



Life cycle assessment of exterior window shadings in residential buildings in different climate zones



Hamed Babaizadeh ^a, Nasim Haghighi ^b, Somayeh Asadi ^{c,*}, Reza Broun ^d, David Riley ^c

^a Stantec Consulting Inc., 500 Main Street, Baton Rouge, LA 70801, USA

^b Department of Civil & Architectural Engineering, Texas A&M University, Kingsville, TX 78363, USA

^c Department of Architectural Engineering, The Pennsylvania State University, 104 Engineering Unit A, University Park, PA 16802, USA

^d Department of Civil Engineering, University of Texas at Arlington, Arlington, TX 76019, USA

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ABSTRACT

Use of exterior shading systems is important to increase energy savings in residential sector, mainly in warmer climates exposed to direct sunlight. These types of shades can keep inside temperatures cooler and consequently reduce cooling loads and costs. This study employs Life Cycle Assessment (LCA) to compare the effects of three different shading materials on building energy consumption and their impacts to the environment within five major climate zones defined by American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). To achieve this objective, A Life Cycle Inventory (LCI) is used to quantify the energy and emissions of the exterior shading systems during the manufacturing process, in-service and end of life. The Building for Environmental and Economic Sustainability (BEES) model and SimaPro 8.0 software (Ecoinvent 3.0 database) were employed to develop the life cycle inventory of the shadings through all life cycle stages. The LCA framework used in this study was based on a life cycle methodology that follows the International Organization for Standardization (ISO) 14040 standard for Life Cycle Assessment and the ASTM standard for Multi-Attribute Decision Analysis. Based on the analysis conducted for wood, aluminum, and polyvinyl chloride (PVC) shadings, it may be concluded that the use of external shadings on residential window panes, in most cases, carries a positive effect on fossil fuel depletion impact, while it increases environmental loads in other environmental impact categories. Among the three aforementioned materials, wood and PVC shadings are the most and the least environmentally-friendly materials, respectively.

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1. Introduction

Design of sustainable buildings requires the analysis of environmental performances in every stage of their life cycle. Life Cycle Assessment (LCA) is a technique used to evaluate potential environmental and economic performances of building envelopes and products throughout their life cycle. Architectural features intended to reduce unwanted heat gain are increasingly utilized to improve building performance but are not commonly scrutinized during project design for their overall environmental impacts. The LCA technique has been widely applied to building components including windows, walls, and roofs and entire buildings. Stazi et al. [1], applied an integrated approach for the optimization of energy

and environmental performances of complex building envelopes to an exemplary solar wall system and calculated the environmental performance in terms of energy demand and CO₂ emissions within the manufacturing and use phases. In another study conducted by Mora et al. [2], an integration framework was developed to facilitate the inclusion of life-cycle considerations in the design process from the outset. Therefore, materials and systems can be selected not only from environmentally friendly resources, but mainly, to match service life performance expectations. The developed framework can be executed iteratively to assess these requirements. This framework helps to have a better understanding and modeling of the dynamics of the built environment to which materials, components, and systems are exposed. Babaizadeh and Hassan [3] compared LCAs of a clear float glass window and a similar nano-sized titanium dioxide (TiO₂) coated glass window, as a potential substitute for clear glass windows commonly used in residential buildings, to evaluate the ability of the coating

* Corresponding author. Tel.: +1 8148653013.
E-mail address: asadi@engr.psu.edu (S. Asadi).

technique in purifying the environment by capturing some of the pollutants in the air. Abeyundra et al. [4] have investigated the environmental, economic, and social life cycles of two main construction materials (i.e. timber and aluminum) used in typical doors and windows in Sri Lanka. Based on the conducted study, it was concluded timber elements are more favorable in environmental and economic aspects while aluminum performs better in social terms. In another study conducted by Broun et al., the breakdown of primary energy use and greenhouse gas (GHG) emissions of insulated concrete form (ICF) and cavity walls, the two most common exterior type walls in the U.K., was investigated to determine the more environmentally-friendly wall type option to be used in residential building sector [5]. Life cycle environmental cost characteristics of extensive and intensive green roofs versus conventional roofs were compared by Kosareo et al. over the life cycle of a typical building to quantify the energy use reduction [6]. Bribian et al. introduced the state-of-the-art regarding the application of LCA in building sector, providing a list of existing tools, potential users, and purposes of LCA in this sector. This simplified LCA methodology allows global comparisons between the emissions and the embodied energy of the building materials, in addition to the energy consumption and its associated emissions at the use phase [7]. Annex 31 was established under the auspices of the International Energy Agency's (IEA) agreement on energy conservation in buildings and community systems with objective of promoting energy efficiency by increasing the use of appropriate tools by practitioners [8]. The building sector constitutes 30–40% of the society's total energy demand and 44% of the total material use [9]. Therefore, LCA technique can be used to compare building components alternatives and lead building professionals towards using more sustainable and environmentally-friendly substitutes.

An essential objective in designing sustainable buildings is to decrease energy consumption over life cycle of building components with minimum environmental drawbacks [10–13]. Fluctuations in outside temperature and solar radiation result in variable interior façade surface temperatures and transmitted solar gains. Windows are the most important components of the building envelope in terms of energy use and comfort. Window shadings can play a major role in indoor air conditioning of the buildings depending on their properties, tilt angle and climate [14]. Exterior shading devices are appropriate systems to protect buildings against extreme solar radiation effectively before it passes through fenestration glazing. They reduce the overall cooling and heating loads and lower the peak cooling and heating power, efficiently reducing the energy consumption and equipment costs for active air conditioning systems [15]. On the other hand, they can decrease the visual comfort and increase the energy consumption of artificial lighting. Therefore, a thermal optimization process is required to design efficient configurations of the shadings. David et al. [16] compared multiple types of exterior shadings such as simple overhang, overhang with infinite width, simple overhang with rectangular side fins, and simple overhang with triangular side fins using different indices and sizes to evaluate their efficiencies. In another study conducted by Li and Tsang [17], the impact of five main parameters including daylighting designs; shading devices, glaze type, building area, building orientation, and color of external surface finishing on the daylighting performance in 35 buildings in subtropical Hong Kong was investigated. Based on the simulated results, it was concluded around 20%–25% of total electric lighting energy could be saved for the studied buildings. Moreover, additional savings in heat rejection and cooling energy could be obtained due to less sensible heat gains generated by artificial lighting fittings. A series of measurements and simulations have verified the distinguished advantages in illumination and building energy consumption by using external shading devices [18–21]. Exterior

shadings screening the entire glass surface area can reduce direct solar gain by a maximum of 80% [22].

The focus of this study is to conduct a comparing life cycle assessment of windows exterior solar shades. Due to nature of materials and the processes they require to form the final product at the manufacturing companies, the amounts of emissions to the environment and depleted resources are different for different materials. Some may produce more greenhouse gases while some may consume more water and energy during manufacturing and installation phases. On the other hand, ASHRAE specifications mandate specified dimensions and thicknesses for the shadings to minimize heating and cooling loads in the buildings during in-service phase depending on the material type and its heat transfer characteristics, geographical conditions, and climate zone. Taking all these main factors into consideration, the required properties and consequently the mass of different shading types vary. Therefore, the overall resulting environmental inventories and consumed/saved energy amounts during life cycle of the shadings vary from one material to another and from one climate zone to another one. Aluminum, wood and PVC are the most common materials can be used in shading systems. Five common shading configurations in five climate zones defined by ASHRAE are compared to each other. To achieve this objective, this study compiled a Life Cycle Inventory (LCI) for quantifying the energy and emissions of the shadings during the manufacturing process and in-service. The Building for Environmental and Economic Sustainability (BEES) model (used for LCA of sustainable construction alternatives in the United States) and SimaPro 8.0 software were employed to develop the LCI of the exterior window shadings. The life cycle assessment framework used in this study was based on a life cycle methodology that follows the International Organization for Standardization (ISO) 14040 standard for life cycle assessment and the ASTM standard for Multi-Attribute Decision Analysis (MADA).

2. Methodology and problem formulation

2.1. Climate regions choice

Energy consumption varies greatly from building to building located in different climatic regions. U.S. Energy Information Administration (EIA) categorized the climate regions in the United States into 5 main categories based on the last 30-year average

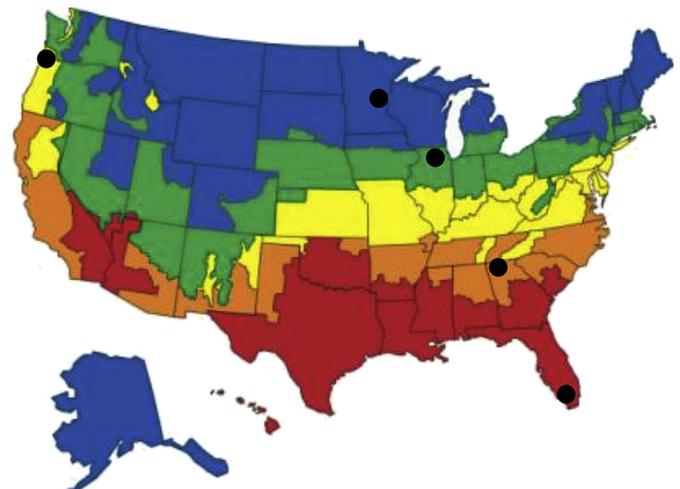


Fig. 1. Energy Information Administration (EIA) climate zones with cities [23,24].

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