Journal of Cleaner Production 130 (2016) 260–272

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Tool for life cycle analysis of facade-systems for industrial buildings

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ARTICLE INFO

Article history:
Received 17 March 2015
Received in revised form
16 October 2015
Accepted 17 October 2015
Available online 26 October 2015

Keywords:
Life cycle costing
Life cycle assessment
Industrial building
Decision making support
Planning tool

ABSTRACT

Minimal investment cost, flexibility and expandability of the construction have been the highest priorities in the design of industrial facilities. With the sharpening of building codes and the upcoming polices on energy efficiency, life cycle optimisation is starting to gain importance among industrial investors. On the case study of an energy efficient industrial facility, a decision-support tool was developed for analysing life cycle economic and environmental impacts of facade-systems. The tool was tested by analysing three different facade-systems (steel liner tray, steel sandwich panels, cross laminated timber panels) of the proposed building model. The construction cost of the tested facade-systems are largely differing (up to 27%), however after a period of 35 years, the life cycle costs are diverging by only 6%. In terms of ecology (Global Warming Potential) the cross laminated timber facade, with the highest initial costs, features the best performance by 80% less emissions. The test underlines the large impact the design stage has on the life cycle performance, when determining facade elements and shading concepts. The tool has large implementation potential as a relatively easily applicable decision-support instrument for designers and investors, when studying and determining sustainable construction and facade systems; thus improving the traditional decision-making process, still based on the choice of the lowest costing construction.

1. Introduction

The highest priority aims in the design and construction of industrial facilities have primarily been minimal investment costs, flexibility and expandability of the built structure. Industrial buildings have a relative short life cycle duration in comparison to other building typologies, partly due to the short production life cycles. Following costs, as well as the resources and energy optimisation of the industrial buildings have been regarded as secondary issues compared to the management of the production processes and workforce. However, with the sharpening of building codes, the upcoming number of European regulations on the climate protection and energy efficiency; such as the zero-energy buildings (EC, 2012), as well as the raising awareness of a corporate social responsibility, life cycle optimisation is starting to gain importance among industrial investors. Especially with the growing global demand for more ecologically sound products, investors are striving for realization of "green" industrial facilities, as a part of a complete value chain. Nonetheless, there is still a large gap between ecologic and economic interests, mostly based on the short payback periods. Decision-making support tools, enabling a balance between economic and environmental aims, are largely lacking.

One of the key success factors for over-all energy and resources-efficient industrial facilities is an energy efficient building envelope coupled with high-performing technical building services, usually intertwined with or incorporated in the building structure. In 2009 the average cost of the exterior building skin of an administration-office building in Germany was calculated at 24% of the total construction cost (König et al., 2009). In industrial buildings this proportion is considerably lower, since the facade surface area to volume ratio is quite different and technical building services hold a significant role concerning total costs. However, decisions about the facade are crucial even in industrial facilities, as the thermal building envelope is an essential parameter responsible for the

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Abbreviations: EEFA Tool, Economic Environmental FAcade Tool; LCC, Life Cycle Costing; LCA, Life Cycle Assessment; BIM, Building Information Modelling; AEC industry, Architecture, Engineering and Construction Industry; GWP, Global Warming Potential; AP, Acidification Potential; PED, Primary Energy Demand; PEnr, Primary Energy non-renewable; PEr, Primary Energy renewable; EPD, Environmental Product Declaration; E, East; W, West; N, North; S, South.

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http://dx.doi.org/10.1016/j.jclepro.2015.10.063
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energy demand, as well as originator of following costs (cleaning, maintenance) affecting to a large extent the future running costs. Such decisions made in the early design phases determine the future path of a project.

1.1. Goal and scope

In order to facilitate the design and planning process of energy efficient industrial facilities for the planners and investors, a Tool for Economic and Environmental life cycle analysis of FAcade-systems (EEFA) was developed (Waltenberger, 2011). The focus of the analysis is a single, but highly complex and costly building element – the facade, as key success factor for an energy and resources-efficient building – and not the whole building.

EEFA is an Excel-based Tool thus easily applicable and modifiable, developed and tested on a case study of an energy efficient industrial facility within the research project INFO (Interdisciplinary Research for Energy efficient Production). The Tool is compiled to support the decision-making process based on integrated life cycle analysis, comparing economic and environmental impacts of industrial facade-systems over their whole life cycle.

EEFA focuses on the evaluation of various facade-systems, applying life cycle costing methodology for analysis of economic impacts, and life cycle assessment methodology for analysis of environmental impacts for the stages production, operation and demolition along the life cycle.

The adoption of EEFA, which assesses up to six life cycle performance indicators (construction costs, life cycle costs, GWP, AP, PEnr, PEr) and also delivers a synthetic indicator compiled in a radar-diagram (combination of all the outputs), allows planners and investors a quick and transparent visualisation of the best performing facade already in the early design stage, the stage which determines the latter building performance.

This paper is structured as follows: in the next chapter the state of the art of life cycle analysis approaches is outlined through literature review, further on the methods for the life cycle costing (LCC) and life cycle assessment (LCA) are briefly introduced. Next the EEFA Tool with its modules and functions is presented, followed by a Tool test through a comparison of LCC and LCA performance of three exemplary facades and a discussion on the results, as well as applicability and possible implementation areas for the Tool. In the concluding chapter, challenges for the implementation and future steps are discussed.

2. Literaturure review

A need for optimisation of building performance along the life cycle has been widely acknowledged in the academia as well as in the AEC industry.

Numerous models and methods have been developed for assessment of environmental impacts, mostly based on singular indicators such as energy consumption along the life cycle and related CO_2 emissions for embedded and operational energy (Ramesh et al., 2010). For example, Gustavsson and Joelsson (2010) focus on the ratio of the primary energy needed for the material production of additional insulation versus the operational energy savings in various construction typologies. Peuportier et al. (2013) investigate the energy related environmental impacts of passive and standard buildings depending on user behaviour over the life cycle using thermal simulation scenarios.

Integrated life cycle analysis, based on combined assessment of environmental (life cycle assessment) and economic (life cycle costing) impacts of buildings along their life cycle as combined approach, was introduced by Kohler and Lützkendorf already in 2002, finally resulting in the development of the software tool for calculation of life cycle costs and environmental impacts LEGEP (Kohler et al., 2005). Such combined approach is used e.g. by Kesicki (2012), who investigates the CO_2 and monetary saving potentials through scenario-development for thermal and heating systems refurbishment in the UK social housing stocks, whereas Ristimäki et al. (2013) investigate various heating systems (district heating vs. heat pump) in terms of life cycle costing and environmental impacts. Debacker et al. (2013) employ combined approach exploring the environmental and financial impacts of heating and ventilation systems, as a decision support instrument for planners and builders. Motuziene et al. (2016) explore single-family house design based on multiple criteria analysis, applying thermal simulation, life cycle assessment and life cycle costing thus enabling decision making process based on multiple criteria.

However, the implementation of such approaches and related knowledge transfer still faces difficulties in the practice (Gluch et al., 2013). The reasons are numerous – standards clearly define the scope, but most of the methods are too complex to be adopted by practising professionals, requiring significant efforts mostly due to the lack of data (Malmqvist et al., 2011). With the use of more powerful software tools such as Building Information Modelling (BIM), hope arises that integrated life cycle analysis will become more spread in the planning practice, supporting the decision-making process towards life cycle optimisation (Russell-Smith et al., 2015).

Life cycle assessment in construction is most extensively applied for improving the environmental performance of building materials. Due to the scarceness of raw materials on the one hand and as construction materials are one of the major contributors to the future waste on the other, a framework for decision-making support allowing cradle-to-cradle oriented material management is proposed by Silvestre et al. (2014). Detailed analysis of environmental impacts along the life phases of manufacturing, construction, operation and end-of-life has been carried out for specific materials. Kua and Kamath (2014) study the environmental impact of replacing concrete with bricks as building construction material. Ingrao et al. (2014) perform a life cycle inventory analysis for precast-concrete storage sheds and Feiz et al. (2015) analyse the CO_2 emissions of cement production.

Furthermore, during the recent decades, extensive research has been conducted on assessment of buildings for residential use, e.g. of Indian residential stocks by Ramesh et al. (2012) or of Spanish residential cases applying energy certificates by Zabalza et al. (2009). Gustavsson et al. (2010) compare the primary energy consumption of low-energy and standard energy residential buildings in dependence of construction material or heating system. Uihlein and Eder (2010) explore the impact of EU-policies energy savings through thermal refurbishment of residential building stock. Garrido-Soriano et al. (2012) explore the impact of regional and national policies on energy savings of Catalan residential stock.

On the contrary, office or industrial buildings, which are in focus of this paper, are seldom assessed. Regarding the life cycle analysis of industrial facilities, a significant body of research has been conducted about optimisation on product level, as summarised by Luz et al. (2015), or on manufacturing processes, as reviewed by Shin et al. (2015), but much less about optimisation of buildings. Industrial facilities have not been thoroughly studied under this perspective and limited work has been published, as acknowledged by Heravi et al. (2015). However this does not comply with advances in the research on an over-all eco-efficient industrial production, assessing multiple factors such as material, energy, cost, time and environmental impact to propose a sustainable manufacturing model (Deif, 2011).

Among the conducted research on building level, several authors proposed holistic models for planning of more sustainable