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Zero energy buildings and the rebound effect: A solution to the paradox of energy efficiency?

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ABSTRACT

Do energy efficient buildings save energy or spare it for other uses? Cost-effective energy efficiency improvements increase the available income of a household, or business. The increase of household income may be re-spent on the same energy service or elsewhere in the economy, or invested. This problematic, termed "rebound effect", receives renewed attention. Its micro- and macroeconomic implications can in part explain why governmental energy efficiency programmes failed to reduce total energy needs in our societies.

This paper identifies zero energy buildings (ZEBs) as both a solution and a contributor to this energy efficiency paradox. The E2 (economy–environment) vector is used to qualitatively illustrate the rebound effect link to energy efficient and zero energy buildings. The paper argues that a robust energy balance, one that shall ensure ZEBs effectively contribute to the global mitigation of greenhouse gas emissions, needs to address this paradox of energy efficiency. The paper proposes ways to do so.

1. Introduction

In order to mitigate the emission of greenhouse gases, governments are seeking ways to improve energy efficiency. This approach is supported and encouraged by the United Nations Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) which recommend cost-effective energy efficiency improvement as a way to significantly reduce anthropogenic emissions of greenhouse gases [1,2]. The development of zero energy/emission buildings (ZEBs) taking place in many OECD countries, and in particular in Europe [3], follows this logical assumption that an increase in energy efficiency will contribute to reducing global emissions. ZEBs aim to reduce net emissions associated with buildings by a high level of energy efficiency and by offsetting their remaining emissions by harvesting energy from renewable sources. From a physical or engineering point of view, ZEBs are expected to have a positive effect on the environment, requiring less energy than traditional buildings and offsetting that energy by harvesting renewables. However, a holistic perspective challenges these expectations.

Improvements in energy efficiency reduce the cost of energy services for its users. Users pay less for the now more efficient service, thus increasing their available incomes. This marginal increase in income triggers a surge in energy demand by a combination of (1) increased purchase of the now cheaper energy service, (2) the purchase of other services or goods, or (3) through investments and savings. Those are microeconomic implications of the *rebound effect*. The wide adoption of energy efficiency solutions reduce the price for energy globally thus leading to macroeconomic effects. These macroeconomic effects sometimes lead to "backfire", i.e. the energy efficiency measures ultimately lead to an increase in global energy demand.

Sorrell [4] defines the rebound effect as an umbrella term for a variety of mechanisms that reduce the potential energy savings from improved energy efficiency. The Breakthrough Institute [5] refers to the rebound effect as an economic mechanism driving an increase in demand for energy following a below-cost improvement in energy efficiency. From a broader environmental perspective, Hertwich [6] refers to the rebound effect as a behavioural or other systemic response to a measure taken to reduce environmental impacts that offsets the effect of the measure.

Rebound effects are difficult to quantify and have so far been neglected in ZEB energy balance, see e.g. Marszal et al. [7]. However, the UK Energy Research Centre's [8], reviewing more than 500 worldwide sources, came to the key conclusion *that rebound effects are of sufficient importance to merit explicit treatment. Failure to take account of the rebounds effects could contribute to shortfalls in*

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the achievement of energy and climate policy goals. Other commissioned report on the rebound effect brings the problem higher on the political agenda, notably in Europe the European Commission Directorate General for the Environment [9].

This paper looks at microeconomic rebound effects in the framework for the development of a robust energy and emission balance method for ZEBs. A robust balance ensures a global reduction of energy demand and a global mitigation of GHG emissions. The article summarises the theory behind the rebound effect, illustrates the implications for ZEBs and proposes ways to counteract the possible paradoxical consequences of cost-effective energy efficiency improvements in buildings. The analysis presented is focused on a northern heating-dominated climate.

2. The rebound effect

Authors distinguish between different categories of rebound effects without completely agreeing on how the different sub-effects should be shared among these. For the purpose of this article, it is desirable to only distinguish between micro- and macroeconomic rebound effects as only the formers are relevant within the current scope of ZEBs energy balance. Microeconomic effects are the ones taking place at the household level, or building level for the sake of ZEB energy balance. They are the three effects presented in the introduction. These effect are sometime divided between direct and indirect effect, see e.g. Herring [10] and Sorrell [11]. They may also be referred to as substitution and income effects, see e.g. Hertwich [6] and Greening [12].

Macroeconomic effects are economy wide implication of the rebound effect. While only microeconomic effects are relevant within the current framework for energy/emission balance of ZEBs, macroeconomic effect must be well understood and kept in mind by policy makers in order to make sure ZEBs provide the global reduction in energy demand and emission of greenhouse gases for which they are commissioned.

2.1. Microeconomic rebound: Examples from the building sector

The installation of a heat pump in a building previously relying on direct electrical heating reduces substantially the operating cost of space heating. Households may therefore choose to heat up more rooms to higher temperatures for longer periods. This behaviour may reduce, cancel or overcome the predicted energy savings from simple engineering calculations. This type of rebound is very common, see e.g. [13] for statistics for Norway, and more probable in low income households where the price for heating is too high for them to afford a desirable level of comfort prior to energy efficiency improvements. Households in developing countries are especially prone to this type of re-spending. Saturation is fast reached for OECD households.

When all rooms are already heated up to a comfortable temperature for the desired period prior to the implementation of energy efficiency solutions re-spending is most likely to take place on other goods and services or to be invested (saved). The money not spent on heating can, for example, finance an overseas flight. It may also be used to increase the house size when the operating costs of a larger house are significantly reduced by the energy efficiency improvements. The magnitude of the effect highly depends on the energy/emission intensity of the goods or services where the money is re-spent. For example, a low rebound from re-spending is expected if a households decides to buy more expensive locally produced organic food [6]. A household may also decide not to spend the money, but to save or invest it. Savings and investments also have embodied energy and emissions through re-spending by the financial institutions, investment funds, companies, etc.

Lastly, the energy embodied within an energy efficiency solution reduces the total energy savings from the implementation of that solution. For example, the implementation of vacuum insulation panels may reduce energy requirements for space heating, but the total energy reduction needs to take into consideration the embodied energy in the production, transport and installation of these vacuum insulation panels and the disposal of the previous insulation. As will be shown, this *embodied energy effect* is already taken into consideration in some of the ZEBs energy balance when these are done over the complete building life cycle. If a broader environmental perspective is adopted, one needs to look at embodied environmental impact of different goods and services. Two building materials may have the same embodied energy but very different embodied emissions depending on where and how they are produced.

It is important to realise that there is energy/emissions associated with every dollar in the economy, thus any cost savings from energy efficiency will have energy/emissions associated to it. Microeconomic rebound effects are in most cases not expected to totally overcome, but only to reduce the energy savings predicted by common engineering calculations. See [8,14,15] for a review of different estimates on the magnitude of the microeconomic rebound effect.

3. The case of zero energy/emission buildings

Zero energy buildings aim to eliminate the energy demand from buildings by achieving a very high level of energy efficiency and satisfy the remaining energy demand from renewable sources. *Nearly* zero energy building are defined by the European Commission [3] as *a building that has a very high energy performance [. . .] [and where] the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*. While energy and emissions are central to ZEBs, the basic purpose of the building, which is to provide shelter at a desired level of comfort, stays the same. ZEBs should fulfil the basic purpose of buildings with the added benefit of a reduction in global energy demand and emission of greenhouse gases.

Sartori et al. [16] illustrated basic design principles for net ZEBs. They presented a general pathway to achieve a Net ZEB which consists of (1) reducing energy demand by means of energy efficiency measures and (2) to generate electricity by means of renewable energy supply.

Marszal et al. [7,17,18] studied the approaches to ZEBs energy balance proposed by 10 OECD countries. None of the methodologies takes into consideration any form of energy/emission "take-back" from cost-effective energy efficiency improvements. However, the existence of the rebound effect is well recognised and deemed of outmost importance to achieve true global reduction in energy demand and emission of GHGs. Drawing energy balance boundaries around a single service or goods, as in the case of ZEBs, may lead to shortfalls in energy and emission accounting.

The range of renewable energy supply (RES) options considered within the energy balance boundaries is significant for the study of the rebound effect. RES have been classified as shown in Fig. 1.

3.1. Illustrating re-spending in ZEBs

Goedkoop et al. [19] introduced the E2 (economy–environment) vector to represent the environmental impact per unit added value of a process. The E2 vectors plot the cumulative value against the cumulative environmental load of a good, service or process. Hertwich [6] illustrated how the E2 vectors can be applied to the rebound effect. This approach is modified here in the qualitative