Energy and Buildings 68 (2014) 620–631

Contents lists available at ScienceDirect

Energy and Buildings

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

Relative importance of electricity sources and construction practices in residential buildings: A Swiss-US comparison of energy related life-cycle impacts

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ARTICLE INFO

Article history:
Received 11 January 2013
Received in revised form
23 September 2013
Accepted 30 September 2013

Keywords:
Residential buildings
Life cycle assessment
Building rating systems
Energy-related impacts

ABSTRACT

Comparisons of buildings in similar climates built in accordance with different regional construction practices and building rating systems can provide useful insights in sustainable design practices. The objectives of this study were: (1) to perform energy related life cycle assessments of a typical LEED-H (Leadership in Energy and Environmental Design for Homes) single-family home in New Jersey (US), and a typical Minergie-P single-family home in Chur, Switzerland; and (2) to assess the effect of rating systems and construction practices on the buildings' environmental impacts. Inventory data was obtained from the Ecoinvent 2.2 database with a replacement of the Western European electricity mix with the US or New Jersey electricity mix for the New Jersey home. The Swiss building performed better regarding non-renewable energy consumption, Global Warming Potential and Acidification Potential mainly due to the geothermal heat pump and the Swiss electricity mix while there was less of a difference regarding Ozone Layer Depletion Potential and Eutrophication Potential. The influence of electricity sources exceeded the effects of longer building life time or the removal of the Swiss basement. Regional building practices, local codes and environmental policies should take the electricity mix into account because it is so important.

1. Introduction

Buildings contribute as much as one third of total global greenhouse gas emissions, primarily through the use of fossil fuels during their operational phase [1]. Due to growing concerns about future energy supply constraints, the design of buildings that minimize their overall environmental burdens and especially energy consumption has garnered increasing interest globally. The approaches vary since for example construction practices differ regionally depending on building codes, governmental incentives, job training, public support and cultural preferences.

The past 20 years have also seen the development of different rating systems that recognize sustainable design in buildings, including Minergie and its passive house application, Minergie-P, in Switzerland and Leadership in Energy and Environmental Design (LEED) in the US [2]. Comparisons of buildings that are designed to comply with different rating systems can provide useful insights in sustainable building design practices. For example, a comparison can explain why generally the operational phase contributes less than 50% to the overall life cycle energy consumption of Minergie-certified homes [3], while this percentage is above 50% in most LEED certified homes [4], even though the majority of both building types are light wood frame buildings.

Comparisons of operational and life cycle energy consumptions of Minergie and LEED certified buildings are scarce [5]. However, LEED certified buildings also conform with ENERGY STAR requirements, and therefore comparisons of homes built to Minergie and ENERGY STAR requirements explain some differences. ENERGY STAR buildings are evaluated by the REM/Rate Home Energy Analysis software that assigns buildings a Home Energy Rating System (HERS) index between 0 for a net-zero building and 100 for a conventional reference building complying with the 2006

Abbreviations: AP, Acidification Potential; AAP, Aquatic Acidification Potential; AEP, Aquatic Eutrophication Potential; BEES, Building for Environmental and Economic Sustainability; CED, Cumulative Energy Demand; GWP, Global Warming Potential; NRE, Non-Renewable Energy; ODP, Ozone Layer Depletion Potential; TA/NP, Terrestrial Acidification/Nutrification Potential.

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http://dx.doi.org/10.1016/j.enbuild.2013.09.046

International Energy Conservation Code. A comparison of operational energy consumption and life cycle costs of a typical residential home in Indiana, US, complying either with Minergie or ENERGY STAR requirements showed that Minergie buildings are superior regarding energy efficiency due to more extensive insulation, more efficient mechanical equipment and solar heated hot water usage [6]. Based on the energy analysis, a typical new residential home in Indiana received a HERS rating of 98, the ENERGY STAR home of 79, a standard Swiss building of 54 and a Minergie building of 37. The HERS rating of a Minergie-P building would be even lower than that of the Minergie building while a LEED building should receive at minimum the HERS rating of the ENERGY STAR home. However, the comparison also showed that a Minergie home in Indiana is more expensive than an ENERGY STAR home in the short term, although there was a break-even point after more than 40 years assuming an annual energy escalation rate of 3% and a discount rate of 2%.

While this study explains the lower operational energy consumption of Minergie and Minergie-P homes compared to LEED-certified homes it does not address how much the energy consumption in the material placement phase (i.e., raw material extraction, building material manufacturing and refinement, construction) will increase in a Minergie certified home that for example implements superior insulation compared to a LEED certified building (Table 1).

To better understand the energy related life cycle environmental impacts, the objectives of this study are: (1) to perform energy related life cycle assessments (LCAs) of a 317 m^2 (255 m^2 heated) residential building in Monmouth County, New Jersey (US), which was built to meet LEED-H Silver standards and a 406 m^2 (191 m^2 heated) residential building in Chur, Switzerland that was designed to Minergie-P standards; and (2) to assess the effect of different rating systems and construction practices on mainly energy-related environmental impacts. While the New Jersey, US, building is an existing building with a conditioned basement as typical for the region, the Swiss building is a generic building that complies with Minergie-P requirements and which has an unconditioned basement as representative for this region. Chur was chosen as building location for the Swiss building because only a few additional modifications are needed for the building design to obtain certification and because its climate is similar to the climate in New Jersey.

2. Materials and methods

The LCA was conducted in accordance with ISO standards 14040 and 14044 [7,8]. The majority of the inventory data for the Swiss building were obtained from the Ecoinvent 2.2 database [9]. For the New Jersey, US, building, fewer inventory data were available. Most energy, material and emissions data were obtained from Ecoinvent 2.2. Although mainly focused on Western Europe, updates to this database include conditions for other countries, including the US. Where appropriate, the energy mix for the Western European data was replaced with the US or New Jersey energy mix for manufacturing and operation of the building. For datasets not found in Ecoinvent 2.2, datasets were created based on literature data and company information. The LCA was modeled in SimaPro 7.2.3 (PRé, Amersfoort, NL), which incorporates the aforementioned inventory database. An overview of the simulation process and the implemented tools can be found in the supplemental material (Figs. S1 and S2).

2.1. Buildings

The existing four-bedroom two-story single-family house in Monmouth County, New Jersey has a finished basement and a one-car garage on ground level, which is typical for the region. The building, occupied since 2008, has a gross floor area with garage of 317 m^2 and a net floor area of 286 m^2 of which 255 m^2 are heated. This is about 13% above the heated floor area of new single-family homes in the Northeast of the US for 2010 with 225 m^2 (=243 m^2 gross floor area without garage/1.08) [10]. The light wood frame building is designed to LEED-H (LEED for Homes) Silver standards, the most common LEED standard for single-family homes in New Jersey. Electricity and natural gas for heating are provided by the local utility. The building characteristics are provided in Table 2 and the building material inventory in Table 3.

The four-bedroom two-story single-family house in Chur, Switzerland is a typical Minergie-P certified building design, which was provided by a local construction company. The building has a gross floor area with garage of 406 m^2 and a net floor area of 353 m^2 of which 191 m^2 are heated. This is the typical size for a family of four in Switzerland with an average liveable space per person of 44 m^2 in the year 2000 and the assumption that it is already more than 48 m^2 in the year 2013 [11]. It is designed in the typical Swiss two-level approach for Minergie-P buildings, using concrete and brick for the unheated basement and the below ground garage and light wood frame construction for the first and second floors. Heating is provided by a ground-source heat pump and electricity by the local utility. The building characteristics are summarized in Table 2 and the building material inventory in Table 3.

2.2. Environmental impact categories

The following standard impact categories compare the environmental impacts of both buildings: Non-Renewable Energy, Global Warming Potential, Ozone Depletion Potential, Eutrophication Potential, and Acidification Potential. Three different environmental impact methods provided the characterization factors to convert the inventory data to environmental impacts: IMPACT 2002+ [12], Building for Environmental and Economic Sustainability (BEES) [13] and the Cumulative Energy Demand (CED) [9]. Other environmental impacts included in these methodologies such as human toxicity and ecotoxicity were not applied due to the energy emphasis of this study and because there are more uncertainties concerning these impacts [14].

2.3. System definitions, boundaries and data sources

Only the buildings themselves were considered. This includes the foundations, structure, envelope and interior of each building. The lifetime of the US building was estimated by the builder to be between 50 and 75 years. Since the average lifespan for new residential buildings in Switzerland is 65 years [15], this lifetime was chosen for both buildings. It is assumed that the energy mix and materials used for replacements will remain the same during the entire lifetime of the buildings. This is likely to overstate the actual environmental impacts caused during the building's life cycle, as energy production and material manufacturing technologies become more efficient. The following components were not included in this study: furniture, lighting fixtures and appliances, sitework outside the building footprint, landscaping and utilities outside the building. Burdens from building planning and design were beyond the scope of this study.

The environmental impacts were divided by the floor area to account for the different building sizes. Normalizing by gross or net floor area in each building does not account for the fact that a large portion of the Swiss building's interior space is unheated (i.e., basement), and therefore non-habitable. However, considering solely the heated floor area alone penalizes the Swiss building for not heating rooms that do not require heating, such as laundry