

Implementation of strategies for the realization of ecologically and economically optimized serial type house buildings for social housing

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Abstract. The goal of this research is to develop ecologically and economically optimized implementation strategies for social housing. Therefore, a case study is analysed over its life cycle using life cycle assessments (LCA) and life cycle costs (LCC) regarding the global warming potential (GWP) and its environmental impact costs (cost per ton of CO₂). The case study is optimized regarding the embodied emissions of construction and energy demand during its use stage. Considering the cost ceiling for social housing, it is evident, that an implementation of renewable materials and energies is mandatory in order to prevent the risk of a project failure due to excessive environmental impact costs.

1. Introduction

The aim of this research is to identify the life-cycle based optimized ecological and economical strategies for social housings. This is necessary to work out potentials for the further development, realization and undercutting of cost ceilings. The main focus in this research are the embodied emissions based on the building construction, the technical building services and the operational energy demand. Obstacles to the implementation of cost-effective and ecological buildings in affordable housing will be identified and suitable measures will be worked out. The findings are applied to a case study to develop ecologically and economically optimized type houses with a high series factor in cooperation with the building practice (housing association from Nuremberg and construction company from Regensburg, Germany). The results will be further processed and systematized in such a way that they can be applied to other housing projects as well.

2. Project description

This study is based on the research project ‘BEWOOpt’ of the Institute of Energy Efficient and Sustainable Design and Building of the Technical University of Munich in cooperation with the housing association *wbg Nürnberg* and the construction company *Ferdinand Tausendpfund GmbH & Co. KG*. As a case study, an already developed type house of a four-story residential building, located in Nuremberg, Germany, is used. The base case of the type house (further referred to as v01) is planned using a massive construction method. The external walls consist of sand-lime brick stone with an external insulation made of expanded polystyrene foam ($U = 0.18 \text{ W/m}^2\text{K}$). The other load bearing constructions are planned as reinforced concrete. Regarding the quality of the thermal envelope the foundation has a U-value of $U = 0.37 \text{ W/m}^2\text{K}$, roof $U = 0.14 \text{ W/m}^2\text{K}$, windows $U_w = 1.30 \text{ W/m}^2\text{K}$.



The planned characteristics of the building are summarized as follows:

- Area thermal envelope: $A = 1,605 \text{ m}^2$
- Gross volume: $V_e = 3,836 \text{ m}^3$
- Air volume: $V = 3,068 \text{ m}^3$
- Net floor area: $A_{NF} = 1,227 \text{ m}^2$

Regarding the technical building services, floor heating in combination with district heating is used. The district heating will be provided by the energy provider 'E-ENERGIE' of Nuremberg, according to 'E-ENERGIE' the district heating has a greenhouse gas emissions factor $f_{CO_2\text{-eq.}}$ of $0 \text{ kg CO}_2\text{-eq./kWh}$. This value of zero is made possible by allocating all the occurred emissions to the generated electricity, which is highly debateable but in the context of finding accurate optimization solutions for the given project, this is considered in all the calculations accordingly. Furthermore, no cooling or active air handling units are realized. The domestic hot water will be realized with decentralized flow heaters. For the electricity demand (artificial lighting, domestic hot water and auxiliary energy) the generic dataset for the energy grid in Germany (Dataset: Electricity grid mix scenario 2020 – decarbonisation is not included) is considered according to the freely accessible German LCA-database OEKOBAUDAT 2020-II [1], provided by the German Federal Ministry of the Interior, Building and Community.

3. Methodology

In order to develop and display specific implementation strategies for the optimization of the new type houses, a life-cycle based, multi-step approach is used. The base case (v01), with the given characteristics (see Chapter 2) functions as the starting point for the holistic evaluation and optimization approach. Important to note is that the building size, location, orientation and window area are set and cannot be changed. The ecological and economic performance of the building is evaluated using Life Cycle Assessments (LCA) and Life Cycle Cost Analysis (LCC). The LCA is calculated according to DIN EN ISO 14040 [2], DIN EN ISO 14044 [3] and DIN EN 15978 [4]. For the life cycle impact assessment (LCIA) the OEKOBAUDAT 2020-II with specific datasets for building products is used. Specifically, the LCA is used to identify the environmental impacts and functions as a foundation for calculating the environmental impact costs. The ecological impacts of the building are calculated for the impact indicator Global Warming Potential (GWP) given in $[\text{kg CO}_2\text{-eq}]$. The building assessment is based on the building life cycle stages according to DIN EN 15804 [5] for the following life cycle stages: production (A1-A3), refurbishment (B4), operational energy use (B6) and the end of life (C1-C4). Regarding the lifespan of the building, 50 years are considered. In the first step, different building construction methods are evaluated. In the second step parametric optimizations using building performance simulations (BPS) in combination with optimization algorithms are carried out with IDA ICE 4.8 SP 2 [6]. As for the optimization a combination of the two algorithms Particle Swarm Optimization and Hooke-Jeeves is used. Within the scope of the project the three different types of building construction are a) reinforced concrete b) sand-lime brick and c) wood-hybrid. Furthermore, energy systems a) gas-boiler and b) district heating as well as c) photovoltaic (PV) and d) solar thermal systems (ST) are evaluated. The building is also compared to the reference building according to the German energy saving ordinance (v00) (EnEV) [7]. Based on the results of the LCA environmental impact costs are determined and evaluated. For the costs, the cost groups 300 (building - building construction without the costs of the garages) and 400 (building - technical installations) according to the DIN 276 [8] are considered. The cost ceiling for the construction costs of $2,250 \text{ € per m}^2$ of living space is to be used according to the Bavarian State Ministry for Housing, Construction and Transport [9]. For the calculation of the environmental impact costs (EIC), the minimum cost rate is set according to the 'Climate Protection Program 2030' of the German Federal Government. The cost for one ton of CO_2 is set to $25 \text{ €/t}_{\text{CO}_2}$ [10]. Going beyond this rather conservative estimation, the central environmental authority of Germany is stating higher cost rates. A cost rate of $195 \text{ €/t}_{\text{CO}_2\text{-eq.}}$ is set based on a higher weighting of the welfare of current versus future generations. If the weighting is equal between present and future generations a cost rate of $680 \text{ €/t}_{\text{CO}_2\text{-eq.}}$ is proposed [11]. Based on the LCA results the EIC are calculated for the described cost rates and compared to the cost ceilings for social housing in Bavaria,

Germany as described in [9]. In the cost analysis an annual price increase of 5 % and a calculation interest rate of 1.5 % is considered.

4. Results

Based on the assessment as described in Chapter 3. a total amount of five different building variations are compared. The characteristics of the five variations are shown in the following Table 1.

Table 1. Overview of the different analysed building and energy system variations

Variation	Construction	Energy system	PV / ST	Optimized
v00	Reinforced concrete	Gas-boiler	-	-
v01	Lime-Sand Stone	District heating	-	-
v02	Wood-Hybrid	District heating	-	-
v03	Wood-Hybrid	District heating	yes	yes
v04	Wood-Hybrid	District heating	yes and accounted according to DGNB [12]	yes

The results of the respective LCA are displayed in Figure 1 and the environmental impact cost analysis in Figure 2. Since the environmental impact costs are calculated based on the LCA results, the respective ratios are the same. The values for the building constructions include the production, refurbishment and the end of life. In the use stage, heating, domestic hot water, electricity for artificial lighting and auxiliary energy is considered. In the technical building services, the heating system itself as well as photovoltaic and solar thermal system is included.

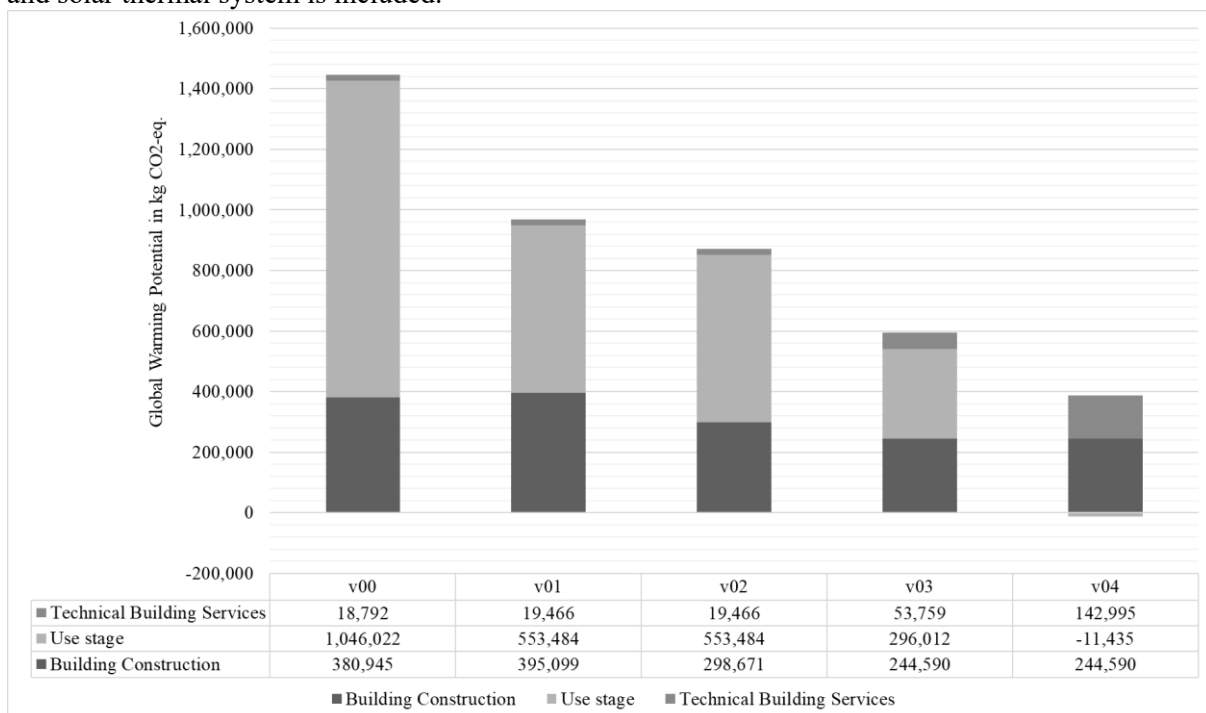


Figure 1. LCA results for the different variations regarding GWP [kg CO₂-eq.] over 50 years

For the reference building according to EnEV (v00) the total GWP amount to 1,445,759 kg CO₂-eq. In regards to the change of the energy system (v01) a reduction of 477,7108 kg CO₂-eq. is achieved. Furthermore, by changing the building construction between (v01 – Lime-Sand-Stone) and (v02 – Wood-Hybrid) it can be seen, that the share for the building construction can be reduced from 395,099 kg CO₂-eq. to 298,671 kg CO₂-eq., which equals a relative reduction of -38 %. Since there is no change in the energy system from v01 and v02, the GWP for the use stage and the technical building

services are the same. In total this results in a reduction of -10 %. Based on the first results, for the further evaluations only the wood-hybrid construction is used. Hence, the actual optimization process is based on v02. Furthermore, PV and ST systems are considered. The individual analysed and optimized parameters are displayed in Table 2. By taking the whole life-cycle and different components of the building into account, it is possible to find the optimal combination of parameters. For v03 it can be seen, that the use stage was reduced significantly compared to v02. A reduction from 553,484 kg CO₂-eq. to 296,012 kg CO₂-eq. is achieved. This is possible due to the fact that the PV and ST system directly contribute to reduce the remaining energy demand for electricity. The remaining energy demand for the use stage in v03 derives from electricity for lighting, domestic hot water and auxiliary energy. Regarding the optimized parameters for v03, see Table 2, it is evident, that regarding the thickness of the thermal insulations and the PV and ST systems, there is a life-cycle based sweet spot (Optimum). Increasing or decreasing each parameter is not goal-oriented and would result in an increase of the total GWP, due to more GWP in the building construction and technical building services or in more GWP for the use stage. Excess renewable energy can be credited positively towards the total amount of GWP according to German Sustainable Building Council (DGNB) within the framework of the ‘Climate positive: Now!’ initiative [12]. Methodically, fossil non-renewable electricity is displaced by supplying renewably generated electricity to the power grid. By taking these measures into account the optimization algorithms make use of the maximum defined area (200 m²) for PV. By using the renewable generated electricity and supplying the excess energy to the grid, a net positive use stage can be achieved, see Figure 1, v04. Taking the reference according to EnEV (v00) and the base case (v01) into account a total GWP reduction of -74 %, respectively -61 % is achieved.

Table 2. Analysed and optimized building parameters for the variations

No.	Parameter	Unit	Min-Max-Values	Optimized v03	Optimized v04
1	Thickness insulation of ext. wall	m	0.02...0.50	0.28	0.28
2	Thickness insulation of roof	m	0.02...0.50	0.22	0.26
3	Thickness insulation foundation	m	0.02...0.50	0.20	0.20
4	Solar gain factor of sun shading	-	0.15...0.65	0.55	0.55
5	Solar heat gain coefficient of glazing	-	0.30...0.75	0.55	0.55
6	U-Value windows	W/m ² K	0.60...2.90	0.60	0.60
7	Infiltration rate	h ⁻¹	0.30...3.00	0.30	0.30
8	Area of Photovoltaics	m ²	0...200	55	200
9	Angle of Photovoltaics	°	0...90	25	25
10	Orientation of Photovoltaics	°	-180...180	0	0
11	Area of solar thermal system	m ²	0...200	10	0
12	Angle of solar thermal system	°	0...90	75	-
13	Orientation of solar thermal system	°	-180...180	-20	-
14	Volume hot water tank	m ³	0.10...2.00	0.5	0.5

Based on the results of the LCA, the EIC are as follows, see Figure 2. For the cost rates according to the ‘Climate Protection Program 2030’ of the German Federal Government costs between 63 €/m² (v00) and 8 €/m² (v05) are derived. The EIC increase significantly to 493 €/m² (v00) and 64 €/m² (v05) for the cost rates of 195 €/t_{CO₂-eq.} and 1,720 €/m² (v00) and 222 €/m² (v05) for the cost rates of 680 €/t_{CO₂-eq.} respectively. For the base case (v01) a range between 37 €/m² and 999 €/m² is calculated. In regards to the wood-hybrid building construction in combination with the optimization process a reduction to 22 €/m² to 610 €/m² is achieved.

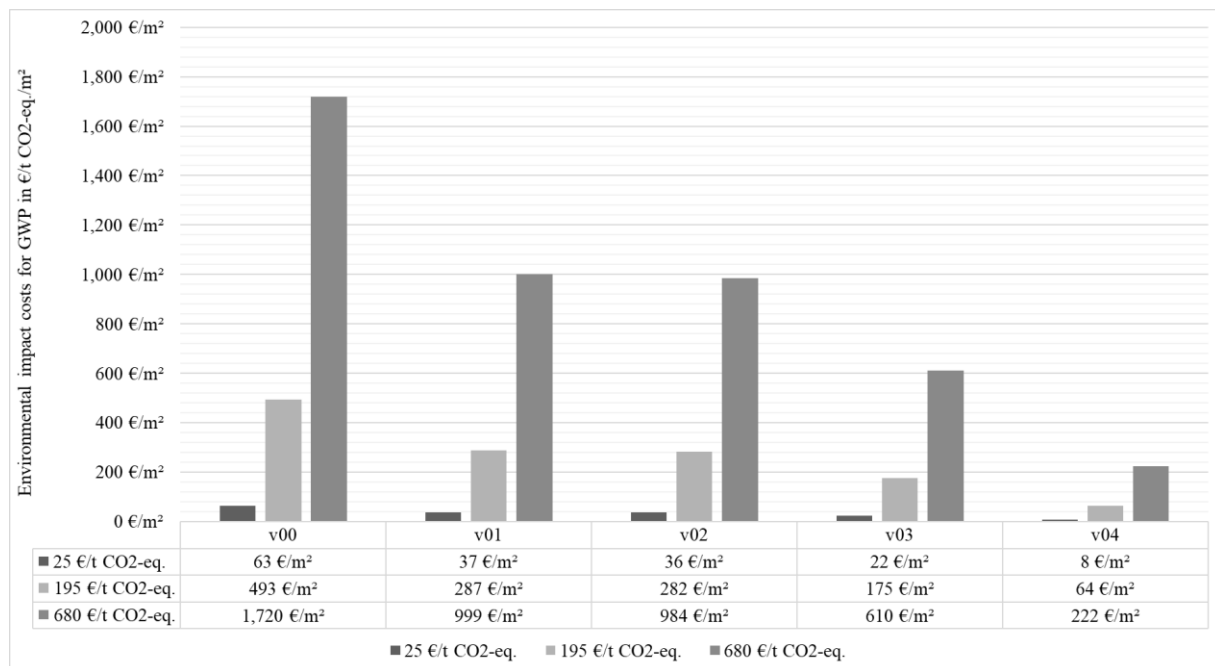


Figure 2. Results of the environmental impact cost analysis for the investigated variations over 50-year lifespan, considering an annual price increase of 5% and calculation interest rate of 1.5%

5. Discussion

In regards to the realization of sustainable social residential buildings it is evident, that the use of renewable materials and energies is mandatory. For social housing the economic aspects are highly important. According to the Bavarian State Ministry for Housing, Construction and Transport a cost ceiling construction costs of 2,250 € per m² of living space (for the cost groups 300 and 400 as in DIN 276 [8]) has to be met. By taking the environmental impact costs, in addition to the construction costs into account, this could provide a very high risk to the realization of such projects. Especially when the cost rates per ton CO₂-eq. significantly increase, as discussed by the central environmental authority of Germany. The rather conservative cost rates of 25 €/tCO₂-eq. defined by the German Federal Government indicate a low risk to the realization of social housing projects. Depending on the different scenarios regarding the cost rates, environmental impact costs between 64 €/m² (v05 - 195 €/tCO₂-eq.) up to 1,720 €/m² (v00 - 680 €/tCO₂-eq.) are estimated. In comparison to the cost ceiling of 2,250 € per m² of living space the environmental impact costs can be a huge risk to the success of realization social housing projects. Therefore, in order to be able to realize social housing projects in the future there is no way around building sustainably. And since buildings and its requirements get more complex, e.g. by taking the whole life-cycle into account, which results in additional parameters, the use of optimization algorithms is necessary. Compared to the minimum required standard, given by the German energy saving ordinance (EnEV) [7], significant improvements over the life-cycle are possible. Furthermore, if one takes the excess renewably generated electricity on the building site and supplies it to the energy grid and displaces fossil non-renewable electricity life-cycle based net positive use stage can be achieved. By implementing renewable materials and energies to the building design, the respective environmental impact costs can also be significantly reduced. This is especially important for the type of building conducted by this research.

6. Conclusion

This study has shown that in order to be able to realize social housing projects in the future the use of renewable materials and energies is necessary. The realization of social housings using conventional building constructions, non-renewable materials and non-renewable energies the resulting

environmental impact cost can provide a huge risk to the success of social housing projects. Since the environmental impact costs are dependent on the respective scenario a high variance is expected. Based on the high variance the focus of developing economically and ecologically optimized solutions are mandatory in order to prevent the risk of a project failure due to the lack of innovation. In comparison to the rather conventional approaches in today's building practise and by taking the possible risks into account, a fundamental change towards sustainable buildings is necessary.

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References

- [1] Federal Ministry of the Interior, Building and Community. ÖKOBAUDAT: Sustainable Construction Information Portal; 2021. Verfügbar unter: <https://www.oekobaudat.de/en.html>.
- [2] Deutsches Institut für Normung e. V. DIN EN ISO 14040: Environmental management – Environmental management – Life cycle assessment – Environmental management – Life cycle assessment – Principles and framework; 2009 2009.
- [3] Deutsches Institut für Normung e. V. DIN EN ISO 14044_2018: Environmental management – Life cycle assessment – Requirements and guidelines; 2018 2018.
- [4] Deutsches Institut für Normung e. V. DIN EN 15978: Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method; 2012 2012.
- [5] Deutsches Institut für Normung e. V. DIN EN 15804: Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products; 2020 2020.
- [6] EQUA Simulation AB. Building Performance - Simulation Software. Verfügbar unter: <https://www.equa.se/en/>.
- [7] Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden (Energieeinsparverordnung – EnEV); 2014.
- [8] Deutsches Institut für Normung e. V. DIN 276: Building costs.
- [9] Bayerisches Staatsministerium für Wohnen, Bau und Verkehr. Materialien zum Wohnungsbau: Förderung von Mietwohnraum in Mehrfamilienhäusern; 2021.
- [10] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit. Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050; 2019.
- [11] Matthey A, Bünger B. Methodenkonvention 3.1 zur Ermittlung von Umweltkosten: Umweltbundesamt; 2020.
- [12] Braune A, Lemaitre C, Jansen F, von Gemmingen U. Climate positive: Now!: How every building can make a contribution to climate action: Deutsche Gesellschaft für Nachhaltiges Bauen - DGNB e.V. German Sustainable Building Council; 2020.