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Life Cycle Analysis and Optimization of a Timber Building

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Abstract

The present study propose a thorough approach to the optimization of the whole-life cost of a timber building focusing mostly on its mechanical, structural and energy subsystems for a life cycle of 20 years. Another parameter that is examined, is the effect of the fuzziness of the design temperature inside a building on its life cycle cost. The objective function of the energy performance optimization problem of the study is a cost function. The components of the timber frame are optimized according to Eurocode 5. Two scenarios for the management of the timber frame components at the end of the building's life cycle are examined.

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1. Introduction

The total life cycle cost of a specific system is dependent on the system's most critical components. These components can be identified through the examination of the system's life cycle stages, which -in the case of construction projects- are mainly the raw material acquisition stage and construction stage (initial cost), the operation/maintenance stage and the waste management stage that also co-estimates the remaining costs at the end of the system's expected life cycle. [1]. In the same manner that the environmental impact of the life cycle can be quantified and measured, the economic cost of the same system can also be estimated on a similar basis. In the latter case, the aim of the analysis is the calculation of the cost associated with the life cycle of the examined system or life cycle cost [2].

. The formula below is a generalized approach for a system's total life cycle cost:

$$LCC = C + PV_{RECURRING} - PV_{RESIDUAL\text{-}VALUE} \qquad (1)$$

where

LCC is the total life cycle cost, C is the Year 0 initial cost, $PV_{RECURRING}$ is the present value of all recurring costs (utilities, maintenance costs, replacements, service costs etc.), $PV_{RESIDUAL\text{-}VALUE}$ is the present value of the residual value at the end of the examined life cycle period. The residual value is either considered to be equal to zero or it can be calculated through the following formula:

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$$PV_{RESIDUAL\text{-}VALUE} = \textit{Subsystem's initial value* (Current year)/(Subsystem's total life cycle (in years))} \qquad (2)$$

In order for the life cycle cost of a specific building to be minimized, it is important to determine -during its design and construction stage- the subsystems that affect its life cycle cost with the view of taking optimal design decisions. In general, the following subsystems have a considerable impact on the life cycle cost of a building:

- Building Envelope (insulation profiles, shading systems, glazing, roofing etc.)
- Mechanical and Energy Systems (use of photovoltaic panels or alternative sources of energy, ventilation systems, water distribution systems etc.)
- Structural Systems (selection of appropriate frame materials, sizing of the frame components)
- Siting (landscaping and irrigation-related design decisions).
- Electrical Systems (lighting sources and control, distribution)

For typical cases of buildings in Greece, practical experience as well as data derived from statutory sources in building construction cost analysis studies, have shown that the most critical subsystems that affect its total whole life cost are those related to its massing, its structural and energy performance.

Apart from that, it is also necessary to consider the average life cycle of the above mentioned subsystems in order to predict any potential replacements that may occur during the examined life cycle period. These maintenance processes affect the life cycle of the examined system, both in environmental and in economic terms. Their estimated service life provides useful guidelines regarding their potential replacement or repair. According to various sources [3], [4], [5], the average life cycle of -frequently used- building materials and subsystems (that were considered in the present study either because they are invariably encountered in buildings or because of their popularity in the Greek market) is as follows:

- Building Exteriors, Doors, and Windows: 80 years (lifetime)
- Timber structural systems: 50 years (lifetime)
- Mineral wool insulation profiles: 50 years
- Photovoltaic panels: 25 years
- HVAC systems: 15-20 years
- Gypsum boards: 75 years

2. Methodology

The present study focused on optimizing a timber office building from a structural and an energy performance standpoint, after having conducted a life cycle analysis about its components. Noteworthily, it is one of the first published attempts to optimize the energy design of buildings according to KENAK [3], [4]; the recent Greek code for the energy design of buildings. There are also very few studies about the structural optimization of timber structural components according to Eurocode 5 [6].

2.1 Subsystems considered in the optimization problem and market research

At first, a market research took place in an attempt to discover average, real-life cost figures of the subsystems that would be used in the algorithm. Therefore the costs of the following subsystems were taken into consideration:

- Wall and roof inner & outer layers (gypsum boards and wood, respectively).
- Structural systems (selection of appropriate wooden frame materials, sizing of the frame components)
- Mineral wool insulation of various thicknesses.
- High energy class air-conditioning systems (A and A+++ energy class).
- Double and triple-glazed aluminum windows (with regular or low-e values).
- Photovoltaic system cost per kWp.
- Structural timber cost per m^3.

2.2 Initial considerations

It was assumed that the building will be used as an office building located on Athens, Greece and this influenced the considerations that were used in the optimization algorithm (thermal or cooling loads generated by the theoretical population of building users per sq.m., minimum required ventilation) that was created in Matlab. Since the algorithm was structured according to guidelines of KENAK [3], [4], it took into account the cost effect of the following parameters that affect the energy balance of the building: thermal conductivity of the envelope components, ventilation and solar gains [7]. The thermal bridges are also incorporated in the algorithm with the use of the approximate standardized values of the national standards [3], [4]. Furthermore, in order to save computational time and unify parameters that have an impact on each other and correlate energy performance parameters with the resultant cost, curve-fitting and multiple linear regression has been used. This resulted in the creation of cost functions for the windows and the thickness of the mineral wool insulation. The cost functions take advantage of the homogeneity of the above mentioned subsystems [7] and -some of the ones that were used in the algorithms- are demonstrated in order for the reader to be able to understand the logic behind that idea (see section 4, for explanation of the symbols):