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Executive summary

1. There is clear evidence that reducing the use of concrete and steel in new buildings, and replacing them where possible with timber or with hybrid timber-concrete and timber-steel components, will reduce embodied impacts.
2. There is little evidence to support increasing the thermal mass of new buildings in cooler climates such as the UK. This is unlikely to reduce energy use or therefore carbon emissions from heating, and will increase embodied carbon from the use of heavyweight and carbon intensive materials.
3. The whole life (including embodied) impacts of all building services components, including low carbon energy technologies, should be undertaken before these are recommended as solutions. More evidence is needed of the carbon impacts of these technologies.
4. Retention and retrofit of existing buildings is a lower carbon option than demolition and rebuild, and should be the default position. Any planning applications for demolition should be required to demonstrate through independent verified LCA calculation the whole life carbon benefit of demolition and rebuild over retention and retrofit. VAT on refurbishment and retrofit projects should be removed.
5. Retrofit of all existing buildings should be encouraged and incentivised through simple schemes, and with particular support for residents in fuel poverty. For older and heritage residential buildings (including around 20% of the UK residential housing), advice should take into account the real energy use, preferences and behaviours of residents before imposing retrofit options. RdSAP is inappropriate for these older buildings.
6. The use of Nature Based Solutions within cities is a complex area which needs more research. More trees and plants have benefits for air quality, mental health, and increasing active transport options during hot weather. However the trend towards growing plants and even trees on balconies and roofs should be dissuaded due to the additional structural materials required and the excess watering requirements.

Our reason for submitting evidence

This submission includes evidence based on the work of Dr Moncaster with colleagues and PhD students within the Built Environment Group at the Open University, and at the Centre for Sustainable Development at the University of Cambridge, as well as work with collaborators at the University of Cambridge, Edinburgh Napier University, KTH Royal Institute of Technology, Sweden, Aalborg University, Denmark, and the National Technical Norwegian University in Trondheim. Together we have led research into embodied and whole life carbon emissions from buildings since 2010.

More information on our work can be found at

https://www.open.ac.uk/stem/engineering-and-innovation/research/engineering/built-environment
http://stem.open.ac.uk/people/amm2528

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To what extent have the Climate Change Committee's recommendations on decarbonising the structural fabric of new homes been met?

1. Question not answered.

How can materials be employed to reduce the carbon impact of new buildings, including efficient heating and cooling, and which materials are most effective at reducing embodied carbon?

Firstly the impact of materials in reducing carbon impacts from heating and cooling:

2. There are two areas of research in this area, looking at the impact of 'thermal mass' and at phase-change materials.
3. The effect of 'thermal mass' is considered predominantly through the use of heavyweight construction materials such as concrete and masonry. There is an important shortage of empirical evidence for how much this effect might have in reality. However the majority of recent studies suggest that, while high thermal mass reduces energy use in cooling for buildings in hot climates, it has a limited effect on reducing energy used in heating buildings in cooler climates such as the UK (for example Sharston & Murray, 2020). Heavy stone buildings such as churches serve as an example that most people in the UK might relate to, being often pleasantly cool in hot summers, but uncomfortably cold through the rest of the year.
4. Reilly and Kinnane (2017) find that when more accurate models are developed, incorporating modern layered wall assemblies and realistic intermittent heating regimes rather than a fixed internal temperature, high thermal mass buildings require more heating energy in cool climates, due to the additional requirement of heating the structural elements as well as the internal space. These authors too find that buildings with high thermal mass have reduced cooling energy for hot climates. Their findings apply to both residential and non-residential buildings.
5. In the UK the majority of energy use is in heating rather than cooling. An analysis of UK energy use in buildings using data from BEIS (BEIS, 2018) found that across the building stock 1582 PJ, or 62% of the total energy used in residential and non-residential buildings, was used on space heating, with the majority in residential buildings. Cooling and ventilation accounted for just 91PJ, or just 3.5%.
6. Average temperatures in the UK are predicted to increase, as are extreme weather events including heat waves, and therefore the use of energy in cooling in the UK is likely to increase. However cooling energy requirements are unlikely to overtake heating energy requirements for several decades. In addition, cooling is powered by electricity, and the current predictions for decarbonisation of the national grid suggest that by 2035 or sooner grid electricity will have fallen from its current value of around 0.25 kg CO_2e per kWh to under 0.05 kg CO_2e per kWh (BEIS, 2019).
7. Therefore, while high thermal mass buildings will require less cooling energy in warmer climates, in the UK there is likely to be a continued higher energy requirement for heating. Most evidence suggests that higher thermal mass has little or no reduction of heating energy use. Some evidence suggests that high thermal mass buildings may increase, rather than decrease, heating energy. The next section of this answer considers the additional embodied carbon emissions from high thermal mass materials.
8. The other group of materials which are increasingly being considered for their potential to reduce energy use in buildings are phase change materials (PCM). There is considerable evidence to suggest that these can have a positive impact on reducing energy use from heating if carefully chosen for the correct temperature ranges and surfaces (see for example Song et al, 2018; da Cunha and de Aguiar, 2020). However there is little research comparing

the carbon emission savings from the reduced energy use with the embodied carbon impacts of the PCM.

The second part of this question asks which materials are best at reducing embodied carbon in new buildings:

9. The International Energy Agency Energy in Buildings and Communities Programme Annex 57 was a major collaboration of national experts to develop state of the art knowledge in this field. Through a detailed meta analysis of over 80 mostly European case studies of individual buildings we found that initial ('cradle to gate') embodied carbon of buildings is on average around 500 kg CO_2e per metre squared (Moncaster et al, 2019, Fig 2). Within individual buildings, concrete and steel tend to be responsible for the majority of impacts.
10. Concrete and steel are also responsible for the majority of carbon impacts from construction globally. Partly this is due to their widespread use, and partly due to their high carbon emissions (see Anderson and Moncaster (2020) for a recent review of published EPD for cements and concretes). It is acknowledged that both sectors are working towards reducing carbon emissions from their products. However the Annex 57 analysis provided evidence that, among a list of other strategies, substituting steel or concrete with timber reduces embodied impacts of buildings (Malmqvist et al, 2018). A further paper (Moncaster et al, 2018) found a similar answer when considering a single case study building and comparing different construction materials, applying a number of different temporal, spatial and physical variations in assessment method. While the purpose of this research was to demonstrate the considerable discrepancies that could be found through applying these variations, the results did also demonstrate that in each case the cross-laminated timber design had the lowest impacts (Fig 7). A recent paper by the REBEL group at Edinburgh Napier (D'Amico et al, 2021) found that the use of Cross Laminated Timber to replace concrete floors in steel framed buildings would have a significant reduction of embodied carbon impacts.
11. In conclusion, there is significant evidence to suggest that, at present, timber is a lower carbon construction material than concrete or steel and that where sensible steel and concrete should be substituted with timber.

What role can nature-based materials play in achieving the Government's net zero ambition?

12. Other than the lower embodied impacts of timber and other biobased materials, the carbon sequestration potential of plants and trees is well-known.
13. Within urban environments, there is also considerable evidence of the effect of green and blue infrastructure on reducing the urban heat island effect and local air pollution, and making outdoor spaces more habitable. This in turn is likely to increase active forms of transport (walking, cycling) and reduce energy use in vehicles. There is less evidence of the impact of shading by trees on reducing cooling requirements for buildings, and of wall climbers on reducing energy used in heating and cooling of buildings, and this is something that needs more research.

What role can the planning system, permitted development and building regulations play in delivering a sustainable built environment? How can these policies incentivise developers to use low carbon materials and sustainable design?

14. There is evidence that increasing regulations for reducing embodied impacts of materials, as has happened in France, has a rapid impact on industry behaviour and construction material supply chains, significantly reducing the carbon emissions from construction.

15. The Irish Green Building Council (https://www.igbc.ie) is currently leading a project to measure and reduce embodied impacts of construction materials, and setting up a basis for national databases where they don't yet exist. The UK Green Building Council with 9 other GBCs is part of a World Green Building Council project Building Life which is developing a 'whole life carbon roadmap' – see https://www.worldgbc.org/buildinglife. However these industry initiatives need to be supported by local and national regulation.
16. The new London Plan now requires all developments over a certain size to calculate embodied impacts following the RIBA methodology. It is important to measure the impact that this has on embodied carbon reduction and as far as I am aware this is not being carried out at present.
17. See too the answer to the final question on incentives for retrofit.

What methods account for embodied carbon in buildings and how can this be consistently monitored and applied across the sector?

18. The European Standard EN 15978 (for buildings and construction works), also published as British Standards, describe a process-based Life Cycle Assessment approach to calculating whole life environmental impacts of buildings, including their Global Warming Potential (measure in carbon dioxide equivalent, and commonly abbreviated to 'carbon'). Although there is evidence that this approach underestimates total embodied emissions compared with Input-output and hybrid analysis (see for example Moncaster and Symons, 2013), they have become the accepted norm around Europe and have led to increased consistency in calculations, and we recommend that they should be used.
19. Within the UK, the RICS Professional Statement on Whole Life Carbon (RICS, 2017) is based on these standards and offers a practical method by which they can be used in practice. This is currently being updated.
20. The method described considers embodied carbon as the carbon emissions arising from energy and chemical processes during the manufacture of construction materials, as well as their transport from the factory to the site, and construction works on site including removal and disposal of waste. The embodied carbon of a building includes the sum of these impacts of materials, as well as the impacts over the life of the building arising from maintenance, repair, and most importantly replacement of materials and components, and the impacts at the end of life of the building including energy used in demolition, transport of waste off site and waste disposal or processing.
21. The first stage, the embodied carbon of the manufacture of materials (also known as the 'cradle to gate' stage), can be calculated through Environmental Product Declarations (EPD) following BS EN 15804. However publication of EPD, although very rapidly increasing, is not mandatory and there are multiple individual and groups of materials and components for which data is scarce. One of these groups is buildings services and HVAC components; CIBSE TM65 has recently been published offering a method by which impacts from these components can be estimated.

Should the embodied carbon impact of alternative building materials take into account the carbon cost of manufacture and delivery to site, enabling customers to assess the relative impact of imported versus domestically sourced materials?

22. Yes. The impact of importing materials, particularly where the materials have high mass or travel a long distance, can be a substantial proportion of the impact, and standard practices of adding a small percentage to allow for transport impacts are not appropriate for these instances. An example is given of importing bricks to Ireland from the UK. The embodied carbon of UK average brick is 213kg CO_2e/tonne. Adding transport from Leicester to Dublin

via lorry and RoPAX ferry would add 106 kg CO2e/tonne, or an additional 50%. (Moncaster, Anderson and Mulligan, 2021).

How well is green infrastructure being incorporated into building design and developments to achieve climate resilience and other benefits?

23. There is a lack of research in this field at present, leaving a real concern that the 'eco-bling' of green roofs and walls will be detrimental to the environment through a requirement for increased structural materials and excessive watering required. However green areas in cities, including parks and trees, have numerous benefits.

How should we take into account the use of materials to minimise carbon footprint, such as use of water harvesting from the roof, grey water circulation, separate foul and surface water drainage systems, porous surfaces for hardstanding, energy generation systems such as solar panels?

24. There is a lack of evidence on the whole life impacts of such systems, and indeed of all technical services components. There is a need for a rapid increase in EPD for such systems, calculating accurate carbon impacts, and for empirical data demonstrating (for example) actual water savings and energy generated. These calculations need to take into account the expected life of the building and, in the case of energy generation, the predicted future carbon emissions of any replaced electricity. It seems reasonable that solar panels are more effective at scale than at a building level. It is tempting to use such 'green' systems and assume that they are the best option for the environment. However unless whole life calculations with evidence-based inputs are undertaken, this may well not be the case. (Moncaster, 2013). Looking at impacts from specific components and materials, the IEA Annex 57 studies showed that technical equipment could be responsible for around 30-40% of the whole life impact of a building, partly due to the fact that such components will need replacing once or more over the life of a building (Moncaster et al, 2019, Fig 12).

How should re-use and refurbishment of buildings be balanced with new developments?

25. The IEA EBC Annex 57 project also collated some case studies of 'deep retrofit' projects, which aimed to improve energy efficiency to current day building regulations. We found that these projects had only about half the embodied impacts of new builds (Moncaster et al, 2019). Where embodied emissions are calculated over the whole life of the building, and in particular where operational carbon savings are a) calculated based on an accurate picture of pre- and post-retrofit use and b) take into account future decarbonisation of energy, there is considerable evidence to show that retrofit is a significantly lower whole life carbon choice than demolition and rebuild.
26. For her PhD Hannah Baker looked at the reasons behind decisions to demolish and rebuild, or retain and retrofit, larger buildings on masterplan sites, and found that local and national planning legislation had a major impact on the decisions of developers (see for example Baker et al, 2017, 2018).
27. For his PhD, Wei Zhou has modelled the whole life energy of the urban residential building stock in China. His model demonstrates that increasing the life span of residential buildings would decrease the whole life energy use (and hence carbon emissions) (Zhou et al, submitted). While residential buildings in China have shorter service lives than those in the UK it is considered that the results would apply here too.
28. Retention of existing buildings should be the default position. Any planning applications for demolition should be required to demonstrate through independent verified LCA calculation the whole life carbon benefit of demolition and rebuild over retention and retrofit. The

removal of VAT on refurbishment and retrofit projects would also be a huge boost in supporting decisions to retain these buildings.

What can the Government do to incentivise more repair, maintenance and retrofit of existing buildings?

29. The incentivisation of retrofit of existing buildings is essential. 80% of the UK's current building stock will still be there in 2050. Much of this building stock is energy inefficient. However at a domestic scale, the use of RdSAP to model the energy use in older residential buildings is flawed, due both to inaccurate assumptions about building materials, and inaccurate assumptions about actual current energy use which is often lower in older buildings (Wise et al, under review). Freya Wise has also found during her PhD that decisions about retrofitting pre-1920s residential buildings are often based on the heritage values that home-owners hold, and don't reflect the focus of Government programmes on replacement windows and external insulation. However these buildings often use less energy than newer buildings, and owners are likely to employ a number of 'soft' energy reduction measures which do not affect the building fabric.

30. Retrofit of all existing buildings should be encouraged and incentivised through simple schemes, and with particular support residents in fuel poverty. For older and ungraded heritage residential buildings, advice should take into account the preferences and behaviours of residents before imposing retrofit options.

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