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Energy and environmental assessment of industrial hemp for building applications: A review

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ABSTRACT

Buildings significantly contribute to global environmental pollution due to consumption of both natural and primary-energy resources as well as to emission of carbon dioxide in their life-cycles. Therefore, to enable construction of more sustainable buildings, it is important and urgent that new low-environmental impact materials are developed, mainly by reducing the use of non-renewable resources. In this regard, the recent advances in the development of natural fibres represent a significant opportunity to produce improved-materials and energy from renewable resources. For this purpose, assessments of energy and environmental performances are needed to support both the design and the production of the aforementioned materials so as to identify solutions for enhanced contribution to global sustainability. In this context, this study presented a review of the papers published up to February 2015 that have been focussed upon the assessment of the environmental and energy impacts related to the use of hemp-based materials for building applications. The reviewed studies aimed at testing and improving hygro-thermal properties and eco-friendliness of these materials for reduction of both embodied and operational energy, whilst preserving both indoor air quality and comfort. Doing so would enable limiting the use of energy resources and, as a consequence, their impacts to human health and to the environment, so contributing to making buildings healthier and more environmentally sustainable throughout their life-cycles. Based upon the findings of the studies reviewed, these materials have strengths and weaknesses and their use is strictly dependent upon the given structural situation as well as upon specific requirements of thermal, moisture, fire and sound protection. In particular, all studies concluded that the main strength in the use of hemp-based materials comes from the production phase because of the "green" origin of these materials, mainly associated with the carbon sequestration during plantation growth.

Contents

Abbreviations: AAC, aerated autoclaved concrete; CED, cumulative energy demand; CF, carbon footprint; EPS, expanded polystyrene; EROI, energy returned on investment; EU, European Union; FAOSTAT, Food and Agricultural Organisation of the United Nations—Statistics Division; FRC, fibre reinforced concrete; FU, functional unit; GHG, greenhouse gas; GGP, greenhouse gas protocol; GMT, glass–fibre mat thermoplastics; GWP-100, 100-year global warming potential; HDPE, high density PE; LCA, life cycle assessment; LCCA, life cycle cost analysis; LCEA, life cycle energy analysis; NMT, natural-fibre mat thermoplastics; PE, polyethylene; PET, polyethylene terephthalate; PP, polypropylene; SMB, stabilised mud blocks; WTE, waste-to-energy

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1. Introduction

Climate change is increasingly drawing the attention of scientists and policy makers worldwide, thereby becoming a global concern. During the last few decades, the global climate has changed rapidly and will continue to change with time: therefore, interventions are needed to enable global pollution mitigation so as to contribute to preserving the global environment and the planet itself [1]. In this regard, it should be observed that a significant contribution is given by buildings due to consumption of both embodied energy and natural resources as well as to emissions to air, water and soil during all the phases of their life-cycles. According to Dixit et al. [2], the embodied energy (generally expressed as primary energy) represents the energy sequestered in buildings and building materials during all processes of production, on-site construction, and both final demolition and disposal. Direct and indirect energy are the two primary components of the embodied energy: in particular, direct energy is used for construction, operation, renovation, and demolition of a building; whilst, indirect energy is consumed by a building for production of the materials used in its construction and technical installations [1,3]. In addition to the embodied energy, the operational energy should also be considered when intending to assess building life-cycle energy. Based upon the definition provided by Dixit et al. [2], operational energy is the energy expended in maintaining the inside environment through processes such as heating and cooling, lighting and operating building appliances.

According to Sadineni et al. [4], today's buildings are responsible for a significant portion of the energy consumed in the developed countries. Indeed, in many of them building energy consumption accounts for approximately 40% of the whole energy demand, whilst space heating and cooling requires almost 60% of the total energy consumed in buildings [5]. As far as the European context is concerned, buildings account for almost one third (and even more in some specific countries) of the total energy-related emissions of carbon dioxide (CO_2), depending upon the energy consumption fuel mix [6]. Such emissions consist, primarily, of embodied CO_2 as well as of the CO_2 generated during the following phases: material production and building assembly; building operational life (this is directly related to the building energy efficiency and the site-dependent energy generation method applied); and also, building disassembly and subsequent disposal of the component materials [7].

Along time, numbers of researchers have carried out studies aimed at investigating the building sector by assessing the related energy, environmental and economic issues in order to find ways for global sustainability enhancement: in this regard, several reviews have been performed in recent years. For instance, Cabeza et al. [1] carried out a detailed and complete review in order to summarise and organise the literature on Life Cycle Assessment (LCA), Life Cycle Energy Analysis (LCEA) and Life Cycle Cost Analysis (LCCA) studies for estimation of the energy efficiency and of the environmental and economic sustainability related to buildings. Furthermore, with regard to building energy issues, Dutil and Rousse [8] introduced the concept of Energy Returned On Investment (EROI) in buildings as a yardstick to try to shed some light on the claim that the cheapest energy is the one that is not needed. In agreement with Huijbregts et al. [9], they observed that values of estimated EROI in energy saving strategies are high if compared to most of the energy production strategies, thereby highlighting the positive environmental impact of energy conservation. The cheapest energy is the one that is un-used, even though this statement might be questioned in some cases: for example, when an extra-foot of insulation is added on an already well insulated building enveloped. As a matter of fact, it could happen that the benefit in terms of energy conservation is no longer justified based upon the energy used for production, installation and disposal of the insulation system used. In this regard, Kaynakli [5] reviewed numbers of studies in order to estimate the optimum thickness of the thermal insulation material in a building envelope and its effect on energy consumption. The author documented that the optimum insulation thickness and the resulting energy requirements for indoor heating and cooling are strictly dependent upon the number of annual heating and cooling degree-days associated with the climatic zone in which the building is located.

With regard to building materials, Cabeza et al. [10] considered low carbon and low embodied energy materials in buildings, thus highlighting the difficulties found in measuring embodied energy and, also, in comparing published data. However, that study contributed to efforts to develop new materials with less embodied energy. For instance, Gartner [11] discussed the practicality of replacing Portland cements with alternative hydraulic cements in order to allow for lower CO_2 emissions per unit volume of concrete of equivalent performance. According to Reddy [12], stabilised mud blocks (SMB) are energy efficient eco-friendly alternatives to burnt clay bricks since they enable saving around 60–70% of the energy used in burned bricks.

For building insulation materials, Asdrubali et al. [13] presented an updated survey on the acoustical properties of sustainable materials, including mixed and composite ones as well as systems such as green roofs and green walls. The authors highlighted that such materials cause very low impact to human health and to the environment compared to conventional materials and, that the total energy demand for manufacturing and installation is generally low based upon a life-cycle approach that includes also the disposal scenario. Shrestha et al. [14] described a proposed protocol with the aim of providing a comprehensive list of factors to be considered when evaluating the direct and indirect