# ECOLOGICAL EFFICIENCY OF OFFICE BUILDINGS

Raban Siebers[a], Bernhard Hauke[a], Dominik Pyschny[b], Markus Feldmann[b], Markus Kuhnhenne[c]

[a]bauforumstahl e.V, Düsseldorf, Germany, Raban.Siebers@bauforumstahl.de, Bernhard.Hauke@bauforumstahl.de
[b]RWTH Aachen University, Institute of Steel Construction, Aachen, Germany, dpy@stb.rwth-aachen.de
[c] AAINA GmbH, Institute for Sustainable Construction, Aachen, Germany, mku@aaina.eu

## INTRODUCTION

With the introduction of Green Building Labels such as "Leadership in Energy and Environmental Design" (LEED) and even more with the second generation of Sustainable Building Labels such as the German "Deutsches Gütesiegel Nachhaltiges Bauen" (DGNB) [1] Life Cycle Assessment (LCA) has become an integral part of the sustainability assessment of buildings. A substantiated assessment and choice of construction products during the planning phase is one of the main tasks for sustainable construction and management of buildings, which engineers and architects are confronted with.
In order to gain knowledge about the environmental impacts of different types of structural systems for office buildings, five different construction methods are considered in this study: four steel-composite and one reinforced concrete structure as reference case. Since a comparison of the environmental performance of different structural types is only useful and meaningful within the building context, all types follow the same basics for functionality and dimensions. They are suitable for different levels of building services paired with various cladding systems.
The investigations follow the module-based life-cycle description from standard EN 15978 [2]. Since buildings are usually designed for a long period of use, the decisions made during both the planning and construction phase may have major consequences. This paper presents first results, shows cause variables on LCA for office buildings and facilitates future decisions.

## 1 INFORMATION ABOUT LCA

### 1.1 Life Cycle Assessment Information

The European Committee for Standardization (CEN) has established the Technical Committee "Sustainability of construction works" (CEN/TC 350) which has developed several standards for the sustainability assessment of buildings and construction products. The standard EN 15978 [2] deals with the environmental performance of buildings and defines system boundaries that have to be considered within an LCA. The assessment includes all building-related construction products, processes and services used over the life cycle of the building. The information about products and services is obtained from Environmental Product Declarations (EPD). Principles for the preparation of these EPDs are given in EN 15804 [3]. As information from product level is directly used for building assessment, both life-cycles have to be structured identically. Therefore CEN/TC 350 has established a module-based life-cycle description which is composed of five information modules. The building life cycle starts with the extraction of raw materials, covers the construction and use stages and ends with deconstruction and waste processing. In the scheme of complete building assessment information the module D, which comprises benefits and loads that arise from the reuse and recycling of the construction products, has to be taken into account. More information about LCA, EN 15805 and the used Databases in the Paper: "Environmental product declaration "Structural steel" according to EN 15804" from Siebers, Hauke und Vassart.

### 1.2 Data bases

Data bases for this comparison are the available Environmental Product Declarations (EPDs) and the Ökobau.dat 2013 [4] of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The specific input data for the EPDs is delivered from producers or a pool of producers - the owners of these declarations. The Ökobau.dat is based on average data for Germany. Therefore the specific EPD data should be preferred to the market average as reflected by Ökobau.dat. In this study, the environmental indicator “Primary Energy not-renewable” is considered. It includes mainly the use of the natural gas, petroleum, coal and nuclear power. The used data is given in *Table 1*.

*Table 1.* Used data base for different construction products

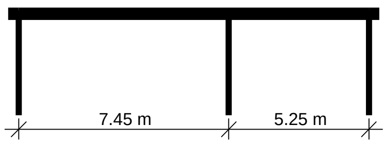
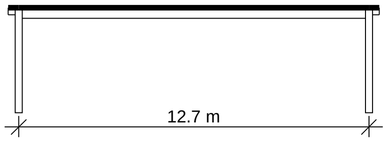
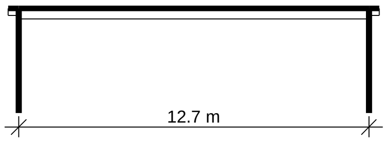
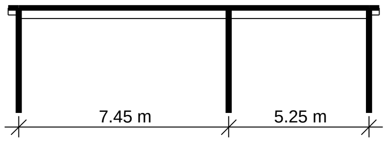
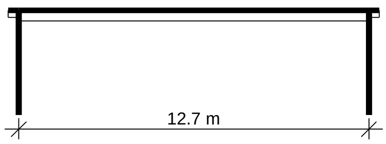
| **Material/ Source** | **Module acc. to EN15804** | **Reference Unit (RU)** | **Primary Energy, non- renewable [MJ/RU]** | **Comment** |
|---|---|---|---|---|
| Structural Steel EPD-BFS-20130094 [5] | **Total** | **t** | **10630** | |
| | A1-A3 | t | 17900 | |
| | D | t | -7270 | 11% Reuse, 88% Recycling |
| Concrete C 20/25, EPD-IZB-2013411 [6] | **Total** | **m³** | **546.2** | |
| | A1-A3 | m³ | 846 | |
| | C3 | m³ | 19.2 | Building rubble processing |
| | D | m³ | -319 | 96% material utilization, 4% landfill |
| Concrete C 30/37, EPD-IZB-2013431 [7] | **Total** | **m³** | **684.2** | |
| | A1-A3 | m³ | 984 | |
| | C3 | m³ | 19.2 | Building rubble processing |
| | D | m³ | -319 | 96% material utilization, 4% landfill |
| Reinforcement, Ökobau.dat 2013, process 4.1.02 [4] | | **kg** | **11.2** | |
| | | kg | 11.2 | |
| | | kg | - | No recycling potential |
| Trapezoidal sheet, EPD-IFBS-2013211 [8] | **Total** | **m²** | **193** | |
| | A1-A3 | m² | 373 | |
| | C4 | m² | 0 | 10% Landfill |
| | D | m² | -180 | 90% Recycling |
| Gypsum plaster fire protection board, EPD Gypsum products [9] | **Total** | **kg** | **3.45** | |
| | A1-A3 | kg | 3.35 | |
| | C3 | kg | 0.1 | Gypsum waste processing |
| Façade, M-EPD-SFA-000003 [10] | **Total** | **m²** | **1049.94** | |
| | A1-A3 | m² | 1859.19 | |
| | C3 | m² | 24.48 | Dismantling, recovery and thermal utilization |
| | D | m² | -833.73 | Recycling: Steel 98%, Aluminium 90%, Glass 90% |
| Roof Insulation, EPD-DRW-2012131[11] | **Total** | **m³** | **1857.16** | |
| | A1-A3 | m³ | 1933.68 | |
| | C4 | m³ | 29.46 | 100%Landfill |
| | D | m³ | -105.98 | Thermal utilization of packing |
| Perimeter Insulation Base Plate, EPD-FPX-2010111-D [12] | **Total** | **0.1 m³** | 241.219 | |
| | Production | 0.1 m³ | 343.752 | |
| | End of Life | 0.1 m³ | -102.533 | 90% thermal utilization |

## 2 INTRODUCTION OF THE CONSIDERED SUPPORTING STRUCTURES

The following basics for design and structural layout are valid for all five construction methods. The steel-composite structures and the reinforced concrete structure are based on identical functional and structural conditions:

- High user flexibility: The frequently reoccurring grid dimension in interior completion 5.40 m x 5.50 m is included. Thus several different floor plans including single, combination and open-plan offices are possible at low effort.
- The building is a skeleton construction. Structural elements such as columns and walls are kept to a minimum, and a contorted building geometry is avoided.
- The lateral stability of the building is provided by a bracing core that is not considered in this study.
- The structural components are provided solely within the grid. Thus disturbing structural elements in the floor plan are avoided.
- The width of 13.7 m allows for a natural lighting and provides good conditions for office use.
- Six full floors for office use are considered.
- The features of the building - installations, raised floor, suspended ceilings, walls, façade etc. - can be adapted to different needs and different designs. The building envelope concept is such that every common façade system can be used for both structural alternatives. From all types of glass façades to classical punctuated façades. To install sandwich panels a support structure is required for both building concepts. For the investigations here a curtain wall façade of steel and stainless steel with transparent and opaque filling was chosen.

*Table 2.* Dimensions of slabs and columns

| Option | Structure | | Sketch |
|---|---|---|---|
| Concrete | Reinforced concrete flat-slab | Thickness: 0.27 m, C30/37<br>Reinforcement: 150 kg/m³ |  |
| | Reinforced concrete columns: | Edge columns: Ø 0.3 m, C30/37<br>Central columns: Ø 0.4 m, C30/37<br>Reinforcement: 350 kg/m³<br>Column grid: 5.40 m x 7.45 m | |
| Steel 1 | RC slab<br>Composite beam | Thickness: 0.20 m, C30/37<br>Reinforcement: 75 kg/m³<br>Beam: IPE 500, S355 |  |
| | Steel columns | HEB 200, S355<br>Column grid: 5.40 m x 12.7 m | |
| Steel 2 | RC slab<br>Composite beam | Thickness: 0.20 m, C30/37<br>Reinforcement: 75 kg/m³<br>Beam: IPE 500, S355 |  |
| | Composite columns | HEB 180, S355<br>Column grid: 5.4 m x 12,7 m | |
| Steel 3 | RC slab<br>Composite beam | Thickness: 0.20 m, C30/37<br>Reinforcement: 75 kg/m³<br>Beam: IPE 360, S355 |  |
| | Composite columns | Edge columns: HEB 120, S355<br>Central columns: HEB 180, S355<br>Column grid: 5.40 m x 7.45 m | |
| Steel 4 | Composite slab<br>Composite beam | Trapezoidal sheet: 135/310<br>Thickness: 0.20 m, C30/37<br>Reinforcement: 27 kg/m³<br>Beam: IPE 500, S355 |  |
| | Composite columns | HEB 180, S355<br>Column grid: 5.4 m x 12.7 m | |

– In order not to distort the results due to different foundations, which depends mostly on the existing soil conditions, the base plate as a supporting structure (thickness 40 cm) was assumed to be the same for all designs. (Concrete C20/25)

Technical building data:

– Dimensions: 32.40 x 13.70 m
– Floor height: 3.50 m
– Floor area: 448 m²
– Grid: 5.40 m x 5.50 m linear grid for different office areas

Structures:

The structural analyses for the five building structures were optimized in view of respective type of building. To make the objects comparable, the following design loads were defined for the structures:

– Life load: p = 5.0 kN/m²
– Expansion load: g = 1.5 kN/m²

The steel-composite and concrete structures are designed for the above mentioned loads. Structural fire protection is provided by plasterboards and concrete cover. *Table 2* shows the dimensions for the slabs and columns of the different structural systems.

## 3 LCA RESULTS

*Fig. 1 a)* shows the masses of the materials used for the five different structural systems (slabs and columns) for one floor (448 m²) per m² gross floor area. The concrete clearly dominates and governs for more than 90 % of the masses. At the same, it can be observed that the steel-composite solutions have an average weight of about 500 kg/m² contrary to the concrete variant with 700 kg/m². *Fig. 1 b)* represents the associated primary energy demand (non-renewable). It is striking that, compared to the ratio of the masses, steel has a bigger influence on the primary energy demand (reinforcing steel as well as structural steel and steel sheets). Nevertheless, the steel-intensive solutions still show an overall lower primary energy demand than the concrete construction (not least because of the quantity of the reinforcing steel).

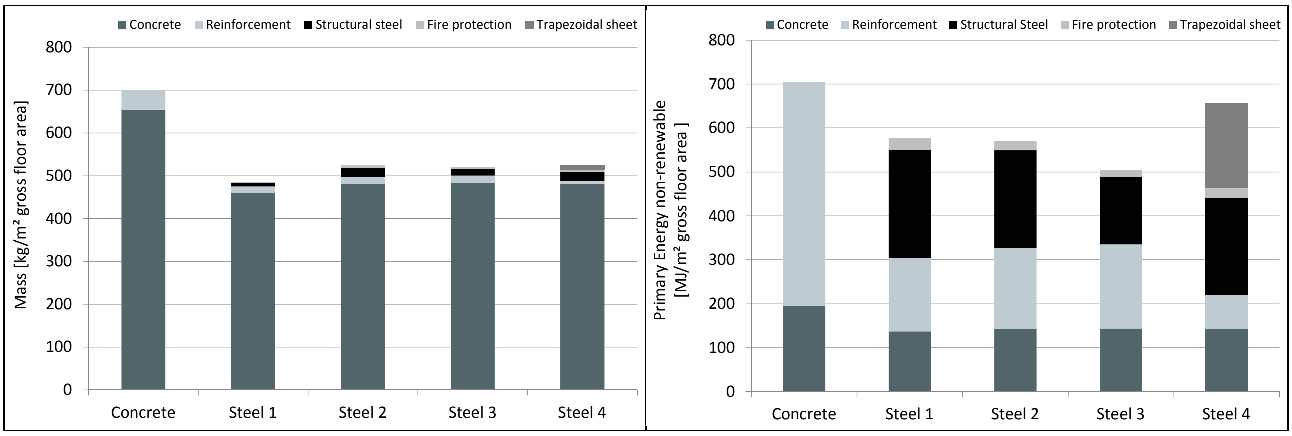



*Fig. 1.* Masses *a)* and Primary Energy demand (non-renewable) b) per m² gross floor area of 1 floor (only slabs and columns) divided by materials

*Fig. 2* shows the primary energy demand (non-renewable) of the five different structural systems (slabs and columns) for one floor (448 m²) per m² gross floor area divided by the different life cycle stages: the product stage (modules A1-A3) , the end of life stage plus benefits from recycling (modules C3, C4 & D) and the sum of these two values. It can be observed that benefits for the steel-intensive solutions are higher than these for the concrete variant. Without the credits from recycling the option “Steel 4” had the highest energy demand of all constructions. The fact that reinforcing steel does not get any benefit for recycling at the end of life (because it is made of steel scrap in the electric furnace route) leads to the highest primary energy demand of the concrete solution during the whole life cycle.

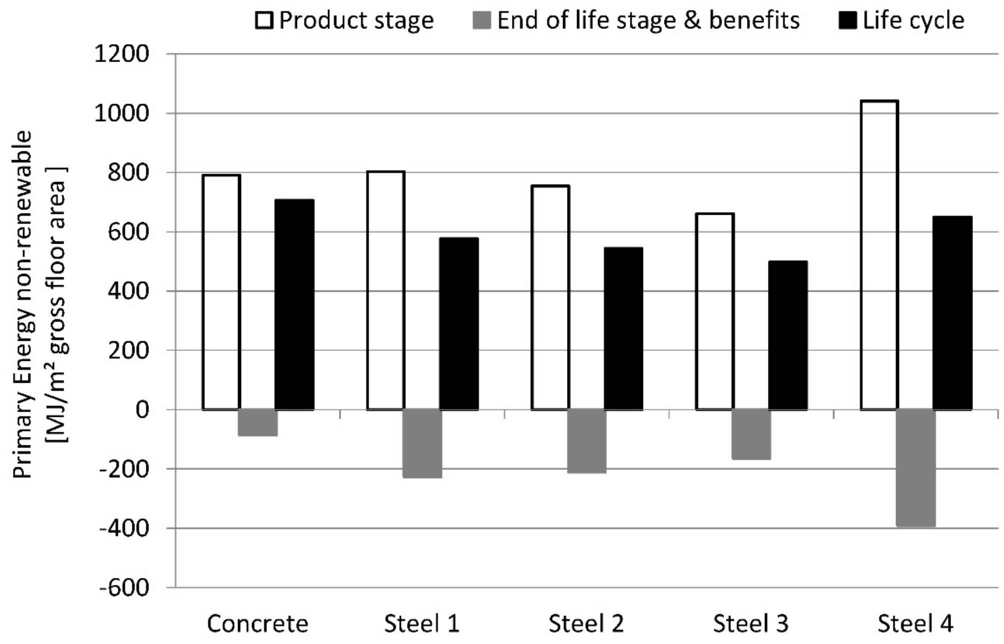



*Fig. 2.* Primary Energy demand (non-renewable) per m² gross floor area of 1 floor (only slabs and columns) divided by life cycle stages

*Fig. 3 left* shows the masses of the components for the whole building per m² gross floor area. The slabs clearly dominate and are responsible for about 70 % of the masses. At the same, it can be observed that the steel-composite solutions have an average weight of about 700 kg/m² in contrast to the concrete variant with 900 kg/m². *Fig. 3 right* shows the associated primary energy demand (non-renewable). It is apparent that, compared to the ratio of the masses, the façade has a quite big influence on the primary energy demand of the building. Thus, on the whole, the differences between the various structural systems reduce and the variants tend to the same level.

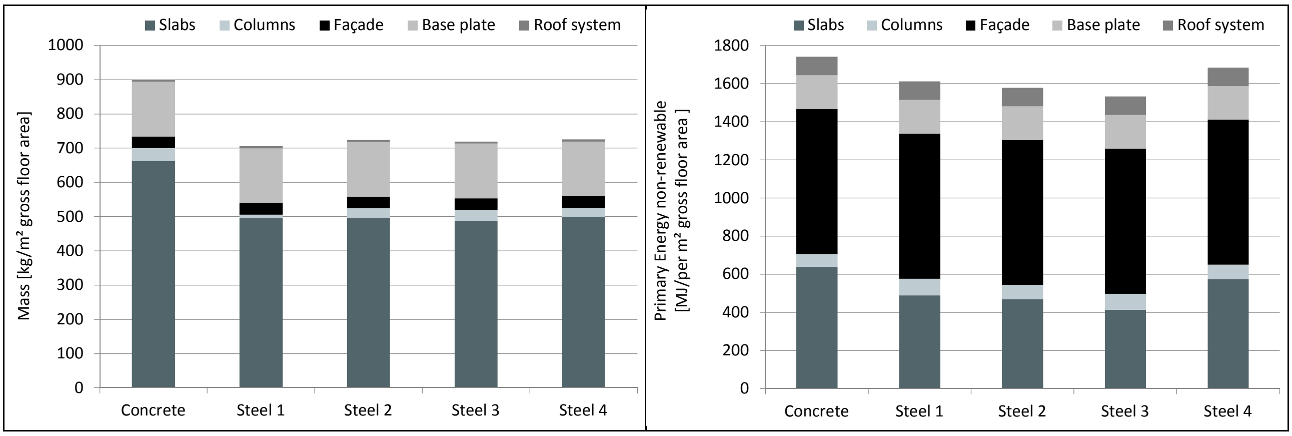



*Fig. 3.* Masses (left) and Primary Energy demand (non-renewable) (right) per m² gross floor area of the whole building (Slabs, Colums, Façade, Baseplate, Roofsystem) divided by building components

## 4 SUMMARY AND OUTLOOK

This paper deals with the comparison of the environmental impact of different structural systems for office buildings. It shows first results of a study that includes additionally calculations of the primary energy demand for different usage scenarios of office buildings. From the performed calculations it can be observed that mass portions of an office building are not automatically indicative of the associating primary energy demand.

For the future, it is important to continue expanding the data base for environmental performance of construction products. Data for more building products must be captured and provided by the manufacturers (e.g. through the wider dissemination of EPDs). In addition, more values for construction processes, maintenance and cleaning as well as end-of-life scenarios must be determined to improve the integrated approach. Engineers need decision guidance and best practice examples for environmental performance oriented structural design. This simplified approach for the impact on life cycle assessment of office buildings should be a preview on future investigations.

## REFERENCES


[1] http://www.dgnb-system.de/en/

[2] EN15978. 2011. *Sustainability of construction works - Assessment of environmental performance of build-ings - Calculation method*, European Committee for Standardization.

[3] EN15804. 2011. *Sustainability of construction works - Environmental product declarations - Product category rules*, European Committee for Standardization.

[4] Ökobau.dat 2013. *www.nachhaltigesbauen.de*. German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html

[5] EPD-BFS-20130094-IBG1 2013. *Environmental Product Declaration - Structural Steel: Sections and Plates, Institute for Construction and Environment*. Berlin: Institut Bauen und Umwelt.

[6] EPD-IZB-2013411. *Environmental Product Declaration – Concrete C 20/25, Institute for Construction and Environment*. Berlin: Institut Bauen und Umwelt.

[7] EPD-IZB-2013431. *Environmental Product Declaration – Concrete C 30/37, Institute for Construction and Environment*. Berlin: Institut Bauen und Umwelt.

[8] EPD-IFBS-2013211 *Environmental Product Declaration – Trapezoidal steel profile, Institute for Construction and Environment*. Berlin: Institut Bauen und Umwelt.

[9] EPD Gypsum products. *Environmental Product Declaration – Gypsum fire protection boards, Institute for Construction and Environment*.2009. http://www.gips.de

[10] M-EPD-SFA-000003, *Environmental Product Declaration – Steel-/Stainless Steel façades*. Rosenheim: ift Rosenheim GmbH.

[11] EPD-DRW-2012131 *Environmental Product Declaration – Mineral wool high density*. Berlin: Institut Bauen und Umwelt.

[12] EPD-FPX-2010111 *Environmental Product Declaration* – XPS, *extruded polystyrene foam, Institute for Construction and Environment*. Berlin: Institut Bauen und Umwelt.

# ECOLOGICAL EFFICIENCY OF OFFICE BUILDINGS

Raban Siebers[a], Bernhard Hauke[a], Dominik Pyschny[b], Markus Feldmann[b], Markus Kuhnhenne[c]

[a]bauforumstahl e.V, Düsseldorf, Germany, Raban.Siebers@bauforumstahl.de, Bernhard.Hauke@bauforumstahl.de
[b]RWTH Aachen University, Institute of Steel Construction, Aachen, Germany, dpy@stb.rwth-aachen.de
[c] AAINA GmbH, Institute for Sustainable Construction, Aachen, Germany, mku@aaina.eu

**KEYWORDS:** Sustainability, Life Cycle Assessment, Office Buildings, Steel Composite Construction.

## ABSTRACT

With the introduction of Green Building Labels such as “Leadership in Energy and Environmental Design” (LEED) and even more with the second generation of Sustainable Building Labels such as the German ”Deutsches Gütesiegel Nachhaltiges Bauen” (DGNB) [1] Life Cycle Assessment (LCA) has become an integral part of the sustainability assessment of buildings. A substantiated assessment and choice of construction products during the planning phase is one of the main tasks for sustainable construction and management of buildings, which engineers and architects are confronted with.

In order to gain knowledge about the environmental impacts of different types of structural systems for office buildings, five different construction methods are considered in this study: four steel-composite and one reinforced concrete structure as reference case. Since a comparison of the environmental performance of different structural types is only useful and meaningful within the building context, all types follow the same basics for functionality and dimensions.

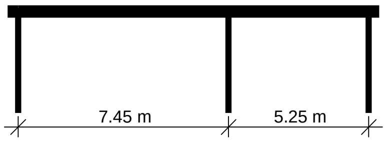
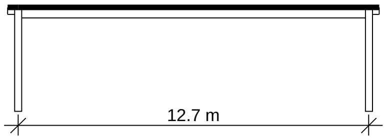
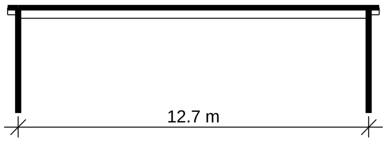
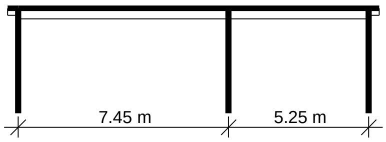
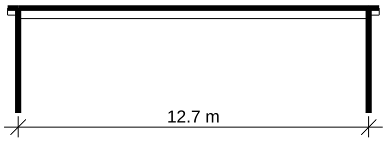
The investigations follow the module-based life-cycle description from standard EN 15978 [2]. The steel-composite structures and the reinforced concrete structure are based on identical functional and structural conditions:

- High user flexibility: The frequently reoccurring grid dimension in interior completion 5.40 m x 5.50 m is included. Thus several different floor plans including single, combination and open-plan offices are possible at low effort.
- The building is a skeleton construction. Structural elements such as columns and walls are kept to a minimum, and a contorted building geometry is avoided.
- The lateral stability of the building is provided by a bracing core that is not considered in this study.
- The structural components are provided solely within the grid. Thus disturbing structural elements in the floor plan are avoided.
- The width of 13.7 m allows for a natural lighting and provides good conditions for office use.
- Six full floors for office use are considered.
- For the investigations here a curtain wall façade of steel and stainless steel with transparent and opaque filling was chosen.
- In order not to distort the results due to different foundations, which depends mostly on the existing soil conditions, the base plate as a supporting structure (thickness 40 cm) was assumed to be the same for all designs. (Concrete C20/25)

Technical building data:

- Dimensions: 32.40 x 13.70 m
- Floor height: 3.50 m
- Floor area: 448 m²
- Grid: 5.40 m x 5.50 m linear grid for different office areas

*Table 1.* Dimensions of slabs and columns

| Option | Structure | | Sketch |
|---|---|---|---|
| Concrete | Reinforced concrete flat-slab | Thickness: 0.27 m, C30/37<br>Reinforcement: 150 kg/m³ |  |
| | Reinforced concrete columns: | Edge columns: Ø 0.3 m, C30/37<br>Central columns: Ø 0.4 m, C30/37<br>Reinforcement: 350 kg/m³<br>Column grid: 5.40 m x 7.45 m | |
| Steel 1 | RC slab<br>Composite beam | Thickness: 0.20 m , C30/37<br>Reinforcement: 75 kg/m³<br>Beam: IPE 500, S355 |  |
| | Steel columns | HEB 200, S355<br>Column grid: 5.40 m x 12.7 m | |
| Steel 2 | RC slab<br>Composite beam | Thickness: 0.20 m Reinforcement: 75 kg/m³<br>Beam: IPE 500, S355 |  |
| | Composite columns | HEB 180, S355<br>Column grid: 5.4 m x 12,7 m | |
| Steel 3 | RC slab<br>Composite beam | Thickness: 0.20 m, C30/37<br>Reinforcement: 75 kg/m³<br>Beam: IPE 360, S355 |  |
| | Composite columns | Edge columns: HEB 120, S355<br>Central columns: HEB 180, S355<br>Column grid: 5.40 m x 7.45 m | |
| Steel 4 | Composite slab<br>Composite beam | Trapezoidal sheet: 135/310<br>Thickness: 0.20 m, C30/37<br>Reinforcement: 27 kg/m³<br>Beam: IPE 500, S355 |  |
| | Composite columns | HEB 180, S355<br>Column grid: 5.4 m x 12.7 m | |

## CONCLUSIONS

From the performed calculations it can be observed that mass portions of an office building are not automatically indicative of the associating primary energy demand.

For the future, it is important to continue expanding the data base for environmental performance of construction products. Data for more building products must be captured and provided by the manufacturers (e.g. through the wider dissemination of EPDs). In addition, more values for construction processes, maintenance and cleaning as well as end-of-life scenarios must be determined to improve the integrated approach. Engineers need decision guidance and best practice examples for environmental performance oriented structural design. This simplified approach for the impact on life cycle assessment of office buildings should be a preview on future investigations.

## REFERENCES


[1] http://www.dgnb-system.de/en/

[2] EN15978. 2011. *Sustainability of construction works - Assessment of environmental performance of build-ings - Calculation method*, European Committee for Standardization.