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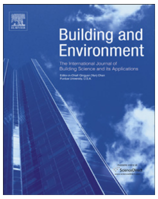

Developing a roadmap for the modernisation of city quarters – Comparing the primary energy demand and greenhouse gas emissions

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A B S T R A C T

In this study, a new method based on 3D urban geometry in CityGML format is presented and used to evaluate the energy demand and greenhouse gas emissions during the different life cycle stages of a city quarter. The method is applied to a case study in Stuttgart/Germany, while considering the specific building characteristics of the city quarter. Four different development scenarios to reach a similar building standard for all residential buildings are assessed, which include either the refurbishment or the demolition and reconstruction or a combination of both.

The total reduction of the primary energy demand for building operation is the same in each scenario. However, different production and construction energy inputs are needed for the four scenarios, which are highest for new constructions. The end-of-life energy demand is negligible by comparison.

This leads to the conclusion that from the life cycle energy point of view, refurbishment to a high building standard is better than reconstruction under the condition that the structural condition of the building allows it.

If the plan is to refurbish or partially reconstruct all buildings in a city quarter, a specific order needs to be chosen. This order has a high influence on the temporal development of the energy demand reduction of the city quarter.

1. Introduction

Urban areas consume approximately 70% of global energy and in light of a growing population and increasing densification of urban areas, this share is expected to further increase in the future [1]. Buildings account for 40% of the total energy consumption and 36% of CO_2 emissions in Europe [2]. Therefore, the focus of the European Union is to increase energy efficiency and consequently reduce greenhouse gas emissions especially in the building sector. To enforce these goals, an energy efficiency directive and a directive on energy performance of buildings were passed in 2012 and 2010 respectively. They state that all member states need to carry out energy efficient refurbishments for at least 3% of government buildings [3], draw up a refurbishment strategy for all buildings and establish minimum energy performance standards for new buildings [4].

Consequently, the Federal Republic of Germany introduced the roadmap to reduce the primary energy demand of buildings by 80% until 2050 compared to the 2008 level [5]. The long-term goal is to generate a carbon neutral building stock [6]. A combination of more energy efficiency, the use of renewable energy and a more energy and climate friendly urban development is needed to achieve this ambitious goal. 80% reduction of primary energy demand for building operation is an important goal; however, the energy demand of the production and end-of-life of the buildings should also be evaluated [7] and be included in these goals to ensure a complete assessment of the energy demand. In most studies [8–10] only the operational energy demand of buildings is considered. However, since the energy demand for the production and end-of-life of buildings is increasing while the operational energy demand is decreasing [11–13], it is important to evaluate the whole life cycle.

More than 60% of German buildings were built before 1978, which means that there is usually no insulation in these buildings if they have not yet been refurbished [14]. Only after the introduction of the first Heat Insulation Ordinance in 1977 as a consequence of

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the oil crisis in the 1970s, moderate energy saving standards for newly constructed buildings were compulsory [15].

The average refurbishment rate in Germany is only 1% per year, without any indication to the depth of this refurbishment [14]. To reach the goals set by the Federal Government, the refurbishment rate needs to double to approximately 2% per year [6].

For an efficient implementation of the refurbishment goals, strategies should be developed for entire city quarters instead of focusing on each building individually. Most studies so far only consider individual case study buildings [16–19] instead of providing generic data that can be transferred to the city quarter level. With generic data, a standardized approach can be facilitated [20]. There are also many design tools to analyse and simulate the energy demand of individual buildings but they are too detailed and too complicated to transfer them to the level of city quarters [21]. However, an individual roadmap is needed for a specific city quarter to implement the strategy in the most efficient way, as the climatic conditions, specific urban development goals and specifications (building type, size, age et cetera) of each quarter vary. As the main innovation in this study, the detailed geometry and building characteristics of each individual building (based on the CityGML data format) has been taken into account when analysing the specific conditions of each quarter. In most other studies [22–24] which assess buildings in city quarters or large neighbourhoods, all buildings are represented by few typical buildings which can result in an increasing uncertainty. Moreover, life cycle assessment has not been conducted using CityGML data before [25].

In this work, a method for developing such a roadmap for a city quarter is presented. First, the goal of the assessment and the appropriate assumptions need to be defined, e.g. the time period in which the modernisation takes place. Secondly, an overview of the entire city quarter is needed to assess its condition. Then, the targeted energetic building standard according to the climatic conditions should be determined and buildings need to be identified whose condition is too bad to allow refurbishment or that can neither be refurbished nor torn down because they are protected historic buildings. The rate for refurbishment or demolition and reconstruction needs to be determined and translated into a total number of buildings that are to be considered each year. Additionally, the buildings need to be ranked according to their age, their specific space heating demand or their total heat demand. The results then show the reduction of the primary energy demand over a certain amount of time.

The chosen approach in this study is based on life cycle assessment (LCA) according to ISO 14040 and 14044, where the requirements for conducting a LCA are defined [26, 27]. The results can be displayed in various impact categories, e.g. primary energy demand or greenhouse gas emissions.

The methodology has been applied to a case study city quarter in Stuttgart/Germany. An individual roadmap for the partly refurbishment and partly new construction of a city quarter until 2050 was obtained and is presented in this work.

2. Methodology

To develop a roadmap for the refurbishment or reconstruction of all buildings in a city quarter, the energy and greenhouse gas values for their production, use and end-of-life stages in the considered city quarter must be calculated and analysed.

2.1. Summary of previous work

In a previous study [28] a method for the life cycle assessment of individual buildings including the production, use and end-of-life stages was developed.

To calculate the production and end-of-life stages of a building, first the values for the energy and greenhouse gases embodied in the building materials as well as the values for the energy needed and greenhouse gases emitted during the disposal of the building materials must be determined. These values are calculated using the software for life cycle assessment Umberto, developed by the German ifu institute [29], with the ecoinvent 3.2 database [30]. The use of this database includes uncertainty because the mean values are only approximations to the real building data. In reality there might be a difference between the value that has been investigated (or measured and reported) and the “real” value [31,32]. As for any LCA study, assumption of values and the provision of generic data usually imply some uncertainty caused by data variability [33]. Additionally, due to choices like the functional unit or the allocation method in the LCA process, uncertainties are unavoidable.

Further, these calculated energy and emission values are integrated into the building physics library of a simulation platform for urban energy demand named SimStadt [34]. SimStadt was developed to simulate the energy needed during the use stage of a building or city quarter and was extended by the previous study to calculate the production and end-of-life stages. The building physics library is based on a study called ‘Deutsche Wohngebäudetypologie’ published by the ‘Institut Wohnen und Umwelt (IWU)’ [35]. It includes the material composition of various building types sorted by different periods of time, starting in 1859 up to newly constructed buildings as of 2016, with different energy standards for efficient buildings. Additionally, two refurbishment standards for existing buildings are defined. The first standard is medium refurbishment, which corresponds to the legal minimum standard in Germany. Advanced refurbishment corresponds to present technical and structural advanced standards with a high amount of insulation.

Then the energy and greenhouse gas values for a surface area specific construction effort of the building were taken from literature, added to the embodied energy and greenhouse gases and result in the production stage [16, 36–38]. In case of refurbishment with much less materials to be moved, only 10% of this value is used. This corresponds to the amount of material that is added during refurbishment, i.e. the additional materials account for 10% of the total amount of materials of the refurbished building. This value is an average percentage out of different building types and ages from the aforementioned IWU study.

Also, the values for the demolition [36, 39] of the building are added to the energy needed and greenhouse gases emitted during the disposal of the building materials and result in the end-of-life stage.

Since the methodology of this research is based on generic data, the software and its calculation results are applicable to a large scale to allow a comparison of different buildings, city quarters or even regions. In combination with a CityGML-file, including a 3D model like the one in Fig. 1 and specifications of each building, SimStadt calculates the energy and greenhouse gas values of the production, use and end-of-life stages for all buildings in the considered case study.

2.2. Current study

The traditional life cycle assessment of a building consists of its production stage, a use stage over a defined lifespan and its end-of-life stage. When analysing an entire city quarter however, the assessment can only include a part of the life cycle of this city quarter. This is due to the fact that not all the buildings were constructed at the same time and might have been refurbished at different times in their lifespan and the city quarter can therefore