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A parametric tool for the assessment of operational energy use, embodied energy and embodied material emissions in building

Nicola Lolli[a]*, Selamawit Mamo Fufa[b], Marianne Inman[b]

[a]SINTEF Building and Infrastructure, Høgskoleringen 7b, NO-7465 Trondheim, Norway
[b]SINTEF Building and Infrastructure, Forskningsveien 3B, NO-0373 Oslo, Norway

Abstract

Current European legislation calls for the abatement of greenhouse gas (GHG) emissions through better building design and technological solutions, in order to reduce operational energy use, embodied energy and embodied material emissions originating from buildings. Presently, environmental performance assessment tools for buildings fall short of documenting all of these parameters. Comparative life cycle assessment (LCA) may be used to obtain a clear overview of mass and energy flows in a building. However, construction professional consider LCA calculations as complex and time consuming. Therefore, this paper outlines a methodology for the development of a dynamic parametric analysis tool (PAT) for the comprehensive assessment of operational energy use, embodied energy and embodied material emissions during the production and operation phases of a building. A simple, conceptual building case study is presented to demonstrate the potential use of this parametric analysis tool. The results show that the PAT developed in this study can be used to define optimal solutions of building envelopes for the different parameters of the analysis. In conclusion, this study facilitates the first steps of development and testing for a PAT that evaluate optimised solutions that minimise operational energy use, embodied CO_{2eq} emissions and embodied energy. The tool, which is not meant to give precise results, given its limitations in the calculation method, can be used for performing a comparative pre-assessment of various design solutions. This body of work highlights considerable scope of work for the further development of this tool.

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Keywords: Building; Operational energy; embodied energy; embodied CO_{2eq} emissions; parametric analysis tool

* Corresponding author. Tel.: +47 45063320.
E-mail address: Nicola.Lolli@sintef.no

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1. Introduction

The building sector is responsible for a significant proportion of global energy consumption, which gives rise to greenhouse gas (GHG) emissions and the depletion of energy resources [1, 2]. Current European legislation calls for the abatement of GHG emissions through better building design and technological solutions [3]. Emerging trends towards energy efficient buildings, such as passive house, zero emission and energy-positive buildings, address the target of reducing operational energy and emissions in buildings [4-10]. These targets are typically reached by implementing energy efficiency measures, such as installing effective insulation materials and better performing windows, reducing infiltration losses, recovering heat loss from ventilation systems, and through using renewable energy resources, in order to meet the remaining energy demand [11, 12].

However, as buildings become more energy efficient, the relative proportion of embodied energy and associated carbon emissions arising during the building lifecycle increases [13-16]. Many studies analysed operational energy use and emissions arising from the operational stage of a building, whilst fewer studies examined embodied energy or embodied material emissions arising from building materials in a building [17-22].

Life cycle assessment (LCA) is a widely recognised and accepted method for the assessment of burdens and impacts throughout the lifecycle of a building. LCA evaluates all resource inputs, including energy, materials and water, in order to calculate the environmental impacts of a building at either the material, product or whole building level. Within the construction industry, the life cycle inventory (LCI) phase is considered the largest obstacle, due to the time-consuming process of data collection. There are many existing LCI databases available (e.g. University of Bath's Inventory of Carbon and Energy (ICE) [23] and the Swiss Ecoinvent database [24]), however many of these databases rely on generic data and require a platform for LCA calculations. Often these calculations are carried out in process-based LCA tools such as Simapro or Gabi [25, 26], which are not designed specifically for buildings. The Ökobaudat is an LCI database that consists of a mixture of generic data and environmental product declarations (EPDs) [27], which have the advantage of taking into account regional production variations [28]. There have been many developments within the building sector to simplify LCA calculations, and the IEA Annex 31 developed an assessment tool classification system, which is divided into five parts: 1) Energy modelling software, 2) Environmental LCA tools for buildings, 3) Environmental assessment frameworks and rating systems, 4) Environmental guidelines for design and management of buildings and 5) environmental product declarations [29]. Many energy modelling tools (e.g. SIMIEN, IDA-ICE, EnergyPlus [30]), environmental assessment tools for buildings (e.g. ATHENA Environmental Impact Estimator, Building Environmental Assessment Tool (BEAT), EcoEffect [31]) and environmental product declarations (EPDs) from different EPD program operators (EPD Norge, the International EPD system, IBU) stem from this classification [32].

In addition, there are a number of parametric analysis tools (PAT) available for a range of parameters such as optimal structure, optimal daylighting or optimal comfort. Parametric analysis is a useful since it facilitates for the dynamic testing of multiple scenarios simultaneously. However, few PATs combine and assess the environmental impacts arising from both operational energy and material use in buildings. Previous studies evaluated existing sustainable building assessment tools, [31, 33-35] and found that they cover a wide range of building types and different aspects of a building's life cycle. Some previous PAT studies focused on the parametric design in tall buildings [36], optimised daylighting in a Grasshopper based PAT [37], the performance of a PAT in energy efficiency measures [38], the performance of building envelopes in residential buildings [39].

The objective of this study is to build upon the existing body of knowledge outlined above, by combining three types of tools identified by the IEA Annex 31 classification system; namely, energy modelling, environmental LCA tools for buildings, and EPDs; into one interactive parametric analysis tool. This parametric analysis tool differs from the other existing tools, as it combines three assessment tools into one holistic tool for buildings. Therefore, this paper investigates ways of simplifying the data collection process for users through the implementation of an environmental parametric analysis tool. The tool is designed to help architect, engineer and constructor (AEC) professionals identify which design options lead to lower operational energy use, embodied energy and embodied CO2eq emissions. For that reason, we developed a PAT in MS Excel with a simple and intuitive user interface.

This paper presents a tool specifically developed to perform a parametric analysis of wall and window components in a building, in order to evaluate optimised solutions that minimise operational energy use, embodied CO2eq emissions and embodied energy. A residential zero emission building (ZEB) concept model, developed by