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Operational vs. embodied emissions in buildings—A review of current trends

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ABSTRACT

Global awareness of environmental impacts such as climate change and depletion of ozone layer has increased significantly in the last few years and the implication for emissions reductions in buildings are widely acknowledged. The goal, therefore, is to design and construct buildings with minimum environmental impacts. Lifecycle emissions resulting from buildings consist of two components: operational and embodied emissions. A great deal of effort has been put into reducing the former as it is assumed that it is higher than the latter. However, studies have revealed the growing significance of embodied emissions in buildings but its importance is often underestimated in lifecycle emissions analysis. This paper takes a retrospective approach to critically review the relationship between embodied and operational emissions over the lifecycle of buildings. This is done to highlight and demonstrate the increasing proportion of embodied emissions that is one consequence of efforts to decrease operational emissions. The paper draws on a wide array of issues, including complications concerning embodied emissions computation and also discusses the benefits that come with its consideration. The implication of neglecting embodied emissions and the need for an urgent policy framework within the current climate of energy and climate change policies are also discussed.

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1. Introduction

The singular most important first step towards attaining the three goals of energy policy, namely, security of supply, environmental protection and economic growth, lies in energy efficiency improvements [1]. Nearly 40% of the world's energy consumption and one third of related global greenhouse gas (GHG) emissions are attributable to the building sector as it creates significant economic, environmental and social impacts [2–4]. The United Nations Environment Programme [2] reports that the environmental (including carbon) footprint of the building sector consists of: 40% of energy use, 30% raw materials use, 25% of solid waste, 25% water use, and 12% of land use. This trend may seem to be rising since Pérez-Lombard et al. [5] also stated that global GHG emissions from buildings continue to rise at an annual rate of 1.5%. In the UK, the building and construction sector represents an important economic sector. Historically it has contributed approximately 10% of GDP [6] but also accounts for approximately 50% of total emissions [7], while contributing to acidification, eutrophication, smog and solid waste emissions [8]. Understanding the flow of energy usage from the products, processes and activities involved in the lifecycle of buildings is therefore crucial in meeting national and global emissions reduction targets.

Energy is consumed by buildings during all the lifecycle stages, including construction, use, maintenance, renovation and demolition. As such, several energy policy frameworks, for example, the 2007 policy statement for target of zero carbon homes [9], have acknowledged the significance of lowering energy use in buildings, requiring all new domestic and non-domestic buildings to be 'zero carbon' by 2016 and 2019 respectively. A building is said to be 'zero carbon' when it has no net carbon emissions arising from its operational emissions, including space and water heating, lighting and the use of equipment and appliances [9]. However, there has been little consideration from such policy frameworks of the energy associated with the materials and construction processes associated with buildings [10]. There are substantial emissions implications arising from the extraction of raw materials, processing, manufacture, transportation, on-site delivery, construction, maintenance, renovation, final demolition as well as all the activities and processes along the supply chain that constitute the building. These are collectively known as embodied emissions.

It is often assumed that the operational emissions of a building are higher than its embodied emissions, so a great deal of effort is put into reducing energy consumption in this phase. Innovations and technological advances in the area of renewable energy technologies, energy efficiency and inducements to change behaviour have offered promising operational emissions reductions in buildings. However, these measures often lead to an increase in materials use and energy demand for their production and explain the growing importance of the other phases in the total lifecycle of a building. Several studies, such as [11–13] have revealed the growing significance of embodied emissions in buildings and have shown its relationship to lifecycle carbon emissions. In the UK, embodied emissions in new construction and renovation each year accounts for about 10% of the total CO_2 emissions [14,15]. Within this, approximately half is used in the extraction of raw materials and manufacture of the materials and about half is used in transport [14].

The Climate Change Committee [16], reports that a typical new 2 beds home built with traditional materials (brick, concrete foundations etc.) embodies around 80 tCO_2 with a carbon payback time (through lower operational CO_2 emissions) of several decades. Despite this increasing awareness, supported with statistical evidence, regarding the growing importance of embodied emissions in practice; it is still very much underestimated. This paper presents a critical review of the current trends concerning operational versus embodied emissions in buildings. It centres on complications concerning embodied emissions computation as well as a wide array of benefits that comes with its consideration, and gives insights into the importance of its inclusion in building energy analysis. The implications of neglecting embodied emissions and the need for an urgent policy framework within the current climate of energy and climate change policies are also discussed.

2. Structure and significance of the paper

A retrospective approach is taken to critically review the relationship between embodied emissions and operational emissions over the lifecycle of buildings and to highlight the increasing importance of embodied emissions in building emissions assessment. The paper is organised into six parts. Section 3 draws a clear distinction between energy and carbon in the context of embodied and operational emissions. This is important as both terms are often erroneously interchanged, leading to incorrect interpretations. A wide array of different definitions and interpretations of embodied emissions and its various forms are presented in Section 4. Section 5 provides a detailed and extensive overview and analysis of the varying proportion of embodied emissions as compared to operational emissions across different buildings. This is done to demonstrate the increasing proportion of embodied emissions that is one consequence of efforts to decrease operational emissions. An analysis of the increasing importance of embodied emissions in building construction decision making is detailed in Section 6. The significance of embodied emissions, difficulties, challenges as well as the benefits associated with the inclusion of embodied emissions in decision making within the building sector is equally highlighted in this section. Section 7 discusses the need and urgency for a policy framework regarding the consideration of embodied emissions. A robust and integrated approach which combines three key variables of emissions mitigation options: financial costs, operational and embodied emissions into a single and robust framework in the form of a policy instrument such as marginal abatement cost curves, for climate change mitigation strategies is also discussed in this section. Finally, summary and conclusions are drawn in Section 8.