Building and Environment 118 (2017) 174–183

Contents lists available at ScienceDirect

Building and Environment

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

The influence of secondary effects on global warming and cost optimization of insulation in the building envelope

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ARTICLE INFO

Article history:
Received 2 December 2016
Received in revised form
13 March 2017
Accepted 14 March 2017
Available online 20 March 2017

Keywords:
Life cycle assessment
Life cycle cost
Optimization
Building envelope
Secondary effects

ABSTRACT

The relative environmental impact from the building construction phase is increasing compared to the operation phase for new buildings. Therefore, it is important to consider the complete environmental life cycle of energy improvement measures. Many advanced optimization methods have been developed in recent years to assess building life cycle impact. However, these previous studies have not fully addressed the secondary effects, in other words, indirect effects outside the actual design option. This may lead to conclusions of optimization studies based on misleading calculation results.

The main purpose this study was to highlight the relevance of including secondary effects in optimization of building design with respect to global warming potential and cost. This was done by conducting a parameter study of the building envelope insulation thickness with regard to global warming potential and life cycle costs, while considering secondary effects induced by the different design options.

Findings from this study show that secondary effects influence the system boundary, algorithm architecture, results and the final conclusions of optimal building design. Omitting secondary effects can thus lead to incorrect decision on optimal solutions with regard to global warming potential and life cycle cost. Therefore, it is therefore important to take them into consideration when performing optimization studies of building design options.

1. Introduction

The requirements for energy performance of buildings are gradually enhanced to decrease energy use and reduce environmental impact. However, there is increasing awareness that the relative environmental impact from the building construction phase is growing compared to the operation phase. Recent research in Sweden show that in a 50 year perspective up to 62% of the global warming potential from a building can be related to the construction process [10]. This means that it is not beneficial to indiscriminately perform energy improvement measures in buildings, as the increased environmental impact from the production phase can be larger than the reduction in emissions from the energy use in the operation phase. Therefore, it is important to consider the complete environmental life cycle impact of energy improvement measures.

There have been previous studies that suggest optimization methods including both the building construction process and energy use in the operation phase. In Refs. [19,20] optimizations of the building envelopes were made by using genetic algorithms on life cycle cost, and some selected emissions from the building life cycle expressed as expanded cumulative exergy consumption [18]. described a global methodology to optimize concepts for extremely low energy dwellings, taking into account energy use, environmental impact, and financial costs over the life cycle of the buildings. It was divided into three parts: optimization, life cycle inventory and life cycle cost analysis. The focus was energy efficiency measures in residential buildings by comparing different design options with a Belgian reference building. To make the optimization, a genetic algorithm was used with Pareto optimization. A genetic algorithm approach was chosen due to the complex nature of buildings and the large amount of parameters involved

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http://dx.doi.org/10.1016/j.buildenv.2017.03.019
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[8]. made a study on optimized building design using a harmony search algorithm. They looked at life cycle cost and global warming potential considering building operation energy and envelope design. An approach to conduct life cycle sustainability assessment for refurbishing buildings was described by Ref. [14]. In this method the possible solutions were not calculated from continuous values as they argued that the measures to be evaluated should be identified by experts to remove unrealistic options from the beginning, although they concluded that this might lead to the fact that some good solutions may not be considered [1]. made an optimization of building operation energy through a mixed-integer linear program. They considered investment and operation cost, as well as environmental impact based on life cycle assessment principles [12]. presented an approach using life cycle assessment together with life cycle cost calculations in a case study of a fictional single family house. The calculations are evaluated using a multi criteria decision analysis. A multi objective optimization of economic and environmental criteria was carried out in Ref. [4] by combining an objective reduction method with surrogate modeling on a cubicle. A genetic algorithm and neural networks were combined in Ref. [2]; as the genetic algorithm was used to adjust the weights in an artificial neural network. The network was then utilized to optimize the external wall and windows for an office building with regard to environmental impact.

The above mentioned studies is a selection of advanced optimization methods that have been developed in recent years. However, these studies have not fully addressed the secondary effects, that is system parameters that are not directly changed in the optimizations but are instead affected by the changed parameters. In systems with complex functions, such as buildings, a design option will in many cases affect building parts outside the induced change in the design option. These kind of effects are in this article referred to as secondary effects. An example of a secondary effect is when thicker insulation is applied in the external wall and the floors have to be elongated to support the thicker wall. The wider floors are not directly included in the design option but is a consequence of it.

[22] investigated the change in environmental and economic impact when more insulation was added to an external wall. In the study it is shown that secondary effects can significantly contribute to the environmental and economic impact of the building, as approximately one third of the global warming potential and one fourth of the cost were caused by materials in secondary effects. The previously mentioned optimization studies replace materials without completely considering secondary effects on the remaining structure. The possible implication of this is that the system boundaries used were not extensive enough, leading to conclusions of the optimization studies based on misleading calculation results. When more parameters are considered, the complexity of secondary effects will increase, partly due to the added parameters but also because dependencies between the building parts get more complex when the design options get more extensive. The effect of increasing the wall insulation can be different depending on the insulation thickness in the ground slab and roof. In a similar way the effect of increasing insulation in the ground slab and roof can depend on the wall insulation thickness.

The main purpose of the study presented in this paper is to highlight the importance of including secondary effects in optimization of building design with respect to global warming potential and cost. The study is based on the work presented in Ref. [22] but also consider the insulation in the external wall, ground slab and roof, as well as examines in detail how secondary effects will affect optimization studies. This is done by using life cycle assessment and life cycle cost analysis in a parameter study of the insulation thickness in the building envelope of a concept apartment house. The results are presented together with the corresponding parameter set with the aim to distinguish how change in parameters affects each result, as well as identify optimal solutions with regard to global warming potential and cost. Altogether 64 combinations of insulation thickness for the external wall, slab and roof are evaluated using life cycle impact assessment and life cycle cost analysis with and without secondary effects included. A sensitivity analysis was carried out with variations of parameters like ventilation heat recovery, energy cost and emission scenarios, and different discount rates to see how such changes will influence the results in comparison to the secondary effects.

2. Method

The building used in the case study was the same as the building described in Ref. [22]. The design was based on a concept apartment building developed by Skanska, with some construction details modified in order to make it more representative of typical building practice in Sweden. Since it was a concept building it does not have a set location, but in this study the assumed location was Gothenburg, Sweden. The building has a rectangular floor layout with inside measurements of 16.5 m width, 17.1 m length and 2.5 m height, and contains six floors.

The external walls contain steel stud frames and mineral wool insulation, and the intermediate floors consist of hollow core concrete slabs. The roof has expanded polystyrene insulation with an insulation board and roof covering. The ground slab is made of reinforced concrete with expanded polystyrene insulation and a crushed stone base beneath. To reduce thermal bridges the slab also has a layer of expanded polystyrene as perimeter insulation. All variations were compared to the baseline case that consists of 190 mm wall insulation and 200 mm insulation in the roof and beneath the ground slab. This baseline design was used as a benchmark for the other calculations, and therefore its global warming potential and costs are put to zero and only the deviations from this baseline design are considered in the calculations. Added insulation was applied outwards and does not affect the building's inside floor area or volume directly. The different thicknesses were chosen from common dimensions used in Sweden and resulted in 64 insulation combinations altogether (see Table 1).

2.1. Goal and scope

To find the insulation thicknesses of the building envelope that induce the lowest environmental impact and life cycle cost an optimization was carried out using results from life cycle assessments and life cycle cost analysis. The functional unit was set to 1 m^2 A_{temp}, which complies with Swedish laws and regulations for 50 years. The definition of A_{temp} is the total floor area intended to be heated above 10 °C inside the building envelope for all floors, including shafts, staircases, internal walls and similar entities, with the exclusion of garage areas [13]. To limit the study we considered global warming potential as environmental impact. The procedure will, however, be similar for other environmental impact

Table 1
Insulation thicknesses for respective element in the building envelope that are used in the calculations. Top row shows the baseline to which all the values were benchmarked against.

Wall insulation	Roof insulation	Ground slab insulation	
45 + 145 mm	200 mm	200 mm	*Baseline*
45 + 120 + 145 mm	300 mm	300 mm	
45 + 120 + 220 mm	400 mm	400 mm	
45 + 220 + 220 mm	500 mm	500 mm	