A holistic analysis tool for calculating the economic efficiency, energy efficiency, and environmental impact of construction measures and buildings: NUKOSI.

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Abstract.

To implement economic strategies that consider the entire life cycle of a property, criteria such as sustainability, agility, usability, safety, time, and cost are crucial. The literature shows that real estate and facilities management researchers strive to develop agile and easy-to-use calculation methods to achieve CO2 reduction goals and better account for building life-cycle costs by choosing green and cost-effective solutions and strategies. However, few tools can address these issues by providing an integrated IT solution capable of assessing the life-cycle cost-effectiveness of construction measures through an easy and performant calculation model. For that reason, through a research project on cost-benefit simulation with partners from the University of Applied Sciences Mainz and the "LBB" (State Office for Real Estate and Construction), we developed NUKOSI, a model for calculating the life-cycle costs, energy efficiency, and the environmental impact of buildings in monetary terms. In this paper, we apply NUKOSI in a case study where we calculate and simulate life-cycle costs based on "User costs of buildings" (DIN 18960 2020-11, ISO 15686-5 2008-06) and assess environmental impact. "NUKOSI" is operationally used by the "LBB" as an IT solution and has been further tested, for example, in higher education, trade, real estate funds, housing, and faith-based institutions.

Keywords.
Life-cycle cost (LCC), Life-cycle assessment (LCA), carbon footprint, Greenhouse gas (GHG), real estate management, facility management, engineering design, software development, simulation, NUKOSI, sustainability, agility, efficiency.

1. Introduction

Natural disasters such as earthquakes and hurricanes are unavoidable results of local climate change. According to climate scientists, among the main reasons for global climate change are anthropogenic greenhouse gas (GHG) emissions. GHG emissions are the primary criterion for environmental impact evaluation and the life cycle Assessment (LCA). As such, researchers are urging policymakers and governments to quickly establish a plan for reducing carbon emissions to avoid further significant disasters from global warming. According to the European

Commission, the building sector, consuming more than 40% of the world's energy, is one of the main contributors to CO2 emissions. Thus, the current European legislation requires that all new buildings be nearly zero-energy buildings (nZEB) (Milano 2021).

As shown in Figure 1, the German government aims to minimize GHG emissions by 2030 (UBA 2021).

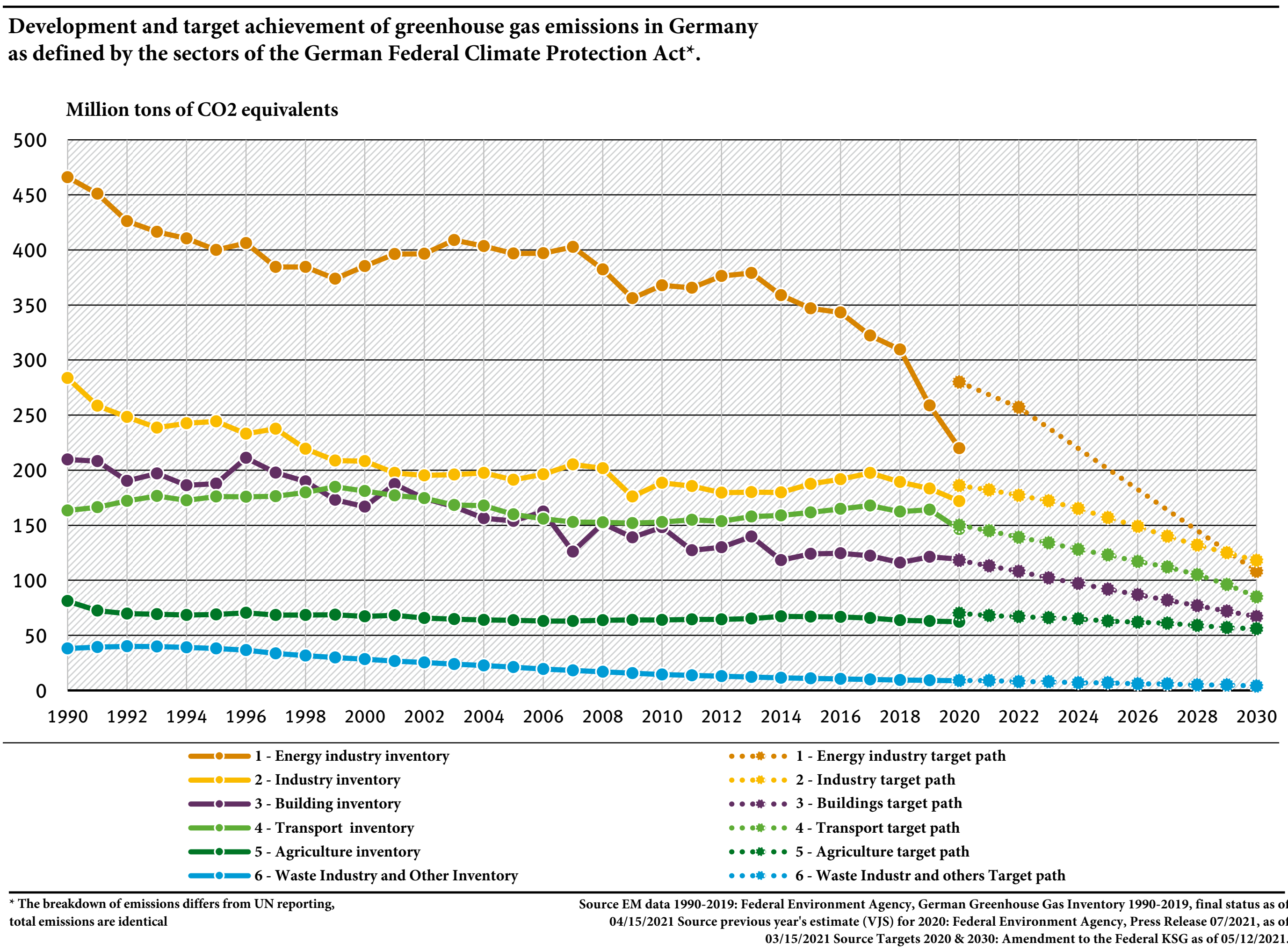


Figure 1 Development of Greenhouse gas emissions in Germany

Studies conducted by the government, private, and academics confirm that the building sector is still not meeting its climate targets while missing the modernization ratio. In addition, the European Taxonomy Regulation, the Building Energy Law, and the real estate industry's customers are calling for further attention in terms of environmental impact in the building sector (Bogenstätter 2018). At least the focus should be on the vast number of building stock. The building stock offers a lot of potential for reducing CO2 emissions: E.g., the building stock in

Germany covers about 5.5 billion square meters, and the energy standard requires improvements (Bogenstätter 2018). Some of these buildings are listed; in this case, energetic modernization needs particular solutions.

As outlined, the carbon footprint is a way to measure the impact of human development on the environment. Therefore, real estate owners must optimize their carbon footprint and increase energy efficiency to achieve sustainable properties.

Indeed, there is an acute global need to evaluate the building's environmental impacts and carbon footprint. The literature shows that the carbon footprint of buildings is not considered sufficiently in most construction measures, and few of the existing integrated IT tools provide calculation methods to determine the life-cycle cost (LCC) of the construction measures through an easy and performant calculation model. IT tools which integrate LCC and LCA in a single application are rare, especially when building data of existing buildings are rare.

In this context, several key questions arise:

- Which measures save the most CO2 and meet the legal requirements?
- How long will our buildings meet the climate protection requirements?
- What will be the cost to achieve the goals?
- Which buildings might be at risk of being unprofitable in the future?
- Are there any tools that can evaluate the LCC and LCA of a building in a single application efficiently in an early planning phase?

This paper shows an example of how to optimize CO2 emissions (Greenhouse Gas) as well as the value of building with an integrated and efficient tool. It's about complying with laws, convincing the decision-makers in the building permit process, or investing money wisely in their own real estate business.

To answer the key questions, a research project "NUKOSI" for the simulation of Life-cycle cost (LCC) and life-cycle assessment (LCA) was started in 2015. NUKOSI was created by the University of Applied Sciences in Mainz and the State Office for Real Estate and Construction (LBB), owner of 1,600 buildings in Germany. The target was to develop a cost-benefit evaluation modeling system that determines the LCC effectiveness of construction measures and energy efficiency (Bogenstätter 2014). It relies on recognized calculation methods that can perform well even if the available data is traditionally insufficient, with rule-based algorithms as an expert system, internal and external databases, as well as model calculations, simulations, and artificial intelligence (AI) based optimization.

We focus to identify appropriate models and compare them to NUKOSI as a solution. For that reason, we analyze the literature to show the recent tools which can measure the carbon footprint and evaluate the environmental impact of a building, as discussed in section 2. In section 3, we present a detailed description of NUKOSI, its objectives, and its functionalities. Then, we provide a case study on the application of NUKOSI. Finally, we conclude by outlining our future perspectives for NUKOSI.

2. Literature review

The world is witnessing rapid progress in various fields. In the era of digitalization and the Internet of Things (IoT), artificial intelligence (AI) strives to make all human or machine operations smarter and faster. The field of construction is an important area of application, especially since it has been an essential part of human life since time immemorial and affects every human's basic needs.

Following the definitions, Property management is the integration of processes in an organization to provide and develop professional management services for properties that are or will be permanently intertwined in the real estate portfolio. Facility management is the integration of processes in an organization to provide and develop services to support and enhance the efficiency of the organization’s core activities (Bogenstätter 2008). Property management and Facility management are both parts of Real estate management; each is necessary to solve the conflict of achieving climate-related goals without increasing user costs.

Real estate management aims to provide buildings that contain elements of modern living, such as affordable rent, individual comfort, low operational cost, and constant maintenance. It should respect energy consumption, healthy materials, and environmental sustainability in the face of the human-made crisis as well. Moreover, sustainability-related endeavors should aim toward bringing human progress and the Earth’s ecological system into conformity harmonically and synergistically without mutually damaging the other. Indeed, LCA is widely used to assess the environmental impacts of building and construction projects (Biswas 2014). In addition, carbon footprint analysis, also known as “greenhouse gas inventory,” is roughly used to indicate the extent of greenhouse gas (GHG) emissions, their origins, composition, and amounts resulting from the activities of persons or organizations (Apul 2013). According to the EU 2020 Taxonomy regulations, acting on the construction of new buildings or renovation of existing buildings, economic activities must adapt to the mitigation and coping with climate change. That includes the installation, maintenance, and repair of energy-efficient equipment controlling the energy performance of buildings in the lifespan of the building. Technologies should also be related to renewable energy, such as solar panels and charging stations for electric vehicles.

Criteria of technical evaluations are based on energy measurements, intelligent control, renewable energies, adaptability of buildings, pollution prevention and reduction, and reduction of noise, dust, and pollutant emissions (Europäischen Parlaments und des Rates 2020).

The Environmental-Social-Governance (ESG) regulations of the United Nations publication enforce suitable and innovative technological solutions consisting of climate protection in the optimization of the building. That includes the manufacturing systems, especially regarding the CO2 ton economized, the use of embodied energy, and the LCC (Haufe Online Redaktion 2021).

The calculation is not simple. It must be taken into account that the scopes of energy flow in the ecosystem, including manufacturing process and transport (upstream activities, reporting company, and downstream activities) and construction techniques, have a significant effect on the environmental impact, LCA and LCC results (WRI 2022).

Additionally, Clark (2019) noted in his comprehensive book "What color is your building?" on the quantification of energy consumption and the overall carbon footprint of buildings that the carbon footprint includes all components of buildings:

- Operating: Electricity, gas, and other fuels used in a building for heating, cooling, ventilation, lighting, hot water, computers, servers, and other equipment.
- Embodied: The energy consumed in manufacturing, delivering, and installing materials used to build, refurbish and fit out a building.
- Transport: The energy used to get people to and from a building.

What data basis can be used for calculation? LCA software is using e.g. a Life Cycle Inventory (LCI) databases such as GaBi and SimaPro in Europe and Athena in the United States (US) and Canada (Islam, Jollands, and Setunge 2015).

Potential for optimization exists. For example, Pečur et al. (2015) prove that we can save 46% of the embodied energy and 39% of the carbon in each panel of crushed and recycled bricks compared to conventional structural concrete insulated panels over a 50-year life span. Regardless of the method used to calculate the carbon footprint, Joensuu et al. (2022) show that the design for disassembly (DFD) of building components in LCA could be a potent climate protection strategy. Furthermore, Scrucca et al. (2020) outline that the unconventional and environmentally friendly use of materials and technologies reduces construction material and energy consumption. The improvement of the microclimate by planting vegetation on the roof of the buildings using, in particular, the family of

Sedum positively affects the reduction of the carbon footprint and improves the energy efficiency of the buildings (Seyedabadi, Eicker, and Karimi 2021).
To consider these aspects of relevance, it became necessary to support the work of experts in the assessment of the building (both existing buildings or buildings under construction), in the evaluation and selection of materials, the saving of time, energy, and costs.
Thus, researchers strive to develop software and tools to support LCA and carbon footprint reductions. It should be noted that the method of calculation and analysis of carbon footprint does not only concern the real estate sector; but all industries, from the design to the phase of use, from a simple product to a complex system. For example, Anggoro et al. (2023) calculated and analyzed the carbon footprint of the production process of ceramics via a method developed by the U.S. Environmental Protection Agency (EPA) and using Vensim PLE software. The aim was to find more suitable technical solutions to reduce the carbon footprint. Da Silva et Al. (2022) further confirm that integrating renewable energy at different stages of the production process, e.g. of wine production, reduces the carbon footprint.
In the real estate sector, Wright et al. (2014) created computer models to simulate the effects of reducing CO2 emissions and energy consumption by replacing heating, ventilation, air conditioning, and hot water systems with equivalent electrically powered systems in a sample of New York City buildings. Schwartz et al. (2016) use four different tools (Life Cycle Carbon Footprint (LCCF), LCC, MOGA (multi-objective genetic algorithms), and non-dominated Sorting Genetic Algorithm (NSGA2)) to optimize the renovation measures of a studied building, leaving a lot of room for error for an inexperienced user.
Carrasco-Amador et al. (2022) provide a method for the construction phase of buildings to reduce the carbon footprint of materials used in the construction of buildings. In the same context, using the conventional LCA method, Li et al. (2022) develop a carbon emission calculation model to analyze construction projects and their carbon footprint by assessing activity characteristics during the construction delivery phase.
Via the application Autodesk Revit 2020 analyzes all materials used in the building's construction to quantify the costs and emissions of each of them to then identify the most polluting ones. In an academic case study, the carbon footprint of the University of Oulu in Finland was calculated using a hybrid combination of environmental input-output analysis and LCA (Kiehle et al. 2023).

To achieve the target HK2050 in Hongkong, aiming to reduce the electricity consumption and the carbon footprint of electricity of commercial and residential buildings by 20% to 30% by 2050, Dong et al. (2023) combine Stirpat and machine learning regression to select the most relevant factors of building energy consumption and analyze them. They conclude that increased modernization of buildings and the use of energy-efficient technologies increase environmental performance and reduce carbon emissions significantly.

In this context, the literature contains few studies that attempt to calculate the carbon footprint of buildings, some of which we have discussed. These approaches will remain insufficient. Some tools are isolated and not integrated. They do not provide the possibility to apply the models to a large range of different applications as they are time-consuming, application-specific, or not exhaustive.

A simple, integrated, and efficient tool is needed to support the decision-makers in their daily work capable of dealing with a large number of existing and unspectacular buildings that incorporates LCC and LCA. Hence the importance of tools like NUKOSI, which we discuss in the next section.

3. Calculation, simulation, and analysis of LCA and LCA by NUKOSI

According to the national financial regulations of Rhineland-Palatinate in Germany, the cost-effectiveness of construction measures must be assessed over the entire life cycle, concerning new buildings as well as existing buildings. Currently, there is no established and systematic method in which the cost-effectiveness calculation of construction measures for a building considers the LCC of individual building elements in appropriate scenarios. For that reason, the University of Applied Sciences in Mainz and the State Office for Real Estate and Construction (LBB) have developed a research project for the simulation of LCC and LCA to consider ecological demands in all stages of the planning, building, and operating process of the building stock. The requirements are similar in other branches of real estate, e.g. higher education, trade, real estate funds, housing, and religious institutions (Bogenstätter 2018).

3.1 Specifications of NUKOSI

NUKOSI is a model for predicting the environmental impact and costs over the entire life cycle of buildings. It considers components, individual properties, or real estate portfolios. The scope of the method follows the specifications of the landlord. To be efficient, it needs at the beginning only a few inputs to evaluate properly as long as the original data is missing. In this case, references to buildings, space specifications, and components are used.

The Portfolio management strategy indicates the expected lifespan of the building. Lifespan can vary up to 100 years. Methodologically, the utilization of cost calculation of a new or existing building is distinguished by the level of intervention, which varies on the strategic objective for an existing building and can be divided into no (re-)actions, repairs, (total or partial) renovation, modernization of building equipment or energy modernization, refurbishment, revitalization (change of use), and environmental impact.

The model calculates the cost groups of DIN 18960 2020-11(Deutsches Institut für Normung 2020) and the capital (CG 100) with specific interest rates and object management costs (CG 200).

The model provides budget estimates of yearly operation (CG 300) LCC and LCA (e.g. water and energy consumption, waste, cleaning, service, inspection, and maintenance); it also predicts LCC (CG 400) and LCA for the repair, including energy sources (heat and electricity) and materials (embodied carbon).

The calculations take into account the age of the building, its construction elements, and the future replacement dates. The result is a retrofit plan, a cost allocation plan, rent and cost planning, and the calculation of profitability, cash flows, and annuities after various years.

The effects on e.g. increasing rents (CG 500 out of range of DIN 18960) can be considered too.

One of the strengths of the model is thus the simple energy balance function combined with the optimization of carbon footprint potentials. The available budgets can thus be optimally allocated in a targeted manner to achieve maximum carbon footprint reduction.

Among the main purposes and functions of the model in terms of environmental impact are:

- Well-founded assessment of the cost consequences and carbon footprint of construction requirements.
- Update of procurement variants (sale, construction, purchase, rental), budget planning, and portfolio management.
- Component oriented CO2 balance, minimization of operating costs, retrofit, and maintenance planning, value maximization, simulation, and scenarios

Table 1 summarizes most of the functionalities that can be calculated or evaluated by NUKOSI manually or automatically.

Table 1 The functionalities of NUKOSI

Functions of NUKOSI	Able	Unable	Automated	Not Automated
Determination of comparable new construction investments for existing buildings	✓		✓	
Determination of the modified residual useful life in accordance with the real value guideline	✓		✓	
Determination of the residual value of the building.	✓		✓	
Sale or acquisition strategy similar to the actual value guideline	✓		✓	
Approximate calculation of the number of building components.	✓		✓	
Determination of rehabilitation requirements.	✓		✓	
Possibility of entering requirements and conditions in the room and building book.	✓			
Calculation of floor space during planning and construction.	✓		✓	
Calculation of investment costs during planning and construction.	✓		✓	
Calculation of cleaning costs.	✓		✓	
calculation of new construction costs using (several) reference buildings.	✓		✓	
Calculation of replacement values for replacement dates.	✓		✓	
Determination of financing costs according to loan types: annuities, amortizations, fixed-rate loans or half-value method.	✓		✓	
Allocation of project costs by cost object for the calculation of financing costs	✓		✓	
Setting of all interest rates (discount and inflation rates) for each type of cost according to DIN 18960 extended (linear, as a curve function or variable, e.g. for capital costs, energy price development) as a basis for static or dynamic investment calculations (present values) as well as for simulation and variant scenarios, for the next 100 years	✓		✓	
Pre-assignment of maintenance and modernization strategies	✓		✓	
Pre-assignment of preferred maintenance and modernization dates for building components.	✓		✓	
Indexing of all costs; user-defined and customizable pre-assignment of index series	✓		✓	
Calculation of administrative costs; user-dependent and building-specific pre-assignment	✓		✓	
Determination of consumption for supply and disposal, e.g. on the basis of VDI 3807; user-dependent and building-adaptable pre-assignment of prices, e.g. of energy sources	✓		✓	
Plausibility check of building operating costs including ongoing maintenance (technical inspection) on the basis of key figures and/or benchmarks	✓		✓	
Assessment of optimization potential through measures, e.g. energy management	✓			
Transfer of the quantity takeoff of the components from the cubature model	✓		✓	
Calculation of cyclic (maintenance) costs from building components	✓		✓	
Consideration of (maintenance) strategies	✓		✓	
Calculation of the environmental impact (CO2 footprint), calculation of the CO2 start balance for existing buildings	✓		✓	
Marking of designs for comparison of variants	✓		✓	

From a technical and conceptual point of view, the database solution covers processes and inventory, from a single building up to holistic portfolio management, enabling projects to be evaluated in terms of cost, energy, and material flows through variants and scenarios. We use a relational data management system (RDBMS), which is a cross-platform relational database application and Websolution. This RDBMS has powerful and user-friendly search tools, able to organize large amounts of internal and external data. A multitude of complex algorithms is used to conduct the estimation of outcome variables and the automated extraction from primary data. Calculation and analysis are always based on individual projects and defined by the quantity and execution of their components. A real estate portfolio is optimized through the sum of the calculations on individual projects. The calculation process is carried out automatically utilizing the relational database. The modeling architecture targeted in our design methodology consists of four parts, as shown in Figure 2:

(1) External database sources can enrich the solution bank with external solutions and user experiences.

(2) In the requirements list, the experts collect all system specifications from his internal or external sources.

(3) The applications cover common and different industry specific solutions, and the experts can optimize these applications.

(4) Via the RDMS platform, the experts use the requirement lists, develop appropriate calculation and evaluation methods, and generate common and specific algorithms.

Finally, via NUKOSI, the user can calculate the optimal solution according to the standards and the laws.

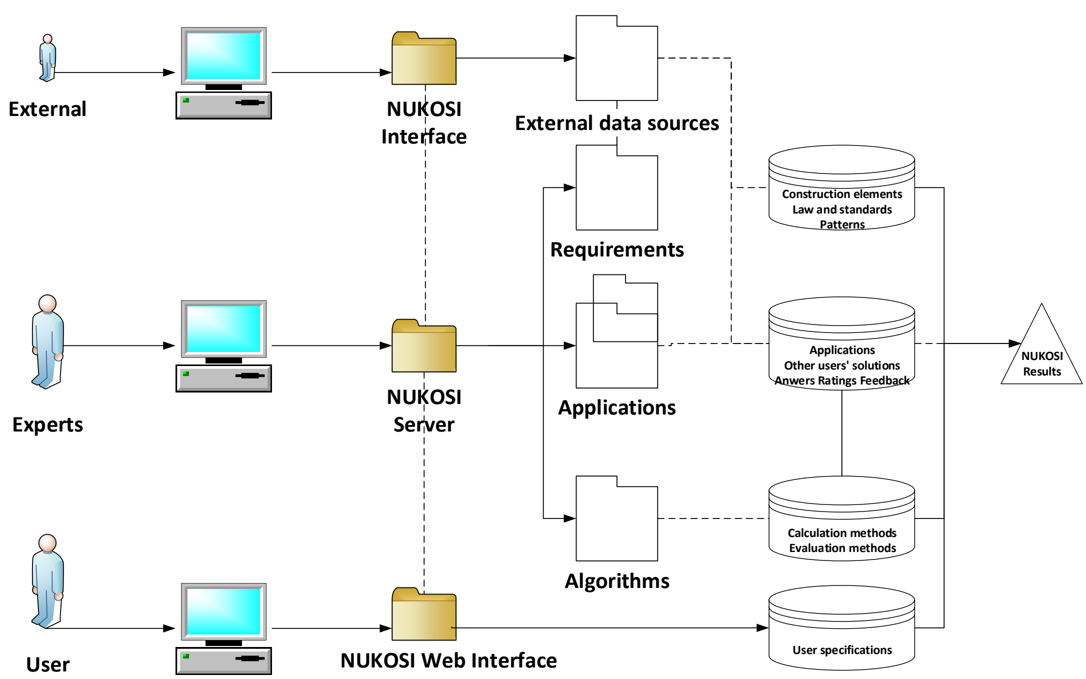


Figure 2 NUKOSI architecture

To calculate LCC und LCA based on components of an individual project, at least 6 components (e.g. construction works), 16 representative elements (e.g. walls), and more than 4,000 variations of these elements are defined and described by the time point of renovation, the cash flow and CO2 flow. The component information is an integrated part of NUKOSI.

The element variations are based on 3,000 sub-elements and 8,000 material specifications for a CO2 balance.

Using this tool enables the calculation of scenarios, including operations and repairs in the planned lifespan of a building's use. Depending on the field of application, different modules, and functional domains are used in the procedure. NUKOSI consists of modules 0 to 8, as shown in Figure 3.

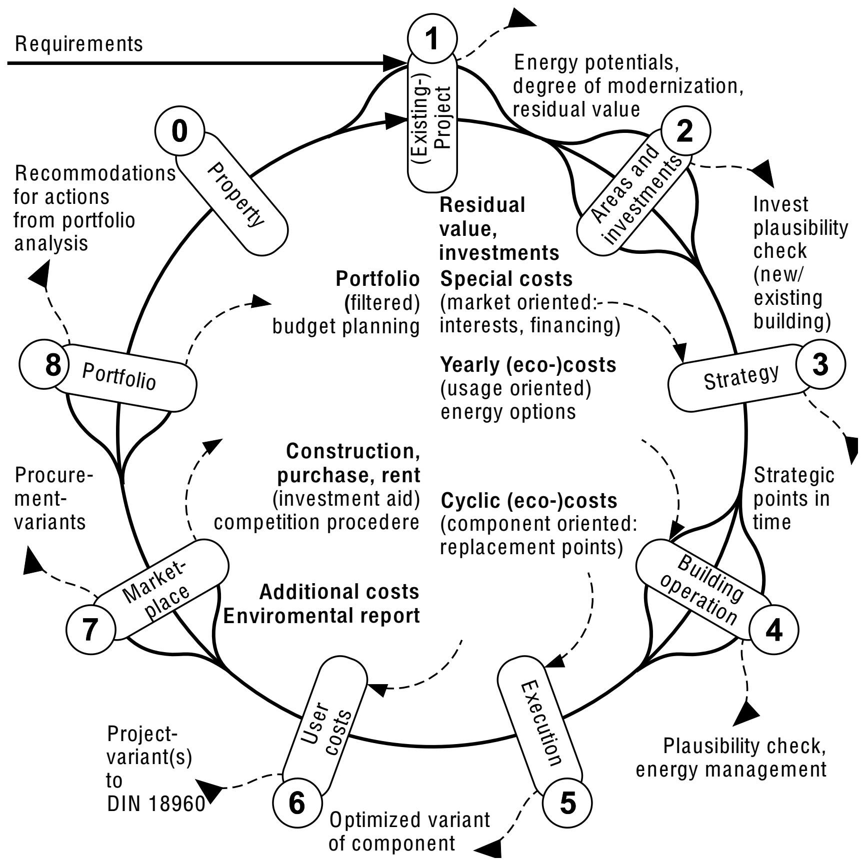


Figure 3 NUKOSI process

Modules and functional areas observe different industry functionalities. The modules are applied in sequence and can be perpetually updated by and for monitoring. The model is designed to calculate a single project or a real estate portfolio. The process is standardized.

However, the parameters of the model follow the landlord´s specifications. In the lack of specifications, pre-settings from different sources of comparable real estate data (e.g. reference buildings according to the Federal or State building allocation catalog with supplements from the contractor), reference building programs, and reference components are used.

The actualization and update of the acquisition variants (sale, construction, purchase, rental), budget planning, or portfolio management are carried out situationally or automatically by own or external staff concerning economy and ecology at any time.

3.2 Case study: Evolution of an existing building

The following case study provides an example of how LCC and the carbon footprint of a building can be calculated using NUKOSI. The model has been trained and used on many buildings, from which one was selected for this paper.

We evaluate an existing office building in the commercial sector in Germany by calculating LCC and the carbon footprint. Because of confidentiality, the address of the building and its owner remain anonymous.

We show you not all calculations and analyses carried out, but a significant part.

Building-related data in this example is limited but sufficient to estimate and predict the variables of interest.

The initial information is:

- Gross Floor Area (GFA) 10,000 m2.
- Year of construction (construction year): 1980.
- Type of use (use): Office (Quality: Standard).
- Location: Germany; Munich.

Does the building need to be modernized?

The landlord required an estimate of LCC and LCA of his property in different scenarios with the target to choose a scenario that would fit his budget and respect the environmental impact according to German law and fulfill ESG compliance rules. NUKOSI meets his needs with a reliable solution.

What are the alternative construction measures?

In the project a total of five scenarios were selected (see table 2, Annex 5). The office building of 1980 does not have mechanical ventilation system and no heat recovery. Modernization should happen during office use.

Less energy consumption means less energy costs and carbon emissions. Thus, the building losses a lot of energy by window ventilation (Var. 1 to 4). The quantity of loss is related to the air exchange rate, which depends on the tenant/user behaviour. The base of the calculation is represented by Var. 1 and Var. 3, which have a lower air exchange rate in the offices (0.3 [1/h]). Var. 2 and Var. 4 have a higher air exchange rate in the offices (0.8 [1/h]). Var. 5, representing a new building on the same site, is based on mechanical ventilation, fulfilling new standards with heat recovery and high efficiency and serves as baseline to evaluate the other variants. Var. is constructed using state of the art sustainable materials, while the CO_2 emissions of the demolition of the old building is incorporated in the variants footprint.

The building contains embodied CO_2 emissions. Thus, life span of materials should be considered. Var. 1 and Var. 2 consider the renew of the existing building with application of the1980's standard. Var. 3 and Var. 4 only consider costs for energy modernization. The description of the variants is:

- Var. 1: Existing building with repair measures to restore the condition of 1980, lower air exchange rate in the offices (0.3 [1/h]).
- Var. 2: as Var. 1, higher air exchange rate in the offices (0.8 [1/h]).
- Var. 3: Energy modernization, a high proportion of window ventilation, low air exchange rate in the offices (0.3 [1/h]).
- Var. 4: as Var. 3., higher air exchange rate in the offices (0.8 [1/h]).
- Var. 5: New building equivalent taking into account residual CO_2 when demolishing the existing buildings, lower air exchange rate in the offices (0.3 [1/h]).

What was the consumption of this building in the last three years?

The energy certificate 2022 gave the consumption data (2019-2021). The comparison between energy certificate and calculation shows that this building is unusually wasteful in terms of energy consumption and uses more energy than it should. To calculate the energy demand based on the shape of the building, we replicate the building in a three-dimensional space to calculate (see Annex 1, Partial dimensional models).

By comparing the energy standard of 1980 and the energy standard of today, the model calculates the saving potential of a modernization (see Annex 2, Carbon footprint reduction potential). We show which components have the highest saving potential. For example, the manager can save considerable energy for heating and ventilation on the exterior walls and on the windows. Finally, the cost of the modernization measures is calculated, enabling the manager to evaluate the different measures financially (see Annex 2).

Which measures save the most CO_2?

The red bars in Figure 4 show that heating offers the largest saving potential. The most efficient options in Var 1 are heating system (KGR 421), façade (KGR 335o), windows (KGR334), and ground floor (KGR 324). The potential of the air ventilation system is not displayed in figure 4; because there is no air ventilation system in the existing building, even though there is a high potential (Annex 2).

Further, the blue bars in Figure 4 show how much CO2 is saved per 1000 Euro (Annex 3 Pre-Check Optimization potential). In this case, the manager can realize a large decrease in CO2 emissions with a small investment.

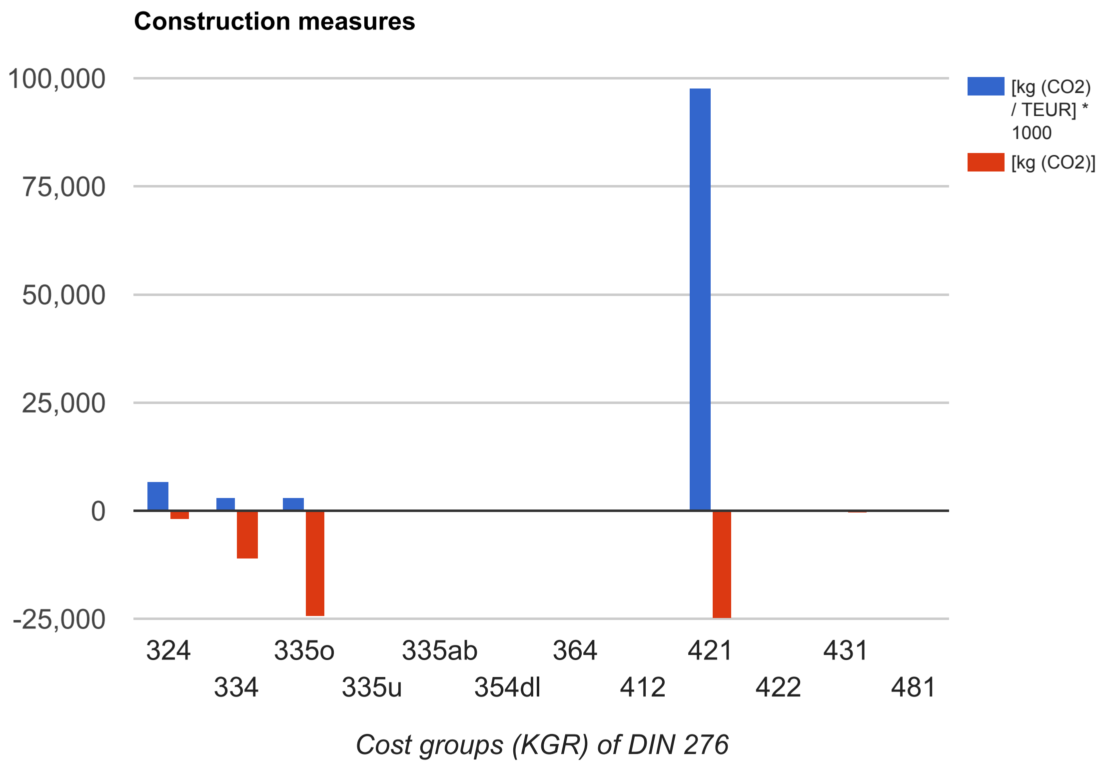


Figure 4 Saving Potential in Var. 1

The model also shows in an extra detailed view the cost of the intervention. The model calculates the residual value of a component. For example, if a window has been installed for only two years, it still has value.

How much longer can it last? How old was the window installed in the past? What is the value of the object?

The model shows in an extra detailed view the time when a construction element is installed and must be replaced.

How much is the investment? How much do we have to spend for an observation period of 50 years? It is possible that the manager will replace this window in 35 years. Therefore, the model calculates the costs for the next 50 years. The model calculates each type of cost. Maintenance, repair and energy costs are calculated, including e.g. cleaning cost and water consumption. All costs of a building are calculated according to DIN 18960 (Figure 5, Annex 4, Cashflow (LCC)).

User costs of buildings of DIN 18960:2020-11

User cost group (UCG) 100 Capital costs			€/m² GFA a. yr.	€/a, Ø yr. (static)	€/50 years (Cash values)
110		Borrowed capital			
120		Equity capital			
130		Depreciation			
190		Capital costs, other			
		Capital costs (Total 110 - 190)			

User cost group (UCG) 200 Object management costs			€/m² GFA a. yr.	€/a, Ø yr. (static)	€/50 years (Cash values)
210		Own personnel costs	11.47	114,748	4,572,175
220		Own material costs			
230		External services			
290		Object management costs, other			
		Object management costs (Total 210 - 290)	**11.47**	**114,748**	**4,572,175**

User cost group (UCG) 300 Operating costs (incl. tax)			€/m² GFA a. yr.	€/a, Ø a/yr. (statisch / static)	€/50 years (Cash values)
310		Supply	16.29	162,910	6,491,224
	311	Water	0.11	1,099	43,775
	312	Oil			
	313	Gas	8.58	85,794	3,418,489
	314	Solid fuels			
	315	District heating			
	316	Electricity	7.60	76,018	3,028,959
	317	Technical media			
	318	Energy (312—317, with no further notice)			
	319	Supply, other			
320		Disposal	1.40	13,975	556,827
	321	Wastewater	0.22	2,175	86,650
	322	Waste	1.18	11,800	470,176
	329	Disposal, other			
330		Cleaning and care of buildings	6.98	69,764	2,779,790
	331	Maintenance cleaning	6.37	63,694	2,537,897
	332	Glass cleaning	0.34	3,433	136,779
	333	Façade cleaning	0.26	2,638	105,114
	334	Cleaning of technical installations			
	339	Cleaning and care of buildings, other			
340		Cleaning and care of outdoor facilities	0.67	6,679	266,132
350		Operation, inspection and maintenance	18.66	186,593	7,434,870
	351	Operation of technical installations	4.52	45,226	1,802,050
	352	Inspection and maintenance of structures	0.43	4,291	170,984
	353	Inspection and maintenance of technical installations	3.17	31,665	1,261,694
	354	Inspection and maintenance of outdoor facilities	0.71	7,110	283,309
	355	Inspection and maintenance of furnishings, works of art			
	356	Maintenance of technical structures	0.75	7,510	299,223
	357	Maintenance of technical installations	6.59	65,870	2,624,615
	358	Maintenance of outdoor facilities	2.49	24,921	992,996
	359	Operation, inspection and maintenance, other			
360		Security and surveillance services	1.51	15,105	601,863
370		Statutory charges and contributions			
390		Operating costs, other			
		Operating costs (Total 310 - 390)	**45.50**	**455,026**	**18,130,706**

User cost group (UCG) 400 Repair costs (incl. tax)			€/m² GFA a. yr.	€/a, Ø yr. (static)	€/50 years (Cash values)
410		Structural repair	33.02	330,209	13,823,368
420		Repair of technical installations	25.56	255,572	11,005,813
430		Repair of outdoor facilities	8.77	87,700	3,929,032
440		Repair of furnishings and works of art	0.33	3,281	130,749
490		Repair costs, other			
		Repair costs (Summe / Total 410 - 490)	**67.68**	**676,762**	**28,888,963**

User cost group (UCG) 100 - 400	€/m² GFA a. yr.	€/a, Ø yr. (static)	€/50 years (Cash values)
User costs (Total NKG 100 - 400)	**124.65**	**1,246,536**	**51,591,844**
Total LZK / LCC (Investments and User)	**169.67**	**1,696,694**	**74,099,761**
Annuity LZK / LCC			**3,449,359**
Annuity [LZK / m² BGF] / [LCC / m² GFA]			**344.94**
Greenhousepotential (GHP) (CO2-Äquivalent [kg abs.])			**20,118,829**
GHP (CO2-Äquivalent [kg/m²] 10.000 [m² BGF]			**2,011.88**

Basic of Investment (DIN 276): KG 100–800 02 Invest (Bedarfswert, |19)

Figure 5 LCC of existing building

The model provides the estimation of energy consumption by heating and electricity systems. The model provides the amount of embodied CO2 of the building during the planned service life too (see Annex 5, environmental report).

To help formulate the best strategy for the building the model offers a comparison between the development of cost and CO2 emissions for the different variants. Figure 6 shows that a new building is the most cost effective. In Var 1 and 2 consider the cost of refurbishment. These variants are not much cheaper as a new building. Var 3 and 4 (energetic modernization) are much cheaper. Figure 7 shows that for this specific building Var 5 breaks even with Var 1 and 2 roughly 20 years after construction. However, Var 1, 2, 3. and 4 has significantly less starting emissions as a new building. A new building needs to be constructed and the modernization measures ensure that Var 3. performs better than Var 5. in total emitted CO2 even after 50 years.

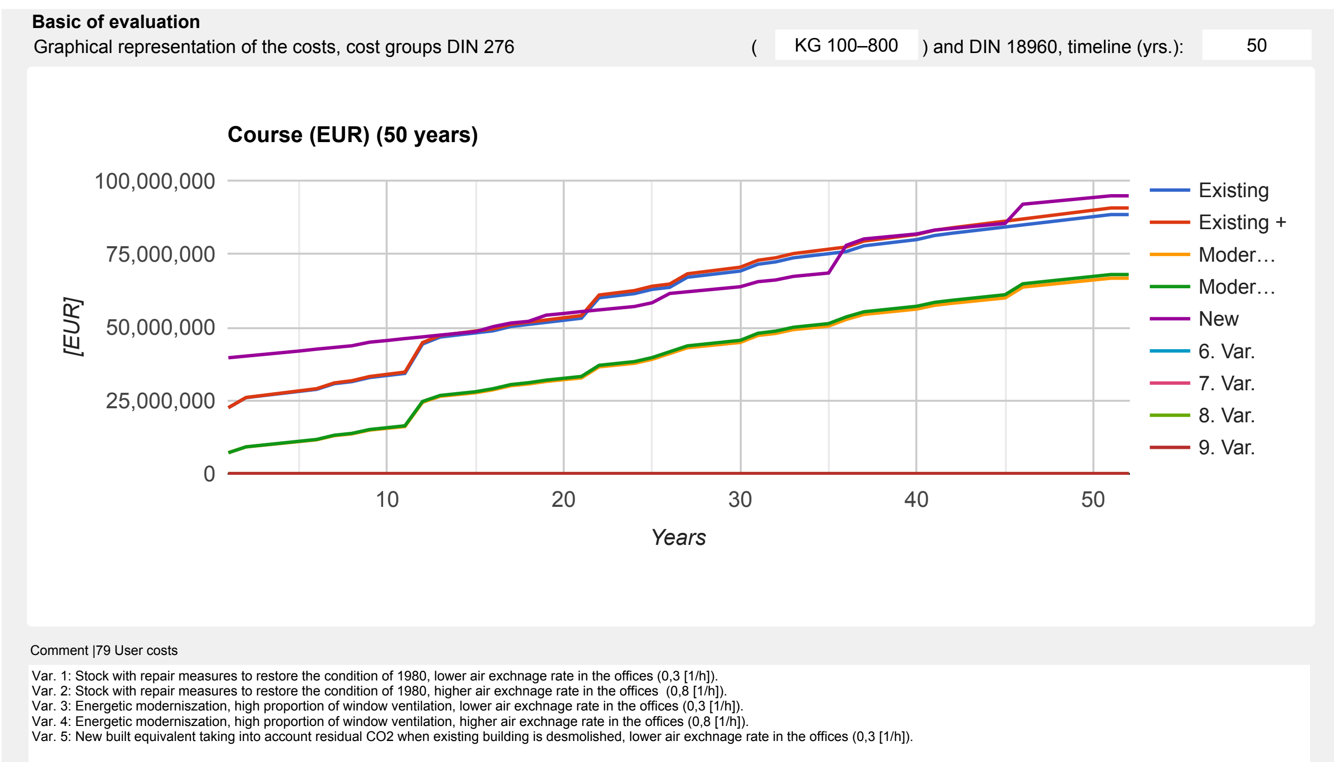


Figure 6 LCC as Cashflow

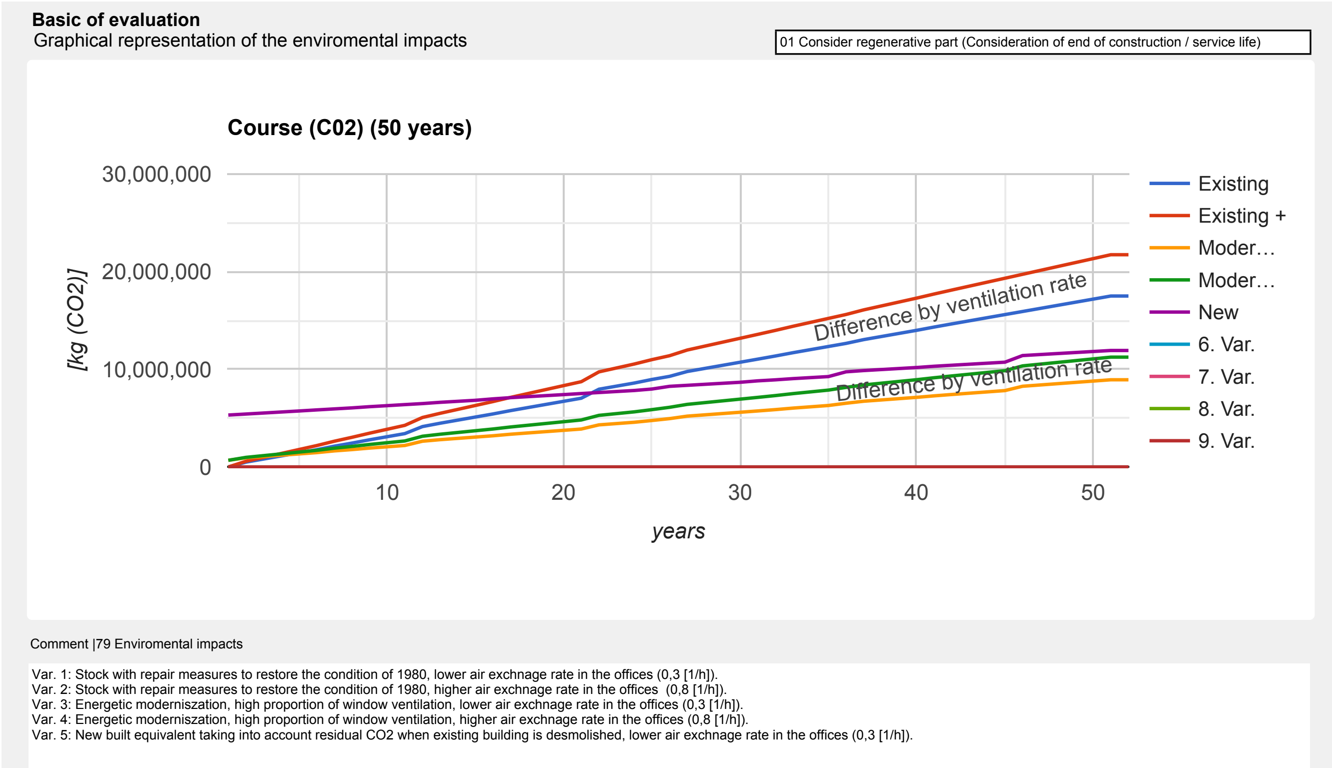


Figure 7 GHG as CO2 flow

3.3 Results and discussions

Table 2 shows the analysis of the 5 variants. Var. 3 shows the best results, indicating that in this case the reinvestment in the building is advisable.

Table 2 The analysis of the 5 variants

Var. 1	Areas in building construction. Gross floor area (GFA) according to as-built plans. Construction floor area (KGF) is relatively low and not plausible. Construction costs. Standard: BWZ (Use of the building) 1300 (administrative building). Assumption: production of new building condition 1980. User cost of buildings. High energy costs, cheaper then Var. 2. User Cost Rank 4. Environmental impacts. Unusually high energy consumption according to the energy performance certificate, may be lower with lower air exchange rates with window ventilation. Energy consumption Rank 4. CO2 emissions Rank 4. **Total Mark 4**
Var. 2	Areas in building construction. Please refer to Var. 1.

	Construction costs. Please refer to Var. 1. User cost of buildings. Highest energy costs of all Variations. User Cost Rank 5. Environmental impacts. Unusually high energy consumption according to energy performance certificate, possibly explainable e.g. by high air exchange rates with window ventilation. Energy consumption Rank 5. CO2 emissions Rank 5. **Total Mark 5**
Var. 3	Areas in building construction. Please refer to Var. 1. User cost of buildings. Standard: BWZ (Use of the building) 1300 (administrative building). Assumption: Only energetic measures for today's standard. User cost of buildings. Lower energy costs then Var. 1, Var. 2 and Var. 4, , more expensive then Var. 5. User Cost Rank 3. Environmental impact. Unusually high energy consumption according to the energy performance certificate, can be much. Lower with lower air exchange rates with mechanical ventilation. Energy consumption Rank 1. CO2 emissions Rank 1. **Total Mark 1,7**
Var. 4	Areas in building construction. Please refer to Var. 1. Construction costs. Please refer to Var. 3. User cost of buildings. Lower energy costs then Var. 1 and Var. 2, more expensive then Var. 3 and Var. 5. User Cost Rank 2. Environmental impact. Unusually high energy consumption according to energy certificates, can be much lower with higher air exchange rates with mechanical ventilation. Energy consumption Rank 3. CO2 emissions Rank 2. **Total Mark 2,4**
Var. 5	Areas in building construction. lower Primary area (NUF), because covered areas were not included; lower Gross floor area (GFA), KGF (Construction area), is plausible and checked. Construction costs. New construction costs BWZ 1300, according to the KFA-M method the construction costs are plausible. User cost of buildings. Lowest energy costs. User Cost Rank 1. Environmental impact. Energy consumption Rank 2.

	CO2 emissions Rank 3, demolition of materials are included **Total Mark 2**

Table 3 shows the energetic measures ranked from best to worst (1st to 4th) from the point of view of life cycle costs and the carbon footprint. The applied energetic measures are parts of options integrated in the model.

Table 3 The analysis of the solutions from the point of view of the Carbon footprint and life cycle cost (for details see Annex 2)

Investment for energetic measures (solutions)	***Ranking LCC and LCA per square meter***
1. Modernization of the heating system. The calculation of the costs of the construction elements shows significant deviations from the BWZ 1300 and must be examined in more detail depending on the type of heating installation. The cost calculation for the building components of approx. EUR 82,610	1st: Renovation of the heating system Investment in the heating system is the most effective measure (kg (CO2) / EUR (investment)).
2. Isolation of the ground floor plate The cost calculation for the building components of approx. EUR 98,103	2nd : Isolation of the ground floor plate The options of isolation of the ceiling between the underground car park and offices should be investigated.
3. Installation of an air ventilation system Due to the importance of the air change rate, the concept must be examined in regard to a mechanical ventilation possibility or the influence of the use. The cost calculation for the building components of approx. EUR 358,315	Out of range: Air ventilation system is not installed yet, therefore possibilities has to be proven: The technical possibilities of installing an air ventilation system with heat recovery should be investigated for retrofit during operation.
4. Substitution of the windows The cost calculation for the building components of approx. EUR 916,000 is therefore in the range from an average to a higher technical standard.	4th : Renew of windows should be done under consideration if a mechanical ventilation concept.
5. Substitution of the façade The values tend to be too high due to the high proportion of window surfaces. The cost calculation for the building of approx. EUR 2,060,000 is therefore in the range of medium to higher technical standard.	3rd : Façade (more potential to save CO2)

4. Conclusion

The case study shows that the key questions of the introduction:

- Which measures save the most CO2 and meet the legal requirements?
- How long will our buildings meet the climate protection requirements?
- What will be the cost to achieve the goals?
- Which buildings might be at risk of being unprofitable in the future?

It can be answered with “yes”.
The model allows, in accordance with the LBB mandate, to verify in a well-founded way of the residual values of the existing buildings, the consequent costs as well as the environmental impact of the building requirements. The model further empowers managers to evaluate construction elements to minimize operating costs, provide modernization and maintenance planning, and maximize value. The Model consists of modules 0 to 8 shown in the sequence of modules corresponding to a systematic approach like a cascade of steps.
The model is based on components, (sub-)elements. The methodology can also be applied to listed buildings. For this purpose, other typical building elements of listed buildings have to be defined, if necessary.
To achieve the goals of reduction of GHG in the building stock a tool is needed. This tool should facilitate the work of managers of real estate efficient to fulfill the targets quickly. Via NUKOSI, an analysis like showcased in the case study can be calculated in less than 6 minutes, with all necessary data available.
Based on the joint research project we believe that it is indispensable to calculate the carbon footprint based on components, elements and sub-elements. The calculation of the carbon footprint is a simplified calculation method, because currently not all phases from production to demolition can be considered. According to DIN EN 15978 2012-10, A1 (raw material procurement), A2 (transport), A3 (production), B2 (maintenance), B4 (replacement), B6 (energy consumption in operation), C3 (waste recycling) and C4 (disposal) are taken into account. The model has some limitations such as available information on components’ carbon footprints, especially for new constructions techniques (e.g. substitute of conventional structural concrete). The definition and certification of components, based by (sub-)elements must be accelerated. Through the application of the model in collaboration with the LBB we were able to improve the model steadily and identify future areas of research such as further automation of tasks.
What are the upcoming topics? There are 3 focal points:

- Images evaluation: identification of CO2 optimization potential through satellite.
- Image recognition: for the automation of building data acquisition, e.g. recognition by building patterns of the building age and used materials, automated acquisition of area proportions, e.g. of windows
- Text analysis tools: extension of the linkage of existing databases by keywords of non-standardized language, e.g. bills of quantities, tender texts or invoices

The use of artificial intelligence will further increase the level of automation.

Acknowledgement

The authors would like to extend a sincere thank you to all the members of LBB (State Office for Real Estate and Construction) and the researchers at the Mainz University of Applied Sciences for their contributions to this project.

References

Anggoro, Paulus Wisnu et al. 2023. "System Dynamics Modelling for Calculation of Carbon Footprint on a Non-Homogeneous Production System: A Case in a Ceramic Studio." *Results in Engineering* 17(November 2022): 100812. https://doi.org/10.1016/j.rineng.2022.100812.

Apul, Defne. 2013. 5 International Journal of Climate Change Strategies and Management *Carbon Footprint Analysis*.

Biswas, Wahidul K. 2014. "Carbon Footprint and Embodied Energy Consumption Assessment of Building Construction Works in Western Australia." *International Journal of Sustainable Built Environment* 3(2): 179–86. http://dx.doi.org/10.1016/j.ijsbe.2014.11.004.

Bogenstätter, Ulrich. 2018. *Immobilienmanagement Erfolgreicher Bestandshalter*. Walter de Gruyter GmbH & Co KG.

Carrasco-Amador, Juan Pablo et al. 2022. "Actions to Reduce Carbon Footprint in Materials to Healthcare Buildings." *Heliyon* 8(11).

Clark, David H. 2019. "What Colour Is Your Building?" *What Colour is Your Building?*

Deutsches Institut für Normung. 2020. *DIN 18960:2020-11 User Costs of Buildings*. Berlin.

Deutsches Institut für Normung. 2021 DIN 277 2021-08: *Areas and volumes in building construction*. Berlin.

Deutsches Institut für Normung. 2018. *DIN 276 2018-12 : Building costs*. Berlin.

Dong, Hanmin, and Lin Zhang. 2023. "Transition towards Carbon Neutrality: Forecasting Hong Kong's Buildings Carbon Footprint by 2050 Using a Machine Learning Approach." *Sustainable Production and Consumption* 35: 633–42. https://doi.org/10.1016/j.spc.2022.12.014.

Europäischen Parlaments und des Rates. 2020. "EU Taxonomie." https://eur-lex.europa.eu/.

Haufe Online Redaktion. 2021. "Koalitionsvertrag 2021 Aus Immobiliensicht." https://www.haufe.de/.

ISO. 2008. *15686-5 2008-06 Buildings and constructed assets: Service-life planning: Part 5: Life-cycle costing, International Organization for Standardization (Ed.), Teil 5, ISO 15686;* Berlin.

Islam, Hamidul, Margaret Jollands, and Sujeeva Setunge. 2015. "Life Cycle Assessment and Life Cycle Cost Implication of Residential Buildings - A Review." *Renewable and Sustainable Energy Reviews* 42: 129–40.

Joensuu, Tuomo, Roosa Leino, Jukka Heinonen, and Arto Saari. 2022. "Developing Buildings' Life Cycle Assessment in Circular Economy-Comparing Methods for Assessing Carbon Footprint of Reusable Components." *Sustainable Cities and Society* 77(November 2021): 103499. https://doi.org/10.1016/j.scs.2021.103499.

Kiehle, Julia, Maria Kopsakangas-Savolainen, Meeri Hilli, and Eva Pongrácz. 2023. "Carbon Footprint at Institutions of Higher Education: The Case of the University of Oulu." *Journal of Environmental Management* 329(November 2022).

Li, Xiaojuan et al. 2022. "Case Study on Carbon Footprint Life-Cycle Assessment for Construction Delivery Stage in China." *Sustainability (Switzerland)* 14(9).

Milano, Politecnico. 2021. "ICBBM 2021 Proceedings of the 4th International." (June).

Pečur, Ivana Banjad, Nina Štirmer, and Bojan Milovanović. 2015. "Recycled Aggregate Concrete for Nearly Zero-Energy Buildings." *Magazine of Concrete Research* 67(11): 575–84.

Pinto da Silva, Luís, and Joaquim C.G. Esteves da Silva. 2022. "Evaluation of the Carbon Footprint of the Life Cycle of Wine Production: A Review." *Cleaner and Circular Bioeconomy* 2(July): 100021. https://doi.org/10.1016/j.clcb.2022.100021.

Schwartz, Yair, Rokia Raslan, and Dejan Mumovic. 2016. "Implementing Multi Objective Genetic Algorithm for Life Cycle Carbon Footprint and

Life Cycle Cost Minimisation: A Building Refurbishment Case Study." *Energy* 97: 58–68. http://dx.doi.org/10.1016/j.energy.2015.11.056.

Scrucca, Flavio et al. 2020. "Energy and Carbon Footprint Assessment of Production of Hemp Hurds for Application in Buildings." *Environmental Impact Assessment Review* 84(October 2019): 106417. https://doi.org/10.1016/j.eiar.2020.106417.

Seyedabadi, Mohammad Reza, Ursula Eicker, and Saghar Karimi. 2021. "Plant Selection for Green Roofs and Their Impact on Carbon Sequestration and the Building Carbon Footprint." *Environmental Challenges* 4(April): 100119. https://doi.org/10.1016/j.envc.2021.100119.

UBA. 2021. "Entwicklung Und Zielerreichung Der Treibhausgas-Emissionen in Deutschland." https://www.umweltbundesamt.de/sites/default/files/medien/384/bilder/dateien/2_abb_thg-emissionen-zielpfade-de_2021-09-03.pdf.

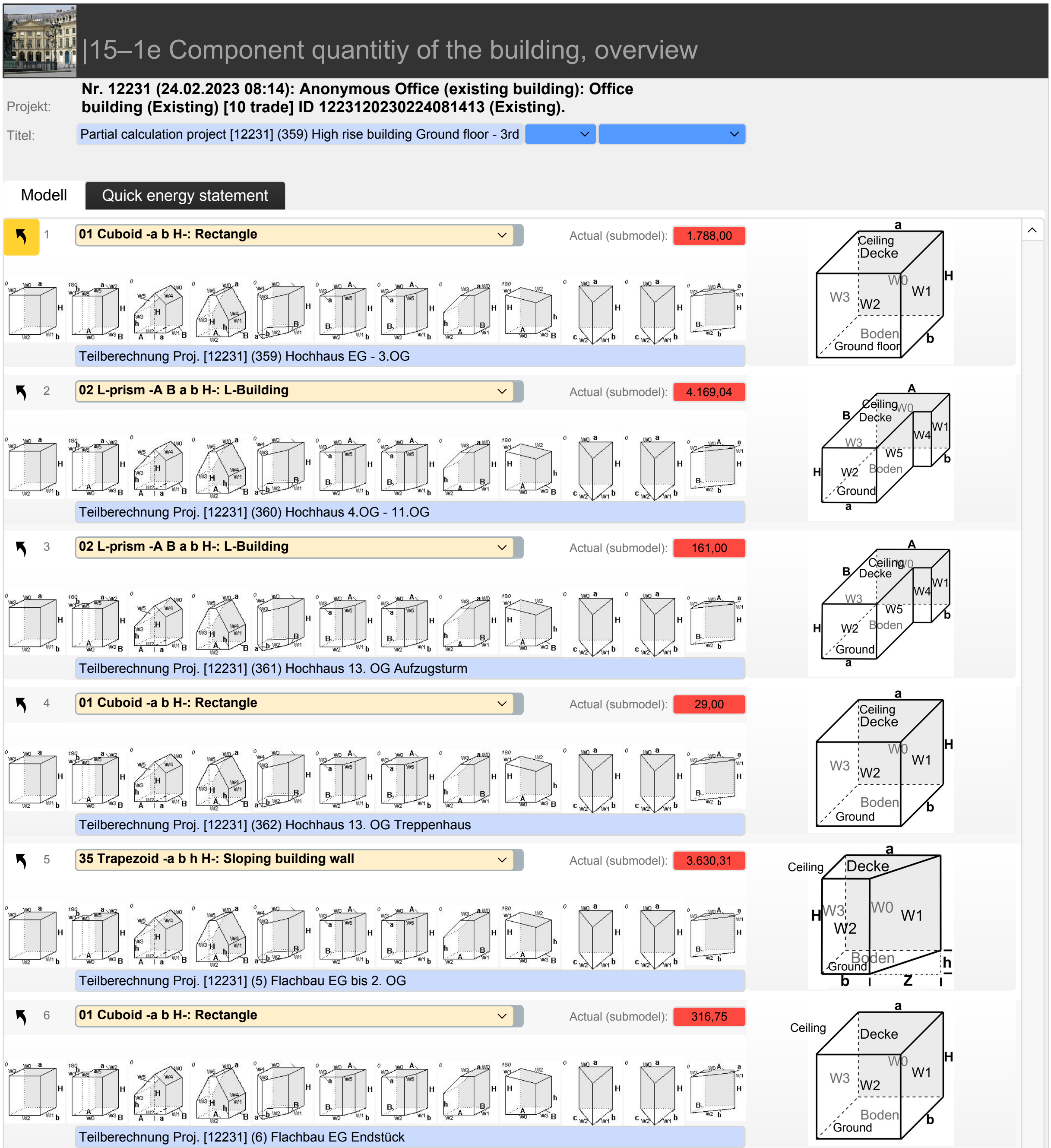
Ulrich Bogenstätter. 2008. *Property Management Und Facility Management*. 2008 | 1. ed. De Gruyter Oldenbourg. Oldenbourg. https://doi.org/10.1524/9783486599855.

———. 2014. "NUKOSI." https://www.hs-mainz.de/studium/projekte/technik/bim/nutzen-kosten-simulation.

WRI. 2022. *Greenhouse Gas Protocol: Technical Guidance for Calculating Scope 3 Emissions (Version 1.1): Supplement to the Corporate Value Chain (Scope 3) Accounting & Reporting Standard, GHG-Protocol V1*. https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf .

Wright, Daniel et al. 2014. "New York City Can Eliminate the Carbon Footprint of Its Buildings by 2050." *Energy for Sustainable Development* 23(1): 46–58. http://dx.doi.org/10.1016/j.esd.2014.06.006.

Annex 1 Partial dimensional models



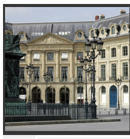
Annex 2 Carbon footprint reduction potential

Total Carbon footprint reduction potential (form)

Nr. 12231 (24.02.2023 08:14): Anonymous Office (existing building): Office Building (Existing) [10 trade] ID 1223120230224081413 (Existing).

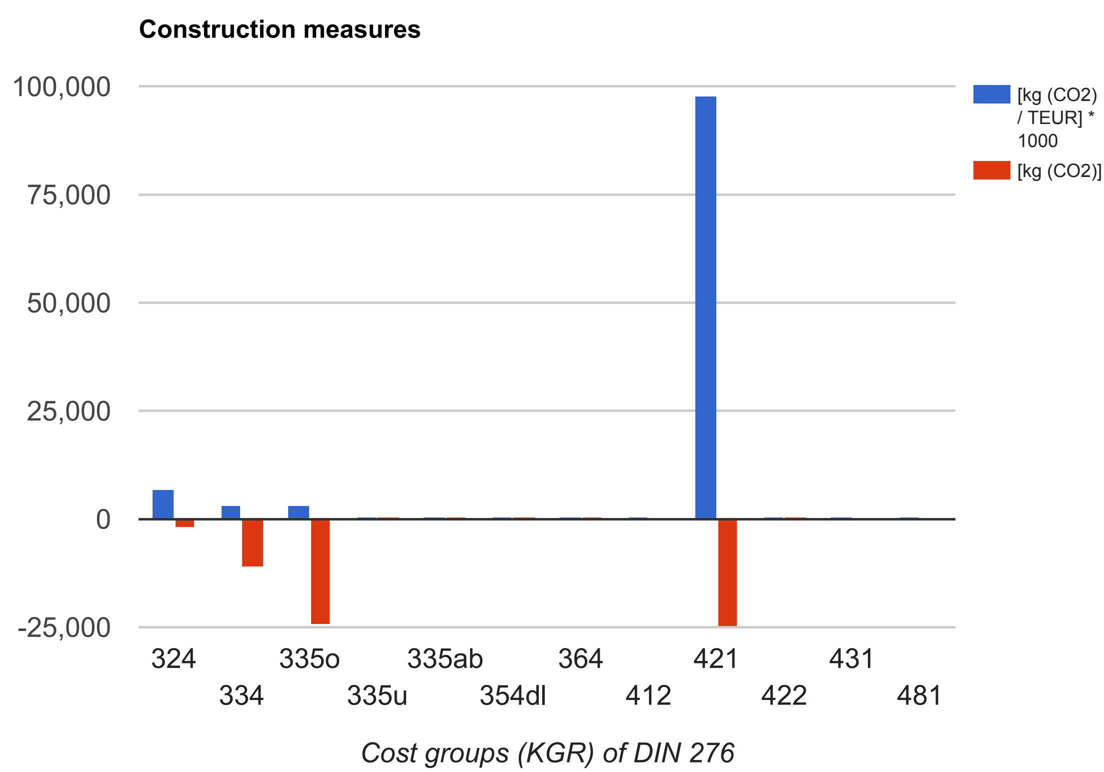
Energy standard:	1977 Wärmeschutzverordnung			2020 Gebäudeenergiegesetz (GEG					
	Actual / Plan			**Energy option**			**Potential for execution**		**Investvol.**
	Year of installation [a]	U-Value	Need [kWh/a]	Reduction [%]	U-value	Need [kWh/a]	Potential [kWh/a]	Potential [t (CO2)/a]	
	Low-investment measures								
Solar profits:	1980		-67,672	0.05		-71,056	-3,384	-0.81	
Hot water demand:	1980		16,640	0.05		15,808	-832	-0.20	0
Distributtion losses:	1980		0	0.05		0	0	0.00	10,822
Internal profits:	1980		-7,577	0.05		-7,956	-379	-0.09	0
	Energetic measures								
Ground floor plate:	1980	0.90	84,561		0.35	32,885	-51,676	-12.40	98,103
Windows:	1980	2.70	382,230		0.90	127,410	-254,820	-61.16	916,930
Walls against									
... outside (air):	1980	1.42	701,194		0.29	143,202	-557,992	-133.92	2,060,032
... soil:	1980	0.90	0		0.35	0	0	0.00	0
... other sidewalls:	1980	0.45	0		0.20	0	0	0.00	0
Basement ceiling:	1999		0			0	0	0.00	0
Roof:	1980	0.45	60,268		0.20	26,786	-33,482	-8.04	339,863
		Heat recovery			Heat recovery				
Ventilation system:	1980	0.00	4,881		0.90	488			
Window ventilation:			198,588			198,588			
Total ventilation:							-4,393	-1.05	358,315
Energy demand:			1,373,113			466,155	-906,958		0
Heating efficiency		* Efficiency			* Efficiency				
Heating renovation:	1980	0.75	457,704		1.11	-46,196	-593,779	-142.51	82,610
Including individual measures: palnned potential									
Energysource:	06 Erdgas			06 Erdgas					
Totals:			1,830,817			419,959	-1,500,737		
Korrektur Bedarf / Verbrauch:		0,0%				Demand / consumption::		61,0%	3,866,675
[kWh/a]			1,830,817			419,959	-1,500,737		
[kg CO2/kWh]	0.2400		[kWh/a] / m2 (BGFe)]			[kWh/a] / m2 (BGFe)]			
[... / GFAe]	7,530		243.14			55.77			

Annex 3 Pre-Check Optimization potential



Pre-Check Einsparkennzahl (kg (CO2) pro EUR)

Nr. 12231 (24.02.2023 08:14): Anonymous Office (existing building): Verwaltungsgebäude (Existing) [10 Gewerbe] ID 1223120230224081413 (Bestand).



Annex 4 Cashflow (LCC)

Form E 3.5 LCC, CO2-flow

User costs of buildings of DIN 18960:2020-11

		User cost group (UCG) 100 Capital costs	€/m² GFA a. yr.	€/a, Ø yr. (static)	€/50 years (Cash values)
110		Borrowed capital			
120		Equity capital			
130		Depreciation			
190		Capital costs, other			
		Capital costs (Total 110 - 190)			

		User cost group (UCG) 200 Object management costs	€/m² GFA a. yr.	€/a, Ø yr. (static)	€/50 years (Cash values)
210		Own personnel costs	11.47	114,748	4,572,175
220		Own material costs			
230		External services			
290		Object management costs, other			
		Object management costs (Total 210 - 290)	**11.47**	**114,748**	**4,572,175**

		User cost group (UCG) 300 Operating costs (incl. tax)	€/m² GFA a. yr.	€/a, Ø a/yr. (statisch / static)	€/50 years (Cash values)
310		Supply	16.29	162,910	6,491,224
	311	Water	0.11	1,099	43,775
	312	Oil			
	313	Gas	8.58	85,794	3,418,489
	314	Solid fuels			
	315	District heating			
	316	Electricity	7.60	76,018	3,028,959
	317	Technical media			
	318	Energy (312—317, with no further notice)			
	319	Supply, other			
320		Disposal	1.40	13,975	556,827
	321	Wastewater	0.22	2,175	86,650
	322	Waste	1.18	11,800	470,176
	329	Disposal, other			
330		Cleaning and care of buildings	6.98	69,764	2,779,790
	331	Maintenance cleaning	6.37	63,694	2,537,897
	332	Glass cleaning	0.34	3,433	136,779
	333	Façade cleaning	0.26	2,638	105,114
	334	Cleaning of technical installations			
	339	Cleaning and care of buildings, other			
340		Cleaning and care of outdoor facilities	0.67	6,679	266,132
350		Operation, inspection and maintenance	18.66	186,593	7,434,870
	351	Operation of technical installations	4.52	45,226	1,802,050
	352	Inspection and maintenance of structures	0.43	4,291	170,984
	353	Inspection and maintenance of technical installations	3.17	31,665	1,261,694
	354	Inspection and maintenance of outdoor facilities	0.71	7,110	283,309
	355	Inspection and maintenance of furnishings, works of art			
	356	Maintenance of technical structures	0.75	7,510	299,223
	357	Maintenance of technical installations	6.59	65,870	2,624,615
	358	Maintenance of outdoor facilities	2.49	24,921	992,996
	359	Operation, inspection and maintenance, other			
360		Security and surveillance services	1.51	15,105	601,863
370		Statutory charges and contributions			
390		Operating costs, other			
		Operating costs (Total 310 - 390)	**45.50**	**455,026**	**18,130,706**

		User cost group (UCG) 400 Repair costs (incl. tax)	€/m² GFA a. yr.	€/a, Ø yr. (static)	€/50 years (Cash values)
410		Structural repair	33.02	330,209	13,823,368
420		Repair of technical installations	25.56	255,572	11,005,813
430		Repair of outdoor facilities	8.77	87,700	3,929,032
440		Repair of furnishings and works of art	0.33	3,281	130,749
490		Repair costs, other			
		Repair costs (Summe / Total 410 - 490)	**67.68**	**676,762**	**28,888,963**

User cost group (UCG) 100 - 400	€/m² GFA a. yr.	€/a, Ø yr. (static)	€/50 years (Cash values)
User costs (Total NKG 100 - 400)	**124.65**	**1,246,536**	**51,591,844**
Total LZK / LCC (Investments and User)	**169.67**	**1,696,694**	**74,099,761**
Annuity LZK / LCC			**3,449,359**
Annuity [LZK / m² BGF] / [LCC / m² GFA]			**344.94**
Greenhousepotential (GHP) (CO2-Äquivalent [kg abs.])			**20,118,829**
GHP (CO2-Äquivalent [kg/m²] 10.000 [m² BGF]			**2,011.88**

Basic of Investment (DIN 276): KG 100–800 | 02 Invest (Bedarfswert, |19)

Enviromental report (Scopes according to GHG-

Nr. 12231 (24.02.2023 08:55): Anonymous Office (New building): Office Building (New) [10 trade] ID 1223120230224085519 (new).

Formation of the key figures of unit...

[m^2 (BGFa)]	6.964

Calculation of CO2 consumption based on:

06 Erdgas
01 Regenerativen (Berücksichtigung Bauende / Nutzungsdauer) Anteil berücksichtigen

Water consumption (according to table |15) (selected)

		Surface area	Water consumption		
		[m^2 (unit)]	total,	year [a] und	[m^2 (unit)]
Water	[m3]	6,964	69,615	1,392.30	0.20

Energy balance ([kWh]) (selected)

			Total (total service life)		
		[m^2 (unit)]	[kWh]	Jahr [a] und	[m^2 (unit)]
|15	Energy balance (heat)	6,964	15,318,059	306,361	43.99
	Energy balance (electricity)		12,890,827	257,817	37.02
	Total energy		28,208,886	564,178	81.01

CO2 equivalent (selected)

			[kg (CO2)] in year 0		Duration	[kg (CO2)], including year 0		
	Calculated discount (%) for regenerative share		total	[m^2 (unit)]	CO2 (kg) / kWh	total,	year [a] und	[m^2 (unit)]
	Table	Description			50			
+	|49.1	Energy source (heat)		0.00	0.240	3,676,334	73,527	10.56
+	|49.2	Energy source (electricity)		0.00	0.163	2,099,400	41,988	6.03
=	**|49**	**Energy source**		**0.00**		**5,775,734**	**115,515**	**16.59**
+	|59	Residual CO2 (e.g. in case of demolition)	2,049,794		Nr. 12231 (24.02.2023 08:14): Anonymous Office			
+	|59	Embodied energy (material, components)	3,269,316	469.43	0.240			
=	**|59**	**Materials (embodied carbon)**	**5,319,110**	**763.75**		**6,738,339**	**134,767**	**19.35**
=	**|69**	**Total**	**5,319,110**	**763.75**		**12,514,073**	**250,281**	**35.94**

CO2 material (according to table |59) (selected)

		Resource		Surface	Resource consumption		
		in year 0		[m^2 (unit)]	total,	year [a] und	[m^2 (unit)]
Primary energy	[MJ]	total		6,964			
Renewable		5,648,804	811.09		8,100,982	162,020	23.26
Renewable (energy)		6,309,684	905.98		9,048,753	180,975	25.99
Renewable (material)		-687,039	-98.65		-985,287	-19,706	-2.83
Non renewable		32,066,690	4,604.32		45,987,020	919,740	132.06
Non renewable (energy)		29,286,805	4,205.17		42,000,371	840,007	120.61
Non renewable (material)		2,428,871	348.75		3,483,258	69,665	10.00
			0.00			0	0.00
Use of freshwater ressources	[m3]	10,340	1.48	Duration	14,829	297	0.04
Potentials (equivalence)				50			
Greenhouse (CO2)	[kg CO2 eq]	3,269,316	469.43		4,688,544	93,771	13.46
Ozone layer depletion (CFC11)	[kg CFC-11 eq]	0	0.00		0	0	0.00
Acidification (SO2)	[mol H+ eq]	7,509	1.08		10,769	215	0.03
Overfertilization (P)	[mol N eq]	927	0.13		1,330	27	0.00
Abiotic resource consumption (Sb)	[kg Sb eq]	279	0.04		400	8	0.00
Summersmog (Ethen)	[Kg NMVOC eq]	1,659	0.24		2,379	48	0.01

	Project	[kg] before/to year 0		Duration	Rest end		
CO2 start balance (Project)	3,269,316	**5,319,110**	**763.75**	50	**1,974,810**		**294.32**

Annex 6 Variant overview

Anonymous Office (existing building)
|79–R792e Variant overview

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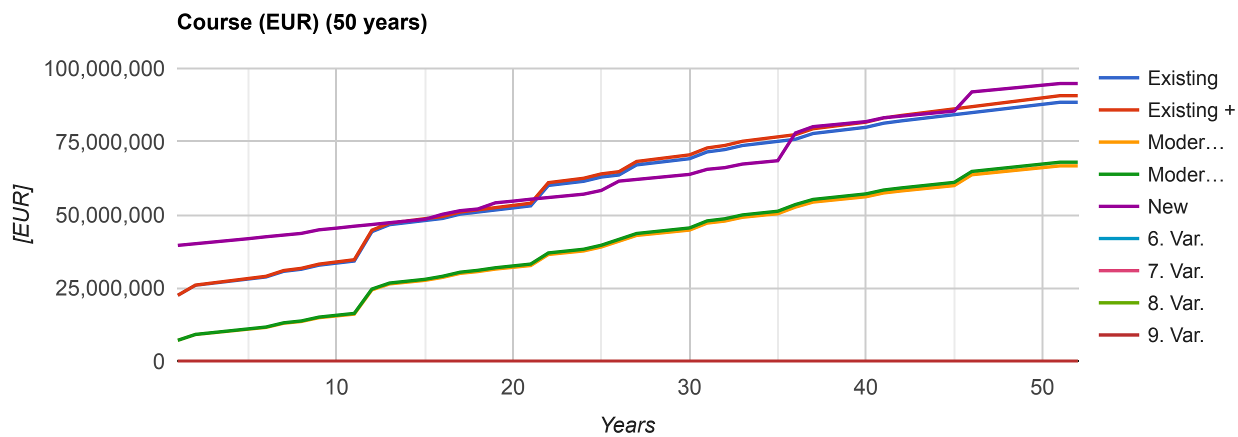
Areas and volumes in building construction		Existing		Existing +		Modernization		Modernization +		New	
DIN 277-1:2016-01	Areas in building construction	$[m^2]$ total	%	$[m^2]$ total	%	$[m^2]$ total	%	$[m^2]$ total	%	$[m^2]$ total	%
NUF	**Primary area**	6,388	63,9%	6,388	63,9%	6,388	63,9%	6,388	63,9%	6,028	60,5%
+ TF	Technical area	434	4,3%	434	4,3%	434	4,3%	434	4,3%	409	4,1%
+ VF	Circulation area	2,313	23,1%	2,313	23,1%	2,313	23,1%	2,313	23,1%	2,182	21,9%
= NRF	**Net room area**	9,134	91,3%	9,134	91,3%	9,134	91,3%	9,134	91,3%	8,620	86,6%
- KGF	Construction floor area	866	8,7%	866	8,7%	866	8,7%	866	8,7%	1,339	13,4%
= BGF	**Gross floor area**	10,000	100,0%	10,000	100,0%	10,000	100,0%	10,000	100,0%	9,959	100,0%
BRI	Gross volume / BRI to BGF	34,900	3,49	34,900	3,49	34,900	3,49	34,900	3,49	34,755	3,49
Building costs (incl. tax.)	KG 100–800	02 Invest (Demand, |19)		02 Invest (Demand, |19)		02 Invest (Demand, |19)		02 Invest (Demand, |19)		04 Invest (New, |29)	
DIN 276:2018-12	Cost group (CG)	[EUR]	... / $[m^2$ (BGF)]	[EUR]	... / $[m^2$ (BGF)]	[EUR]	... / $[m^2$ (BGF)]	[EUR]	... / $[m^2$ (BGF)]	[EUR]	... / $[m^2$ (BGF)]
200	Clearance and development	1,170,894	117.09	1,170,894	117.09	0	0.00	0	0.00	2,323,203	233.29
300	Structure – Construction works	10,681,967	1,068.20	10,681,967	1,068.20	4,256,681	425.67	4,256,681	425.67	17,661,982	1,773.56
400	Structure – Technical systems	4,814,959	481.50	4,814,959	481.50	2,077,451	207.75	2,077,451	207.75	7,961,241	799.44
BWK (300-400)	**Construction costs**	15,496,925	1,549.69	15,496,925	1,549.69	6,334,132	633.41	6,334,132	633.41	25,623,223	2,573.00
500	External works and open spaces	2,237,319	223.73	2,237,319	223.73	0	0.00	0	0.00	4,439,126	445.76
619	General furnishings / furniture, other	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
700	Incidental building costs	2,765,517	276.55	2,765,517	276.55	808,072	80.81	808,072	80.81	5,735,874	575.98
GWK (200-700)	**Total construction costs**	22,401,943	2,240.19	22,401,943	2,240.19	7,142,204	714.22	7,142,204	714.22	39,572,392	3,973.73
User costs of buildings (incl. tax)	KG 100–800	02 Invest (Demand, |19)		02 Invest (Demand, |19)		02 Invest (Demand, |19)		02 Invest (Demand, |19)		04 Invest (New, |29)	
DIN 18960:2020-11	Cost group (CG)	[EUR / a]	... / $[m^2$ (BGF)]	[EUR / a]	... / $[m^2$ (BGF)]	[EUR / a]	... / $[m^2$ (BGF)]	[EUR / a]	... / $[m^2$ (BGF)]	[EUR / a]	... / $[m^2$ (BGF)]
100	Capital costs	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
200	Object management costs	114,748	11.47	114,748	11.47	111,148	11.11	111,148	11.11	100,830	10.13
300	Operating costs	455,026	45.50	482,009	48.20	398,096	39.81	413,252	41.33	381,489	38.31
400	Repair costs	676,762	67.68	676,762	67.68	649,672	64.97	649,672	64.97	597,716	60.02
100-400	User costs of buildings	1,246,536	124.65	1,273,519	127.35	1,158,916	115.89	1,174,072	117.41	1,080,036	108.45
Enviroment impact	Starting balance [kg (CO_2)]	3.431.995	[m^2 (BGF)]	3.431.995	[m^2 (BGF)]	3.431.995	[m^2 (BGF)]	3.431.995	[m^2 (BGF)]	5.319.110	[m^2 (BGF)]
...	Energy consumption [kWh / a]	1.615.824	162	2.035.276	204	704.670	70	934.843	93	564.178	81
…	CO_2 emission [kg (CO_2) 50a]	20.118.829	**2.012**	25.140.335	**2.514**	9.809.029	**981**	12.559.194	**1.256**	12.514.073	**1.797**

Annex 7 Course of life cycle cost (LCC)

Anonymous Office (existing building)
|79–R792e Variant overview

Basic of evaluation

Graphical representation of the costs, cost groups DIN 276 (KG 100–800) and DIN 18960, timeline (yrs.): 50



Comment |79 User costs

Var. 1: Stock with repair measures to restore the condition of 1980, lower air exchnage rate in the offices (0,3 [1/h]).
Var. 2: Stock with repair measures to restore the condition of 1980, higher air exchnage rate in the offices (0,8 [1/h]).
Var. 3: Energetic moderniszation, high proportion of window ventilation, lower air exchnage rate in the offices (0,3 [1/h]).
Var. 4: Energetic moderniszation, high proportion of window ventilation, higher air exchnage rate in the offices (0,8 [1/h]).
Var. 5: New built equivalent taking into account residual CO2 when existing building is desmolished, lower air exchnage rate in the offices (0,3 [1/h]).

Reference:

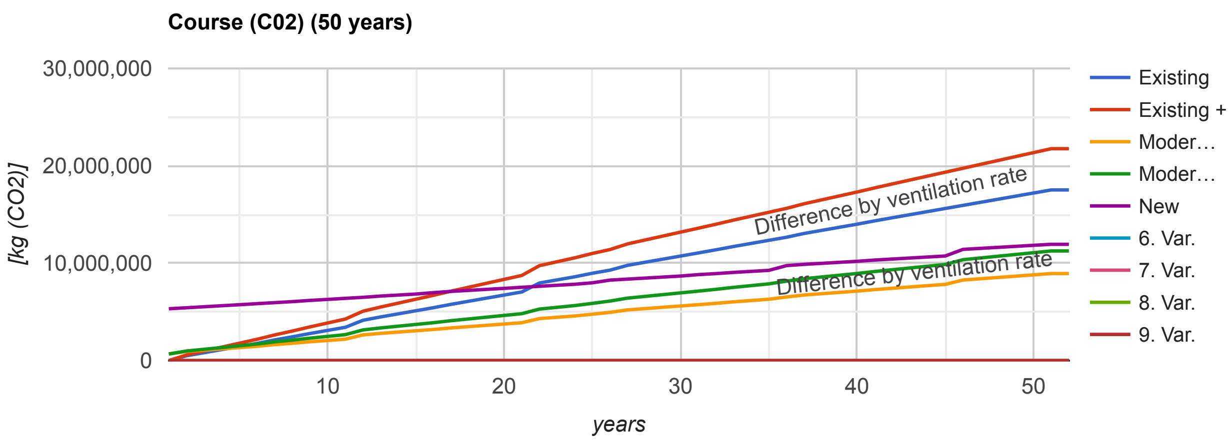
02 In relative proportion (%) to a variant

Annex 8 Course of Carbon footprint (LCA)

Anonymous Office (existing building)
|79–R792e Variant overview

Basic of evaluation
Graphical representation of the enviromental impacts

01 Consider regenerative part (Consideration of end of construction / service life)



Comment |79 Enviromental impacts

Var. 1: Stock with repair measures to restore the condition of 1980, lower air exchnage rate in the offices (0,3 [1/h]).
Var. 2: Stock with repair measures to restore the condition of 1980, higher air exchnage rate in the offices (0,8 [1/h]).
Var. 3: Energetic moderniszation, high proportion of window ventilation, lower air exchnage rate in the offices (0,3 [1/h]).
Var. 4: Energetic moderniszation, high proportion of window ventilation, higher air exchnage rate in the offices (0,8 [1/h]).
Var. 5: New built equivalent taking into account residual CO2 when existing building is desmolished, lower air exchnage rate in the offices (0,3 [1/h]).

Reference:

02 In relative proportion (%) to a variant

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