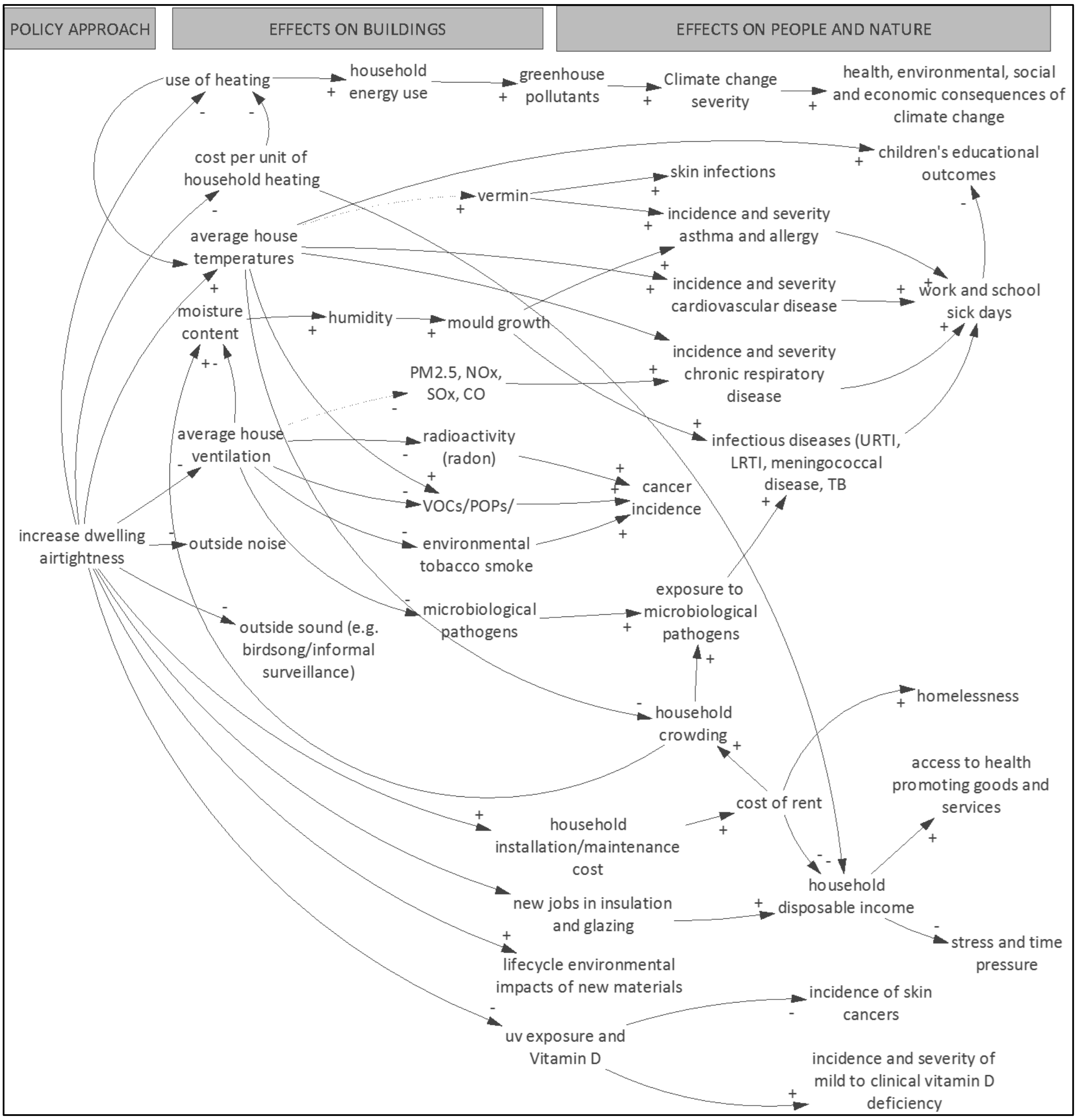

Figure 2 The complex links arising from the policy of promoting airtightness in the domestic stock and the impact on buildings, people and the wider environment.

Impacts associated with purpose provided ventilation

A key approach to dealing with the potential negative impacts of increasing the airtightness of dwellings is to accompany these interventions with purpose provided ventilation systems. However, a number of modelling studies reported that the addition of purpose provided ventilation to airtightness had its own wide ranging effects. Generally, a reduction in most indoor sourced airborne pollutants (mould, $PM_{2.5}$ and environmental tobacco smoke (ETS)) was reported, which yielded health benefits [5, 26, 28]. However, in practice many ventilation systems do not perform to their designed standards, with poor installation and maintenance cited as reasons for further reductions in capacity [29]. Increased ventilation without heat recovery could lead to energy efficiency gains being offset by ventilation heat losses with GHG emission increased or remaining unchanged and increased fuel bills, especially so if systems are not understood by end users [30, 31].

In addition, increases in outdoor sourced pollutants could occur if systems are not filtered or are not working correctly [26]. The application of Mechanical Ventilation with Heat Recovery (MVHR) systems with filters, although proposed as a solution to these problems also has reported impacts, for example disturbed sleep resulting in systems being switched off [32]. Poor installation and lack of maintenance of MVHR systems has also been linked to increases in indoor pollution and microbiological growth [32, 33] and failure to achieve the energy savings anticipated from design data. On the other hand, studies have demonstrated that correctly functioning systems provide good air exchange and a quieter environment resulting in a reduction in household accidents and a general increase in mental alertness [34]. However, current MVHR systems may not be appropriate for the majority of existing properties requiring retrofitting due to the extensive duct work required [35].

Insulation and the consequences of higher indoor temperatures

The assumption of reduced energy demand as a result of better insulated buildings will be affected by, for example, comfort take-back thereby potentially undermining policy objectives [7, 36, 37].

Warmer environments and higher average indoor temperatures resulting from insulation can have a range of positive and negative impacts across a range of domains. The potential benefits of warmer indoor winter temperatures are well described [25]. Much attention in the literature has been given to the potential reduction in winter mortality [36, 38]; but more recent research has highlighted the potential for summer time overheating, especially in the context of expected future climate change coupled with increases in urban heat island effects [6,39,40]. Top floor apartments appear to be particularly at risk [6]. An emerging consequence of overheating is the risk of legal action by residents if homes become uninhabitable due to poor design or lack of adaptation to a warming climate [41]. Higher indoor temperatures can also lead to changes in indoor air quality through an increase in concentrations of indoor sourced pollutants; specifically volatile organic compounds (VOCs) and a balance needs to be struck between airtightness to prevent ventilation heat loss for GHG reduction policies and the need for a healthy air change rate [5, 26, 28]. Warmer environments could give greater room availability resulting in changes in occupant patterns and family dynamics and shifts in home/work relationships and the concept of home which could be either positive or negative [14, 15]. Increased time spent in a more pleasant indoor environment might lead to sedentary behaviour and weight gain [42, 43] and a possible reduction in social cohesion. Alternatively, it was noted that warmer environments led to a reduced cold induced ‘comfort’ food intake, a reduced level of energy required to maintain body temperature and an increase in the frequency of eating breakfast at home [44]. Infant weight gain and developmental status has been shown to be improved by higher temperatures [45]. Increases in the severity of skin infections and reaction to allergens may occur with increases in temperature [22], as well as the attraction of pests and vermin, spreading disease [46]. Conversely, an increase in immunity and decreases in multiplication of common colds, less time off work and higher productivity are seen with higher indoor temperatures and greater mobility/dexterity for arthritis suffers [47, 48] and reductions in high blood pressure [49].Reductions in injuries in the elderly or infirm resulting in reduced hospital admissions have also been reported [47]. Increases in bedroom temperatures are linked to improved mental health across life time [50] and an improvement specifically in adolescent mental health [51, 52].

If cost savings are made as predicted under the Green deal, possible outcomes include increased financial control and reduced stress, which was considered the most important mental health benefit under the Warm Front Scheme [53]. Other consequences relate to the use of any savings. For instance, extra disposable income may be used to purchase quality food increasing micronutrient levels [44]. On the other hand, increased consumption of ‘goods’, while possibly providing economic benefits, could increase carbon emissions in other sectors such as agriculture or manufacturing, undermining GHG reduction targets [54].

For more traditional structures, the introduction of internal insulation to achieve the low U-values specified (0.3 W/m^2K); in the building regulations; is likely to lead to an increased risk of moisture build up and fabric damage in areas of driven rain and exposed masonry; also specific risks of thermal bridging and mould on reveals and party walls [11]. Currently it is perceived that an over estimation of the U-values of solid walls is occurring, resulting in over-engineered/non-optimal applications (see BR443; EN ISO 6946, 1997). This is in part due to a lack of in-situ U-values for traditional wall construction prompting the need for alterations to BR443 and RD299v 9.91 Appendix S, 2012 in order to provide better modelling conventions. A disconnection exists between best research and current guidance leading to inappropriate material specification and/or application; or almost complete lack of available data/research e.g. thermal bridging/thermal mass [11], heat loss via pre-1919 floors [55] and ventilation heat loss [56].

In historic buildings the current use of BS5250, 2011 for moisture risk; the “Glaser method”, makes no allowance for hygroscopic sorption, liquid transport or rain [57]. Increases in moisture ingress and differing coefficients of thermal expansion produced in building elements have been reported leading to thermal cracking [11] and possible loss of envelope integrity resulting in ventilation heat losses. Moisture ingress and movement within the structure leading to interstitial condensation and mould/microbiological growth has also been reported [21] and could exacerbate the severity of asthma and allergies [22]. Furthermore, any refurbishment would require further resources (with additional carbon emissions) to repair subsequent damage.

Similar problems have been noted with external wall insulation (EWI) systems [58] with inappropriate survey practices leading to poor design/application and subsequent thermal bridging noted [59]. EWI is also associated in the literature with damage to, and loss of, the appearance of our cultural heritage [60]. High relative humidity (RH) and mould have been reported where the underfloor space is thermally sealed from the dwelling with the possible ultimate danger of collapse of structural elements in this 'unseen' area [61]. The current lack of consistency in planning policies for historic buildings where energy efficiency is the main driver of change, could lead to the inappropriate application of these measures and damage to heritage assets resulting in disconnection from our sense of history and affecting psychological wellbeing [60,62].

Impacts associated with current models of funding and implementation of policies

Implementation mechanisms and funding strategies influence the success of any policy. Effective marketing, the current economic uncertainty and loans offered at higher interest rates than could be obtained elsewhere, are all issues that influence the success of policies to improve the energy efficiency of housing. Current cash back schemes offered as a means to encourage take up of energy efficiency products are very limited when perhaps a subsidy on base material cost would be more effective [63]. It would appear there is a reliance on voluntary public engagement 'altruism' which could lead to an increase in fuel poverty and the gap between the better-off and poor, with the neediest not benefiting from the policy [7, 54]. If this is not addressed, policy failure might ultimately result in failure to curb GHG emissions from much of the existing housing stock [64]. The scope of finance offered is limited with necessary façade and fabric repairs currently excluded from the scheme [11]. Damage to fabric and contents may occur if such a scheme is implemented as it stands, leading to possible failure to achieve the energy savings expected and possible issues with moisture ingress and health impacts [7, 12]. Additional costs needed may cause delays or a decision not to proceed with a scheme.

Holistic policies which tackle the issues of ventilation, indoor air quality (IAQ) and behaviour could help avoid multiple negative consequences from airborne pollutants [26, 54] and impacts such as mould on building elements and contents [65]. Schemes can have on-costs such as increased installation/maintenance costs, reducing disposable income and creating stress. In extreme circumstances this could lead to a "heat or eat" situation and a social determination of comfort [11, 38]. With current housing shortages, upgrades of dwellings in the rented sector could see increases in rents possibly resulting in overcrowding and increased exposure to pathogens and infectious diseases and could impact social cohesion and mobility [66, 67]; with long term effects on future socio-economic wellbeing and status [68].

Negative impacts on child development [16]; increase in sudden infant death syndrome (SIDS) and additionally rents become untenable; a risk of an increase in homelessness [69].

Should public uptake of schemes driven by energy efficiency policies prove successful, there are clear economic benefits led by the need for new designs, equipment, materials and specification with resulting economic growth, potential growth of UK based manufacturers, supply chains, specialist designers, contractors and general employment [4]. However, as previously discussed, it is essential that this growth is sustainable and does not simply add to the carbon burden [70]. There is the opportunity for increasing the skill set of the current construction work force to ensure buildings reach specification[71, 72] and increase partnership working [73,74] improving business prospects nationally and abroad.

Summary of impacts

A summary of the downstream impacts on domestic properties caused by the application of the various energy efficiency measures investigated are shown in Table 4. In addition the directions of the unintended consequences as seen in the literature search are shown. As previously noted this has been adapted from the framework in order to clarify specific impacts on domestic properties.

Table 4 Downstream impacts on buildings related to the application of the investigated energy efficiency measures and their direction of influence

Downstream impacts on buildings	Direction of influence			
	+ve	-ve	+/-ve	Totals
Noise levels	4	4	2	10
Air change rates/Indoor air quality	9	6	9	24
Indoor temperatures	18	13	4	35
UVB, UV and UVA reception	2	9		11
Energy use		4	8	12
Fabric/Structural components	2	25		27
Totals	**35**	**61**	**23**	**119**

A summary of the total impacted domains discovered are shown in Table 5, which illustrates how unintended consequences translate into impacts that affect people, buildings, society and the environment, with many single consequences impacting multiple domains.

Table 5 Domains of impact and their direction of influence

Domain	Direction of influence			
	+ve	-ve	+/-ve	Totals
Physical health	16	47	13	76
Mental health	4	4		8
Psychological wellbeing	9	5	2	16
Child development	1	1		2
Social cohesion		3		3
Social inequalities		1		1
Social mobility		2		2
Occupant behaviour		1	2	3
Household finances		2	1	3
General economic	9	1	2	20
Building fabric	1	17	2	20
Legal		3		3
Environmental	7	31	9	47
Totals	**47**	**118**	**31**	**196**

It should be noted that the totals seen in Tables 4 and 5 demonstrate where the attention of previous research has focused, rather than necessarily the relative importance of a particular influence on unintended consequences. Tables 3-5 highlight the individual routes to consequences for clarity and in order to achieve the objective of this study in scoping the range and domains impacted by policies to apply energy efficiency measures to the domestic stock. However, this method, although useful, hides the complexity and interconnections that exist between the different domains. Using the example of increased dwelling airtightness seen in Table 2, Figure 2 shows that when taken together, the linkages identified in the literature form complex and dynamic inter-relationships between the individual components.

Discussion

We have undertaken a scoping, cross-disciplinary literature review to identify, enumerate and characterise what is already known about the unintended consequences of current interventions to reduce GHG emissions from the UK housing stock. Guided by a holistic framework for potential impacts we found more than one hundred consequences across a range of domains of human wellbeing, including physical, mental, social, environmental and economic wellbeing.

For the examples we have outlined in detail, there are some individual solutions suggested in the literature. For example, in response to growing understanding of the risk of overheating, several authors have recommended specific solutions: a more flexible approach to design; increasing the thermal mass of buildings and providing reflective roofs [39, 40]. In addition, some argue that the risks of overheating may also be reduced by increasing the availability of air conditioning. However, this would lead to additional GHG emissions undermining any energy efficiency gains achieved through insulation [11]. In contrast to these single focus solutions, which are likely to have further unintended consequences, we have demonstrated with our investigation of airtightness that when taken together, the linkages identified in the literature form complex inter-relationships between various domains, suggesting that more holistic, multi-disciplinary approaches are needed to formulating and implementing policies about housing.

The study of unintended consequences in the built environment, and indeed in other areas of society and policy, is, as yet, underdeveloped. This is the first time that a holistic attempt has been made to characterise the effects of policies to reduce end-use housing energy demand. It builds on previous work to integrate a range of physical and mental health impacts of policy options to reduce GHG emissions of the housing sector, significantly broadening the scope of impacts considered. The review is limited to an initial characterisation of consequences by the broad but non-systematic approach taken. We were therefore unable to draw conclusions about the size of intervention effects, or their relative importance. In addition, there are almost certainly likely to be a greater range of ‘unknown’ unintended consequences, which the current approach to research, is not able to reveal and requires new methodologies to enable investigation.

However, some limited conclusions for policy can be drawn from the review. Possible unintended consequences are related both to faulty policy formulation and to problems with implementation. In complex systems such as housing, policy formulation processes that focus on a single objective, while taking inadequate account for the complex and dynamic inter-relationships between objectives and outcomes, are vulnerable to policy failure and negative unintended consequences. On the other hand, a more integrated policy formulation process has the potential to achieve co-benefits across a range of objectives. This requires a different set of policy formulation methods that can bring a wide range of stakeholders together in a collaborative learning process about dynamic system complexity. Furthermore, it was clear from the review that choices relating to funding mechanisms for policies can either support or undermine policy objectives. Incorporating considerations about funding mechanisms into policy formulation could improve these choices.

Conclusions and recommendations for further work

In order to explore the issues raised here further, we argue that there is a pressing need for an approach such as 'Participatory Systems Dynamics' (PSD) which would require the involvement of multiple stakeholders from a variety of disciplines to investigate these issues holistically [75, 76, 77]. By utilising the findings of this study and understanding the stocks, flows, feedback and reinforcing loops occurring in the system, the use of PSD could help to highlight key issues and ensure that regulatory measures are framed to achieve policy goals without unduly jeopardising general health, well-being and the damage to building fabric, contents and the environment that is otherwise likely to occur. To avoid policy failure and possible liabilities, there is an urgent need for processes that ensure regulatory measures are framed to achieve multiple realistic objectives, including those of high community priority. Part of this process will be the acceptance that multiple trade-offs (for example between emissions reduction and public health) will occur if the current policies are rigidly enforced as they stand.

Furthermore, systematic reviews of the links between aspects of housing and a wide variety of outcomes are also needed. Such reviews need to use a holistic framework that includes potential outcomes across a range of domains, including physical, mental, social, environmental and economic wellbeing.

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