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Towards development of a label for Zero Emission Buildings: A Tool to evaluate potential Zero Emission Buildings

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Abstract: There are many concepts and labels developed with the aim to promote sustainable building. However, most of these address mainly energy aspects and do not consider the entire environmental impact of a building construction. In contrast, the concept of Zero Emission Buildings (ZEB) integrates energy and material (biomass, water) flows, resulting in buildings, which do not produce harmful emissions and on the contrary produce energy, water and resources. It envisions maximum decentralization of a building implying closed resource cycles and hence no environmental impact during its operational use. However, the concept of ZEB lacks a general framework under which potential buildings can be easily assessed. Consequently, the ZEB Assessment Tool was developed in order to easily evaluate potential ZEBs regarding their environmental performance. The ZEB Assessment Tool was developed by considering specific decision parameters and appointing an appropriate characteristic to them. These decision parameters were (i) Pre-Assessment, (ii) System boundary, (iii) Quantification of environmental impact, (iv) Database, (v) Quantification of qualitative aspects, and (vi) Calculation of target value. The evaluation of several case studies from Switzerland with the ZEB Assessment Method showed that the tool is well adapted to the requirements of the ZEB Concept. Firstly, it requires a small amount of input data, which enables a simple primary assessment of a specific building. Secondly, it has the advantage that it evaluates a wide range of factors regarding the building's environmental performance. These are energy, water, biomass and a set of qualitative aspects. Furthermore, it takes into account various environmental impacts and can be applied for buildings with different type of use and in different countries of location.

Keywords: Zero Emission Buildings; evaluation tool; case studies; Switzerland; South Korea; decentralized technologies

1. Introduction

There are many concepts and labels developed with the aim to promote sustainable building. However, most of these concepts address mainly the factor energy and do not consider the entire environmental impact of a building construction. In contrast, the concept of Zero Emission Buildings (ZEB) integrates energy and material (biomass, water) flows, resulting in buildings, which do not produce harmful emissions and on the contrary produce energy, water and resources. It envisions maximum decentralisation of a building implying closed resource cycles and hence no environmental impact during its operational use (Schuetze et al, 2013).

However, the concept of ZEB lacks a general framework under which potential buildings can be assessed. To date there is no tool, which allows an evaluation of the three sectors Energy, Water and Biomass of the ZEB concept. Most evaluationn tools for the issue of an EPC such as GEAK in Switzerland (GEAK, 2013) or the EPC in Germany (DENA, 2013) address solely the energy aspect. The aim was to develop a «ZEB Assessment Method» so that existing buildings could be evaluated under the concept of ZEB.

2. Methods

2.1 Requirements and considerations

The development of a tool to evaluate potential Zero Emission Buildings had to be well adapted to the requirements of the ZEB concept. These requirements are: suitable for the evaluation of existing buildings (→ find case studies), assessment of the three Sectors Energy, Biomass, Water and qualitative aspects, applicable to different countries of location (partner countries) and the incorporation of various environmental impacts. For the development of the ZEB Assessment Tool, six specific **decision parameters** (Pre-Assessment, System boundary, Quantification of environmental impact, Database, Qualitative aspects, Calculation of target value) were compiled in order to be specified in a further step (Figure 1).

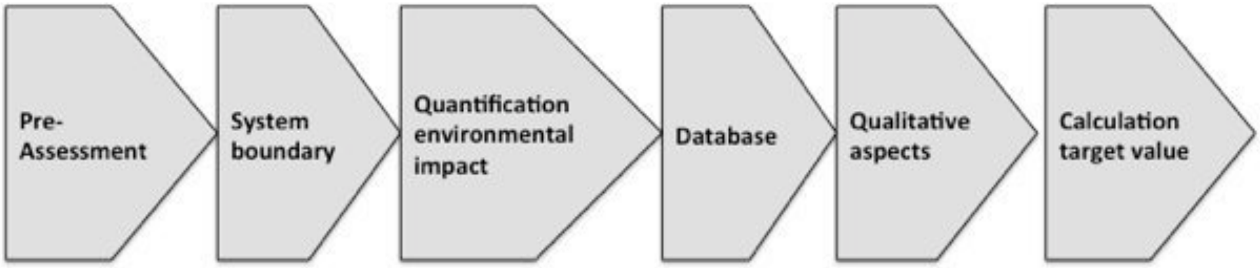


Figure 1: Decision parameters for the development of the ZEB Assessment Tool

Each decision parameter demanded different requirements based on the requirements of the ZEB concept. The considerations for the decision parameters, in order to appoint an appropriate characteristic to them, are listed in Table 1.

Table 1: Considerations of decision parameters for the development of the ZEB Assessment Tool

Decision Parameter	**Considerations**
Pre-Assessment	How can a pre-assessment be easily conducted in order to determine if the building is eligible for a further examination with the tool? What method can be applied to ensure the building address the three sectors to a minimum level?
System boundary	What processes should be considered? Which processes have an environmental impact?
Quantification of environmental impact	How and with what method can the environmental impact be quantified? Which method fulfils the requirements of the ZEB concept?
Database	Which databases can be used to look up the values for the relevant flows?
Qualitative aspects	How can qualitative aspects be assessed in a quantitative way? Which criteria should be considered? How can sensible benchmarks be established?
Calculation of target value	How can consideration be given to different building purposes and corresponding variation of resource consumption? How should the target value be calculated and expressed?

2.2 Development of ZEB Assessment Tool

The Microsoft Excel-based tool was developed by considering the six specific decision parameters (Table 1), and appointing an appropriate characteristic to them. The resulting characteristics of the ZEB Assessment Tool are describes as follows.

2.2.1 Pre-Assessment: Eligible technologies

The Pre-Assessment evaluates whether a building fulfils the minimum requirements of the ZEB concept and is thus eligible for the further assessment as a potential ZEB. A simple questionnaire evaluates whether the building addresses sufficiently the three sectors Water, Energy and Biomass. For each sector a list of so-called "eligible technologies", which target efficient use of resources and energy, was compiled (Table 2). A building received a "*fulfilled*" for one sector if it implemented at least two of the eligible processes/ technologies of the corresponding sector. As a next requirement of the Pre-Assessment, the building had to fulfil at least two of the named sectors. If a building passed the Pre-Assessment it was further investigated with the ZEB Assessment Tool in order to quantify and benchmark the environmental performance. The Pre-Assessment ensures the integrity of the concept up to a certain level. For instance, if a building solely implemented water saving devices, it would be inappropriate to state that the building addresses appropriately the aspect of water within the ZEB concept.

Table 2: Eligible technologies for the assessment of the three sectors of the Zero Emission Building (ZEB) Concept. At least two sectors with at least two technologies each ought to be implemented in a building in order to qualify for further evaluation.

Sector	**Eligible technologies**
Water	Rainwater harvesting, water saving devices, decentralized wastewater treatment, water re-use, urine separation
Energy	Photovoltaic, solar thermal collectors, wind turbine, geothermal energy, highly insulated envelope, heat recovery, use of waste heat, passive energy use
Biomass	Composting of organic waste, composting of faeces, vermicomposting, nutrients recovery from urine, production of fertile soil, biochar production, food production on site (soil based or soilless, such as hydroponic, aquaponics), biomass production on site

2.2.2. System boundary: Site boundary

The system boundary is an essential aspect regarding the analysis of the resource consumption of specific buildings. To take the site boundary as system boundary provoked that solely flows into and out of the site were considered. In addition, only flows that are conveyed by human activity such as grid electricity and fresh water supply were taken into consideration. In doing so, on-site resource management, such as renewable energy generation, e.g. with photovoltaic, or the use of rainwater, while being considered for the Sector Assessment, were not further quantified since they do not have an environmental impact during their operation. The relevant energy and resource flows in the sector energy and water are Grid electricity consumption (*Grid electricity*), Consumption of external energy sources (*External energy*), Consumption of freshwater from central supply facility (*Freshwater*) , and Discharge of wastewater into central treatment plant (*Wastewater*). The notation provided in brackets will hereinafter be used when referring to the energy or resource flow.

A visualisation of the system boundary and the relevant energy and resource flows is shown in Figure 2.

The sector Biomass has fundamentally different characteristics from the sectors Energy and Water and therefore could not be described using the concept of the above resource flows. The considerations in order to assess the sector Biomass are described under point 2.2.3.

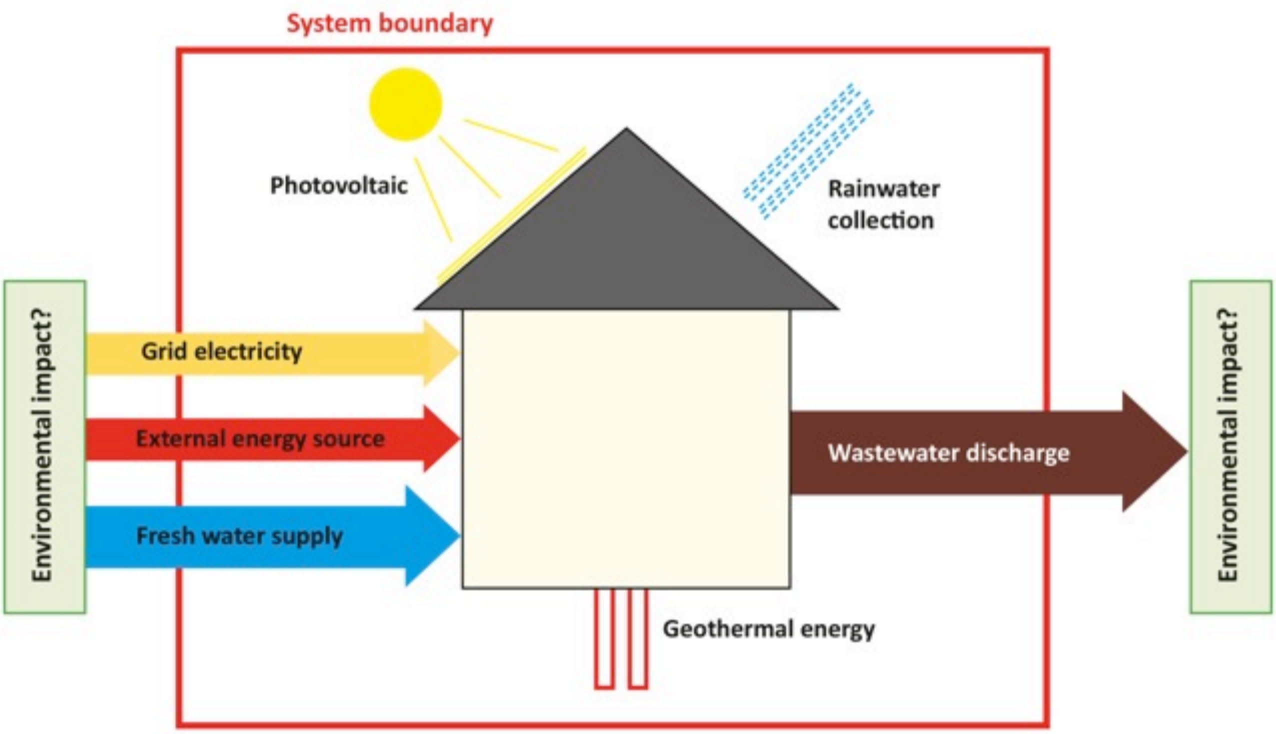


Figure 2: System boundary and relevant flows for the ZEB Assessment Tool. Only resource and energy flows into and out of the system boundary and that are conveyed by human activity are taken into consideration.

2.2.3. Quantification of environmental impact: Ecological Scarcity

The environmental impact of the previously described relevant energy and resource flows had to be quantified in a measurable unit. The so-called "ecological scarcity method" has the advantage that it incorporates multiple environmental impacts and takes into account different countries of location. In contrast to using the global warming potential as a method, aspects such as water scarcity would be neglected. In detail, the ecological scarcity method (Frischknecht et al., 2009) covers the following environmental impacts: Emissions to air, surface waters, groundwater, and soil, consumption of resources, and production of wastes.

The ecological scarcity is a "distance to target" based method. The environmental impacts, as listed above, are weighted with "eco-factors". The eco-factors are derived from environmental laws or political targets. The output is expressed in "Umweltbelastungspunkte" (UBP) (also known as Eco-points) per unit of pollutant emission or resource extraction (Frischknecht et al., 2009). The calculation of an eco-factor is based on the three steps: Characterisation, Normalisation and Weighting. The step of weighting is based on the corresponding political targets that define a critical annual flow in the reference area. Frischknecht et al. (2009) defined the calculation for the eco-factor for every environmental impact as follows:

$$Eco\text{-}factor = K \cdot \frac{1 \cdot EP}{F_n} \cdot \left(\frac{F}{F_k}\right)^2 \cdot c \tag{1}$$

In Eq. (1) K denotes Charaterization factor of a pollutant or of a resource, F_n Normalization flow (current annual flow, with Switzerland as system boundary), F is Current annual flow in the reference area), F_k denotes Critical annual flow in the reference area, c is constant (10^{12}/a). The unit of assessed result is expressed in Eco-points (EP) (Frischknecht et al., 2009).

The UBPs for all environmental impacts of a specific resource flow are summed up resulting in a total number of UBP. This number of UBP was used for the ZEB Assessment Tool to quantify the environmental impact of the relevant resource flows as described under point 2.2.2. In practice, the number of UBP refers to the environmental impact that the considered flow causes. Thus if a building has a high number of UBP, it can be derived that it has a higher environmental impact than a building with a lower UBP value. Conclusively, a building with zero UBP is a true ZEB.

2.2.4. Database: KBOB, Ecoinvent Database, own calculations

The required UBP values for the ZEB Assessment Tool were taken from different databases. The "Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren" (KBOB) is an organisation that makes recommendations for sustainable building and published specialised life cycle assessment data for the building industry in the so-called KBOB-List (Bächtold et al., 2012). The available datasets in the KBOB-list were used for the ZEB Assessment Tool. The remaining datasets were taken from the Ecoinvent Version 3 Database, which is one of the most comprehensive international databases for Life Cycle Inventory data (Ecoinvent, 2013). Due to its comprehensiveness, Ecoinvent could provide most of the remaining datasets for the tool.

The implemented datasets for the sector Water and Energy are listed in Table 3 and Table 4 respectively. The evaluation of the sector Biomass necessitated a different approach than the sectors Water and Energy. The input of biomass into the system occurs in the form of food, faeces or urine. It is difficult if not impossible to determine what environmental impacts these inputs have. For example, it is difficult to determine the UBP value for one kilogram faeces if it is unclear where the food came from and where the faeces is disposed. Even if it were possible to calculate a UBP value, the input of faeces could not be avoided like for instance grid electricity consumption. The solution was not to calculate the UBP value for the input but to calculate how much UBP could be avoided if a specific process was applied. For example, if nutrients were recovered from urine, this would avoid the need for a specific amount of fertiliser bought on the market. The UBP value for fertiliser could easily be looked up in the Ecoinvent database. All the datasets and calculations for the sector biomass are described in Table 5. The input of biomass depends on the number of persons. The values for the biomass flows are also listed in Table 5.

Table 3: Data sources for the sector water in the ZEB Assessment Tool

Parameter	Value	Source	Dataset / Calculation
Freshwater	**UBP/m^3**		
Switzerland	362.9	Calculation	Eco-factor for freshwater CH: 22 UBP/m^3 (Frischknecht et al., 2009) Distribution of water: 338 UBP/m^3 (Stucki, 2013, based on Ecoinvent: *Tap water, at user/RER U**) Losses through distribution: 1.13 m^3/m^3 (Stucki, 2013, based on Ecoinvent: *Tap water, at user/RER U*) 22 * 1.13 + 338 = 362.9 UBP/m^3
Germany	1366.3	Calculation	Eco-factor for freshwater D: 910 UBP/m^3 (Frischknecht et al., 2009) Distribution of water: 338 UBP/m^3 (Stucki, 2013, based on Ecoinvent: *Tap water, at user/RER U*) Losses through distribution: 1.13 m^3/m^3 (Stucki, 2013, based on Ecoinvent: *Tap water, at user/RER U*) 910 * 1.13 + 338 = 1366.3 UBP/m^3
South-Korea	484.9	Calculation	Eco-factor for freshwater KR: 130 UBP/m^3 (Frischknecht et al., 2009) Distribution of water: 338 UBP/m^3 (Stucki, 2013, based on Ecoinvent: *Tap water, at user/RER U*) Losses through distribution: 1.13 m^3/m^3 (Stucki, 2013, based on Ecoinvent: *Tap water, at user/RER U*) 130 * 1.13 + 338 = 484.9 UBP/m^3
Turkey	677	Calculation	Eco-factor for freshwater TR: 300 UBP/m^3 (Frischknecht et al., 2009) Distribution of water: 338 UBP/m^3 (Stucki, 2013, based on Ecoinvent: *Tap water, at user/RER U*) Losses through distribution: 1.13 m^3/m^3 (Stucki, 2013, based on Ecoinvent: *Tap water, at user/RER U*) 300 * 1.13 + 338 = 677 UBP/m^3
Wastewater	**UBP/m^3**		
Switzerland	4077.2	Ecoinvent	*treatment of wastewater, average, capacity 5E9l/year, CH, (Author: Roland Hischier active)*
Germany	4158.2	Ecoinvent	*treatment of wastewater, average, capacity 5E9l/year, RoW, (Author: [System] inactive)*
South-Korea	4158.2	Ecoinvent	*treatment of wastewater, average, capacity 5E9l/year, RoW, (Author: [System] inactive)*
Turkey	4158.2	Ecoinvent	*treatment of wastewater, average, capacity 5E9l/year, RoW, (Author: [System] inactive)*

* The notations in italics stand for the full name of the dataset in the corresponding database (Ecoinvent or KBOB). The Ecoinvent data can be found on www.ecoquery.ecoinvent.org → Login → Database Search → Allocation, Ecoinvent default → *Search for dataset* → LCIA → ecological scarcity 2006 → total UBP

Table 4: Data sources for the sector Energy in the ZEB Assessment Tool

Parameter	Value	Source	Dataset / Calculation
Grid electricity	**UBP/kWh**		
CH Grid electricity	412.68	Ecoinvent	*market for electricity, low voltage, CH, (Author: Karin Treyer active)**
CH Label-certified electricity	50.618	Ecoinvent	*market for electricity, low voltage, label-certified, CH, (Author: Karin Treyer active)*
DE Grid electricity	685.14	Ecoinvent	*market for electricity, low voltage, DE, (Author: Karin Treyer active)*
DE Label-certified electricity	50.618	Ecoinvent	*market for electricity, low voltage, label-certified, CH, (Author: Karin Treyer active)*
KR Grid electricity	626.28	Ecoinvent	*market for electricity, low voltage, KR, (Author: Karin Treyer active)*
TR Grid electricity	1592.7	Ecoinvent	*market for electricity, low voltage, TR, (Author: Karin Treyer active)*
External Energy	**UBP/MJ**		
Heating oil	44.4	KBOB	*Energie – Brennstoffe – Heizöl EL, ID-Nummer: 41.001*
Natural gas	31.5	KBOB	*Energie – Brennstoffe – Erdgas, ID-Nummer: 41.002*
Fire wood, logs	27.6	KBOB	*Energie – Brennstoffe – Stückholz, ID-Nummer: 41.006*
Wood chips	27.1	KBOB	*Energie – Brennstoffe – Holzschnitzel, ID-Nummer: 41.007*
Pellets	27.8	KBOB	*Energie – Brennstoffe – Pellets, ID-Nummer: 41.008*
Biogas	30.4	KBOB	*Energie – Brennstoffe – Biogas, ID-Nummer: 41.009*
District heating	24.2	KBOB	*Energie –Fernwärme – Fernwärme mit Nutzung Kehrichtwärme, Durchn. Netze CH, ID-Nummer: 42.017*
Rape-seed oil	15.51	Simapro**	Calculation with Simapro (Stucki, 2013)

* The notations in italics stand for the full name of the dataset in the corresponding database (Ecoinvent or KBOB). The Ecoinvent data can be found on www.ecoquery.ecoinvent.org → Login → Database Search → Allocation, Ecoinvent default → *Search for dataset* → LCIA → ecological scarcity 2006 → total UBP

**Simapro is a specialised software to calculate Life Cycle Inventory data

Table 5: Data sources for the sector Biomass in the Zero Emission Assessment Tool

Parameter	Value	Source	Dataset / Calculation
Biomass flows:			
Urine per person (L/d)	1.4	(Larsen et al., 2009)	
Faeces per person (kg/d)	0.14	(Larsen et al., 2009)	
Organic kitchen waste per p. (kg/a)	150	(Bayerisches Landesamt für Umwelt, 2011)	
Biomass processes:			
Composting of faeces (avoided UBP/kg faeces)	12.8	Calculation	Ecoinvent (EI): *market for compost, GLO, (Author: [System] inactive)*: 51.261 UBP/kg portion dry matter of faeces: 0.25 (Encyclopaedia Britannica, 2013) 51.261 * 0.25 = 12.8 UBP/kg faeces
N recycling from urine for fertiliser (avoided UBP/L urine)	412.5	Calculation	EI: *market for nitrogen fertiliser, as N, GLO, (Author: [System] inactive)*: 10985 UBP/kg N concentration in urine: 9.2 kg/m^3 (Maurer, 2007) N concentration in fertiliser: Ø 24.5% (Reid, 2008) 10985 / 0.245 * 9.2 / 1000 = 412.5 UBP/L urine
P recycling from urine for fertiliser (avoided UBP/L urine)	23.8	Calculation	EI: *market for phosphate fertiliser, as P2O5, GLO, (Author: [System] inactive)*: 10131 UBP/kg P concentration in urine: 0.54 kg/m^3 (Maurer, 2007) P concentration in fertiliser: Ø 23 % (Reid, 2008) 10131 / 0.23 * 0.54 / 1000 = 23.8 UBP/L urine
Nutrients recovery of organic kitchen waste (avoided UBP/kg waste)	10.25	Calculation	EI: *market for compost, GLO, (Author: [System] inactive): 51.261 UBP/kg* portion dry matter of organic kitchen waste: 0.2 (Wellinger et al., 2006) 51.261 * 0.2 = 10.25 UBP/kg

2.2.5. Qualitative aspects: Additional Points

The ZEB Assessment Tool also provides "malus points" if important qualitative and superior aspects of a building construction were not taken into consideration. As currently no database exists for these aspects, a set of criteria was established based on inputs of experts of the corresponding field (Petra Hagen, pers. comm., Thorsten Schütze, pers comm.). The survey resulted in six criteria, all listed in Table 6.

The assessment of a criterion is based on the allocation of one of the three grades «*Fully applies*», «*Partially applies*» and «*Does not apply*». The benchmarks for the allocation of the grades were established using different methodologies. Criterion 1 *fully applies* if the connection to public transport is directly located at the site and accessible within no more than 10 minutes. The benchmark was set at 300 meters walking distance. The benchmark between "*Partially applies*" and "*Does not apply*" was set at one kilometer since this is still a reasonable distance for walking, however, many people might choose another means of transport. The benchmarks for criteria 2, 3 and 6 were established by choosing two possible options in order to fulfil the criterion. If both options were applied, the building received a "*Fully applies*", if only one option was implemented, the building was graded as "*Partially applies*". If none of the two options were implemented, the building was graded as "*Does not apply*". For criteria 4 and 5, the benchmark values were aligned with benchmark values in the literature such as Minergie (2013) or the references in Table 6.

Dependent on fulfilment of these criteria, additional points were added to the environmental performance of the object: Zero points for "*Fully applies*", 800 points for "*Partially applies"* and 1600 points for "*Does not apply"*. These values were established in relation to the values that examined buildings typically achieved after the assessment of the three sectors Energy, Water and Biomass. The average Rating Points per m^2 after the assessment of the sectors were around 9600. Consequently, the maximal value for additional Points was set to be 9600 if a building has a very bad performance. This value ensures that the qualitative aspects are weighted equitably with the quantitative aspects. All criteria and benchmarks are compiled in Table 6.

Table 6: Compilation of criteria for the evaluation of qualitative aspects

	Criteria	*Fully applies*	*Partially applies*	*Does not apply*
	Additional Points	**+ 0 Points**	**+ 800 Points**	**+ 1600 Points**
1	Good connection to public transport	Public traffic connection within 300 m	Public traffic connection within 1 km	Public traffic connection over 1 km
2	Integration of greenery into the building	Roof and façade greening	Roof or façade greening	No greening
3	Building construction is suitable for a potential change of use	Suitable location and building shape	Suitable location or building shape	None of both
4	Building is constructed of ecological materials, i.e. recycled materials or readily available primary raw materials (Caspar & Rütter-Fischbacher, 2010)	80 – 100 %	40 – 80 %	0 – 40 %
5	Grey energy of construction (per energy reference area, 60 years lifetime; according to bulletin SIA 2032 (Gugerli et al., 2008))	< 30 kWh/m^{2}a	30 – 60 kWh/m^{2}a	> 60 kWh/m^{2}a
6	Building design fits to the surrounding environment	Adapted shape and materials	Adapted shape or materials	None of both

2.2.6. Calculation of target value: Building types, benchmarks, degree of achievement

As a target value for the tool, is was chosen to calculate a degree of achievement based on the achieved Rating Points of the assessed building. The achieved number of Rating Points for the assessed object was calculated as follows:

$$Achieved\ Rating\ points = \frac{UBP_{Water} + UBP_{Energy} + UBP_{Biomass}}{Area} + Additional\ UBP \quad (2)$$

Subsequently, the degree of achievement was calculated:

$$Degree\ of\ achievement\ (\%) = 100 - \frac{100 * Achieved\ UBP}{Benchmark} \quad (3)$$

If a building achieved at least 80%, it was granted the «Zero Emission Building Label». To set this benchmark was a compromise with the actual objective of ZEB, which envisions zero environmental impact thus zero UBP. However, if this goal was applied, presumably no building would have reached the ZEB Label. The benchmark of 80% allowed for some environmental impact but still ensured an outstanding environmental performance.

In how far a specific building reaches a target value, largely depends on the building purpose since this significantly adds to the consumption of resources for the building's operation. Therefore the classification into building types with different allocated benchmarks was essential. The parameter *Benchmark* in equation (3) changes according to the building purpose. The different benchmarks were establishes as follows. In the first step, a basic benchmark was established based on experimental data from different buildings examined with the ZEB Assessment Tool. If these buildings would not incorporate any of the eligible technologies as listed in Table 2, then they would not qualify as ZEB and would have achieved less than 80% degree of achievement. Several such buildings obtained typically values around 100’000 Rating Points for zero degree of achievement. So the 100’000 value was taken as starting value. For the ZEB Assessment Tool, the energy consumption indicator of Minergie was converted into a general consumption index, which is proportionally in line with the energy consumption indicator of Minergie. The chosen classification corresponds to the classification of Minergie (2013). Minergie calculates for every building a weighted energy consumption indicator in matters of end energy. The indicator is expressed in kWh/m^2 and is a crucial benchmark for the Minergie label. The energy consumption indicator varies for the different types of buildings. Subsequently, the benchmark for each building type was calculated from the consumption index where Index 1 corresponds to 100’000 Rating Points. This benchmark value therefore corresponds to zero degree of achievement. The classifications of building types, the Minergie energy consumption indicators and the benchmarks for ZEBs are listed in Table 7.

Table 7: Classification of buildings with benchmarks based on the energy consumption indicator of Minergie. The benchmark value corresponds to zero degree of achievement for the particular type of building.

Building type	**Minergie energy consumption indicator (kWh/m^2)**	**Consumption Index**	**Benchmark (Rating Points)**
Industry Store	20	1	**100’000***
Sport installation	25	1.25	125’000
Apartment building Single-family Home	38	1.9	190’000
Administration Sales School Meeting venue Special construction	40	2	200’000
Restaurant/ Hotel	45	2.25	225’000
Hospital	70	3.5	350’000

* The 100'000 Rating Points benchmark represents the basic benchmark for the ZEB Assessment Tool. It was established based on experimental data of buildings examined with the ZEB Assessment Tool

3. Results and Discussion

3.1 ZEB Assessment Tool

The required input parameters for the assessment of a potential Zero Emission Building by using the ZEB Assessment Tool are listed in Table 8.

Table 8: Input parameters and units for the ZEB Assessment Tool. Units FA, PA and NA denote "*fully applies*", "*partially applies*", and "*does not apply*", respectively.

Input parameter	**Unit or Description**
Country	-
Building type	-
Total effective area of building	m^2
Average occupancy per day	Number of people
Freshwater*	m^3/a
Wastewater*	m^3/a
Grid electricity*	kWh/a
Electricity product	-
External energy*	MJ/a
Application of:	
- Composting of faeces	YES / NO
- N recycling from urine for fertilizer	YES / NO
- P recycling from urine for fertilizer	YES / NO
- Nutrients recovery of organic kitchen waste	YES / NO
- Good connection to public transport	FA / PA / NA
- Integration of greenery into the building	FA / PA / NA
- Construction is suitable for a potential change of use	FA / PA / NA
- Building is constructed of ecological materials	FA / PA / NA
- Grey energy of construction	FA / PA / NA
- Building design fits to the surrounding environment	FA / PA / NA

* Notation according to the definition in point *2.2.2 System boundary*

The implementation of the ZEB Assessment Tool in Microsoft Excel is illustrated in Figure 3 - 6. Figure 3 shows the Pre-Assessment where the implemented technologies can be selected from the list of eligible technologies. The Tool automatically evaluates if the building is eligible for a further assessment based on the defined conditions in point 2.2.1 Pre-Assessment.

Figure 4 shows the assessment of the three sectors Energy, Water and Biomass. The user has to select certain values from a box and fill in the required values for the resource and energy flows.

Figure 5 illustrates the evaluation of qualitative aspects. The user has to select in how far the correspondent criterion applies.

Figure 6 shows the output data of the tool and in how far the assessed building complies with the ZEB concept. The graphics illustrate in how far the parts of the assessment are responsible for the output in order to indicate the potential for further improvement of the building.

Figure 3: Pre-Assessment in the ZEB Assessment Tool

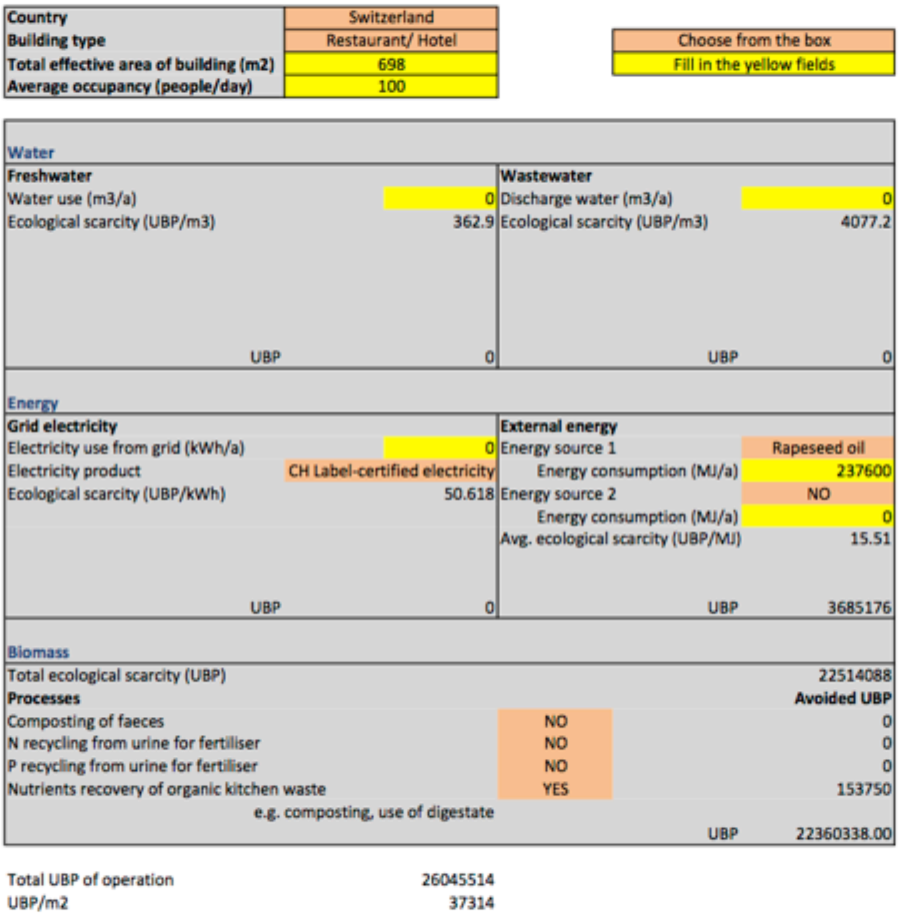


Figure 4: Assessment of the three sectors Water, Energy and Biomass in the ZEB Assessment Tool.

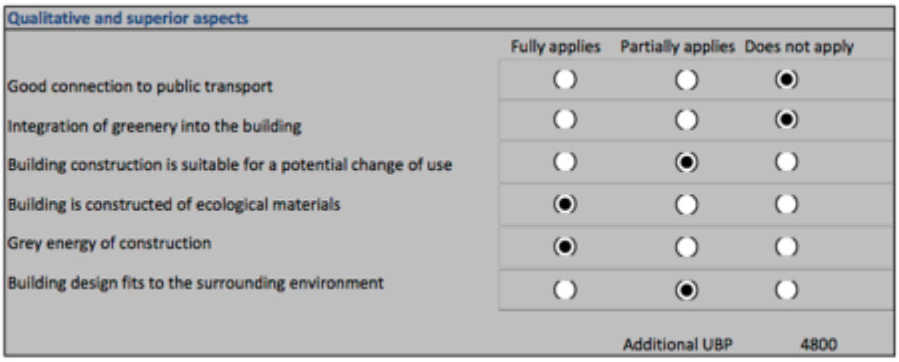


Figure 5: Assessment of qualitative aspects in the ZEB Assessment Tool

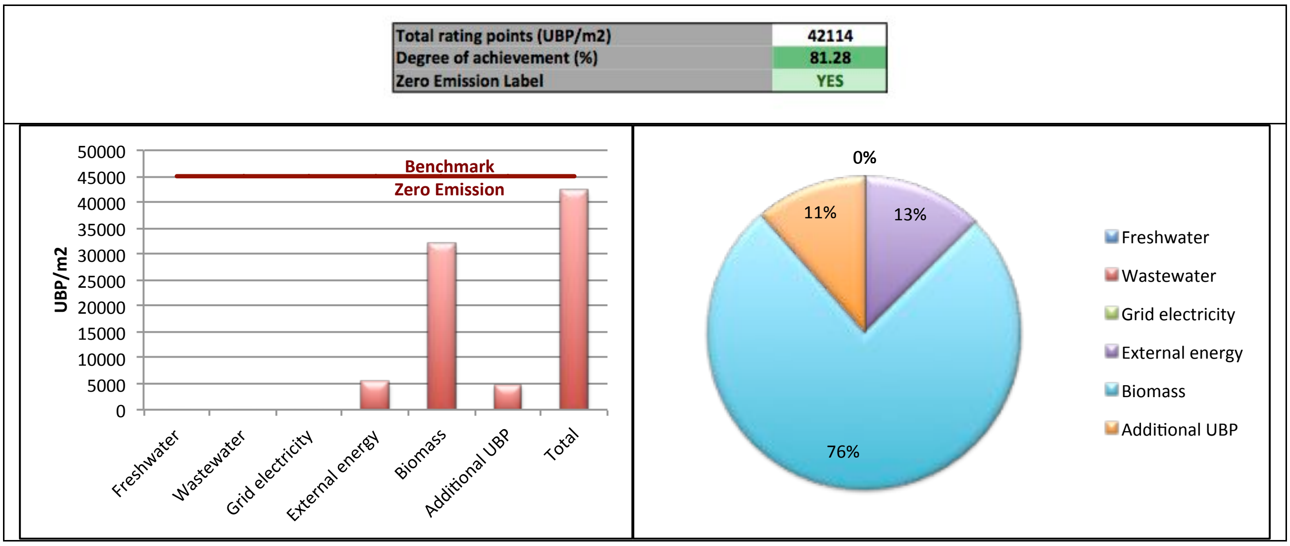


Figure 6: Output data of the ZEB Assessment Tool

3.2 Application of ZEB-Tool on Case Studies from Switzerland and South Korea

The ZEB Assessment Method was used to evaluate potential ZEBs in Switzerland and Korea.

Totally 17 buildings that were constructed under the consideration of sustainable building were assessed with the ZEB Assessment Tool (Table 9). Only 4 of these qualified for further evaluation after the Pre-Assessment. This because, they all considered only one sector, and the tool requires fulfilment of at least two sectors.

Table 9: Evaluation of some sustainable buildings in Switzerland. Fulfilled sectors are marked with x. The shaded buildings qualified for further evaluation with the ZEB Assessment Tool due to the integration of “eligible technologies” concerning energy and material flows

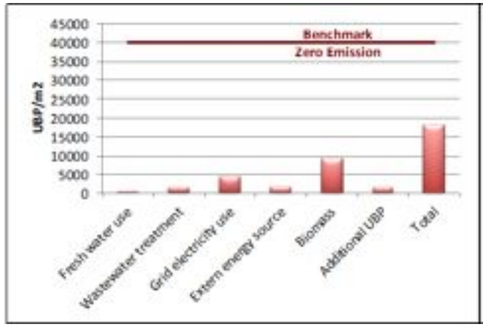
	Sector		
Building Name	**Energy**	**Water**	**Biomass**
Apartment building, Minergie-A-Eco, 9030 Abtwil	x		
Apartment building, Minergie-A-Eco, 3415 Rüegsauschachen	x		
Aquamin, single-family home, 4528 Zuchwil	x	x	x
Credit Suisse administration building, 8036 Zürich	x		
Forum Chriesbach, administration building Eawag, 8600 Dübendorf	x	x	x
Hotel Muottas Muragl, 7503 Samedan	x		
Kantonsbibliothek Liestal			x
Mountain station Hohtälli, Zermatt		x	
New Monte Rosa Hut, Hotel	x	x	
Schollglas AG Insulation factory, 3940 Steg	x		
Single-family home, Minergie-A-Eco, 3700 Spiez	x		
Single-family home, Minergie-A-Eco, 7530 Zernez	x		
Single-family home, Minergie-A-Eco, 3800 Matten b. Interlaken	x		
Single-family home, Minergie-A-Eco, 3204 Rosshäusern	x		
Single-family home, Minergie-A-Eco, 3186 Düngigen	x		
Solar-Restaurant Klein Matterhorn, 3920 Zermatt	x		
Umwelt Arena, Meeting venue, 8957 Spreitenbach	x	x	

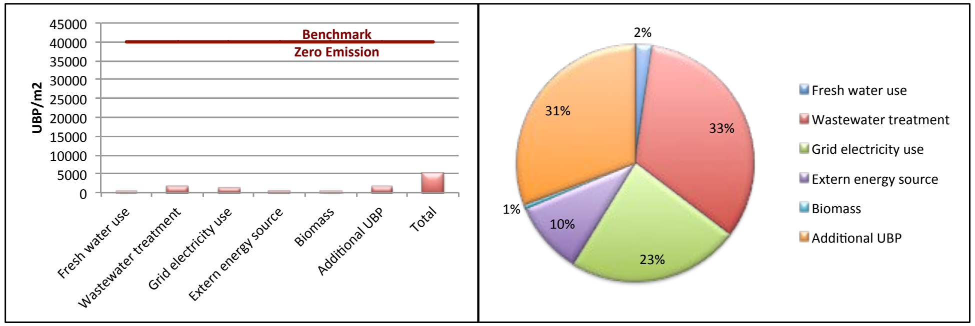
The examined buildings are listed in Table 10.

Table 10: Comparison of case studies which qualified for further evaluation with the ZEB Assessment Tool after the Pre-Assessment (see also Table 9)

Indicator	**Unit**	**Umwelt Arena**	**Forum Chriesbach**	**New Monte Rosa Hut**	**Aquamin Zuchwil**	**Kolon e+ Green Home**
Country	-	Switzerland	Switzerland	Switzerland	Switzerland	South-Korea
Building type	-	Meeting venue	Administration	Restaurant/ Hotel	Single-family Home	Single-family Home
Total effective area	m^2	10000	5012	698	251	295
Average occupancy per day	number of persons	400	240	100	4	4
Fresh water use from central supply facility	m^3/person	6	7	0	23	90
	m^3/m^2 area	0.25	0.33	0	0.36	1.21
Wastewater discharge into central treatment plant	m^3/person	9	9	0	0	100
	m^3/m^2 area	0.35	0.42	0	0	1.36
Electricity use from grid	kWh/person	2100	504	0	1000	133
	kWh/m^2 area	84	24	0	16	2
Electricity product	Type	CH-Label	CH-Label	-	CH - grid	KR-Grid
External energy demand excl. electricity	MJ/person	1440	450	2376	3177	0
	MJ/m^2 area	58	22	340	51	0
External Energy	Type	Biogas	District heating Natural Gas	Rapeseed oil	Pellets	-
Application of: - composting of faeces - N recycling from urine - P recycling from urine - composting of kitchen waste		 - NO - NO - NO - YES	 - NO - YES - YES - YES	 - NO - NO - NO - YES	 - YES - NO - YES - YES	 - NO - NO - NO - YES
Biomass: avoided UBP	UBP/person	223603	654	223603	210788	223603
	UBP/m^2 area	8944	31	32035	3359	3032
Qualitative aspects: - Public transport - Integration of greenery - Change of use possible - Use of ecological materials - Grey energy of construction - Design fits the surroundings	[FA = fully applies PA = partially applies NA = does not apply]	 - FA - PA - PA - FA - FA - NA	 - FA - PA - PA - FA - FA - PA	 - NA - NA - PA - FA - FA - PA	 - FA - NA - FA - PA - PA - PA	 - PA - FA - PA - FA - FA - PA

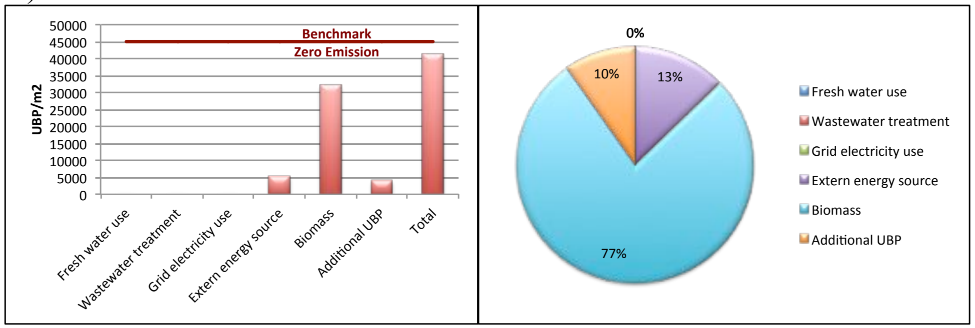
Additional Points	Points/person	4	7	40	800	400
	Points /m^2 area	0.16	0.32	5.73	12.75	5.42
Total Rating Points	Points/m2	19665	6021	42114	15473	12786
Degree of achievement	%	90.17	96.99	81.28	91.86	93.27
Zero Emission Label		YES	YES	YES	YES	YES

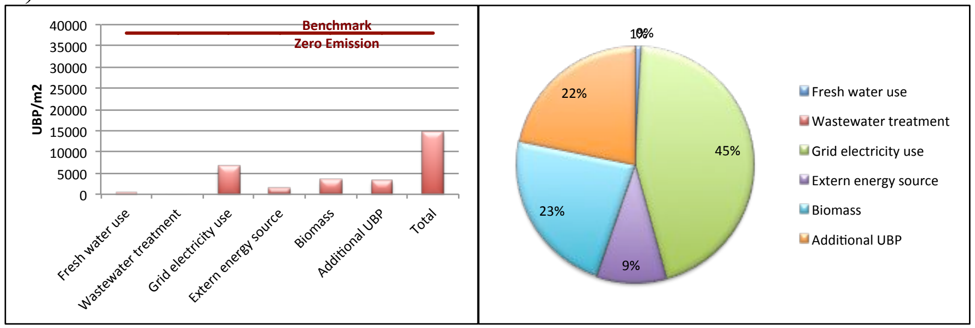




A) Umweltarena.

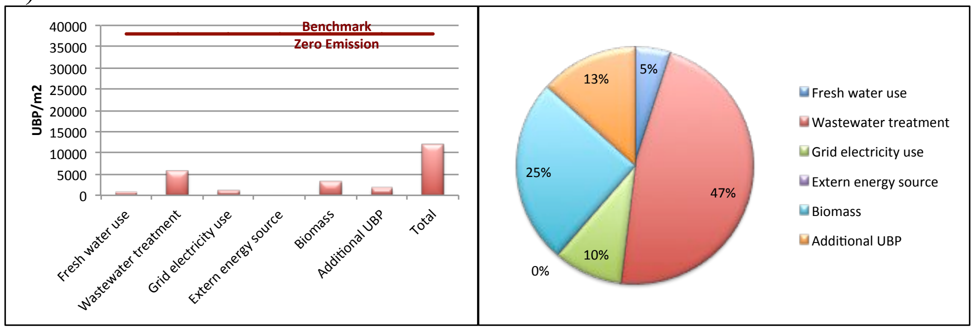
B) Forum Chriesbach





C) Monte Rosa Hut

D) Aquamin House



E) Kolon e+ Green Home

Figure 7: Output data from the Zero Emission Assessment Tool for the five examined buildings.

The comparison of the five buildings shows that Forum Chriesbach reaches the highest degree of achievement, which is therefore the best practice example of Zero Emission Buildings in Switzerland and in Korea. Its main strength is that it addresses all the three sectors of Energy, Water and Biomass to a significant degree. Especially the sector biomass is much further developed in comparison to the other case studies investigated in the framework of this thesis. However, the technologies applied for the resource management in the biomass sector are all still at pilot study level and not yet suitable for the broader application. This also shows the need for more research on such technologies in order to broaden the complete concept of ZEB. The Korean Kolon e+ Green Home achieves the lowest end energy demand per m^2 and person per year. It is the only case study that achieves energy autonomy on a yearly basis and does not use any external energy sources excluding electricity. In addition, the building has low electricity consumption per m^2 and person per year.

Nevertheless, from the table can be seen that each case study achieves minimum one best value for an indicator. Thus each case study demonstrates an outstanding performance in a specific area. The findings from these specific areas serve as valuable sources for the further development of ZEBs. The goal is to combine these insights in future ZEBs.

4. Conclusions

The evaluation of specific case studies with the ZEB Assessment Method showed that the method is well adapted to the requirements of the ZEB Concept. Firstly, the tool requires a small amount of input data, which enables a simple primary assessment of a specific building. Secondly, it incorporates qualitative aspects, which are a crucial factor of the ZEB Concept. In Switzerland there is an existing assessment tool from GEAK (2013) (Gebäudeenergieausweis der Kantone) called GEAK Light for the pre-evaluation of the issue of an EPC. Similar to the ZEB Assessment Tool, it enables a simple primary evaluation of an existing building in 30 minutes. However, GEAK Light solely covers the aspect of energy in order to improve the energetic performance of a building. The aspects of water, biomass and qualitative aspect are not covered at all. Furthermore, there is the German DGNB Label (DGNB, 2013), which also used tools for the assessment and certification of sustainable buildings under the Label. Its strong point is that the second-generation label addresses other factors beside energy, such as sociocultural quality, functional quality, economic quality or life cycle analysis. In addition, it incorporates an approach towards the aspect of water but it lacks the evaluation of the biomass sector. Moreover, DGNB assesses many criteria so that the process is elaborate and complex. Consequently, it is not appropriate for a basic initial assessment of case studies under the ZEB Concept. However, many of the approaches of DGNB would be interesting to integrate into the framework of ZEB regarding the construction and certification of future buildings. Similar to DGNB in Germany, in Switzerland the most common label is Minergie (2013). From the different Minergie certification standards, Minergie-A-Eco is probably closest to the ZEB Concept. “Minergie-A” certified buildings are “Minimum Energy Active” houses that, even more than passive houses, produce more energy than is required for their operation. “Minergie-Eco” stands for superior aspects such as use of ecological materials, grey energy or efficient use of tap water. These are a number of good approaches but other factors such as wastewater treatment or nutrient recovery are not covered in the Minergie-Eco certification system.

Beside the discussed aspects, most tools are adapted to a specific country. The transfer to other countries is usually a complex process. The ZEB Assessment Tool was designed with special attention to this given fact. UBP values vary for different countries and can be easily adjusted for every country. In addition, it allows a simple comparison of different buildings since it assess the overall performance of a building and not single technologies. Nevertheless, there are still some factors missing in the ZEB Assessment Tool. These are for instance economic quality or further qualitative aspects such as noise and light emissions. Also in terms of energy, only end energy consumption was considered. In fact, the primary energy consumption of a building is an important factor regarding energy efficiency and overall sustainability. But the calculation of the primary energy can be relatively complex and would have gone beyond the scope of this thesis. If more factors were integrated into the tool, it would have lost its advantage of simplicity and would have become more complex. All in all, the ZEB Assessment Tool is well suited to easily scan ZEB Case Studies but does not omit the opportunity to include aspects of future developments and societal insights

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Conflict of Interest

The authors declare no conflict of interest.

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