

A parametric method for building design optimization
based on Life Cycle Assessment

Appendix

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Table of content

A. Category indicators according to EN 15978	3
B. Normalization and weighting in DGNB	6
C. Environmental data of modified components for Concretecube	11
D. Detailed results for verification of embodied impact	14
E. Data for Example 1	30
F. Data for Example 2	33

A. Category indicators according to EN 15978

Many different environmental indicators can be found in the literature. The output-related indicators according to EN 15978:2012 which are employed in this thesis are described in the following:

Climate change

Greenhouse gases are gases which accumulate in the troposphere, about 10 km above the earth, and reflect the infrared radiation of the earth. The reflection causes the earth's surface to heat up and provides a moderate temperature (Klöpffer & Grahl 2014, p.235). There are a number of anthropogenic greenhouse gases which have been emitted into the atmosphere and cause an imbalance between incoming energy into the atmosphere (from the sun) and outgoing energy into space. The imbalance causes a rise of the average global temperature, which leads to melting of the polar caps, rise of the sea level, and expansion of deserts, amongst others (IPCC 2013, pp.136–137). The time the gases remain in the atmosphere has to be considered, which is why a time horizon is given for the categorization factor. The Intergovernmental Panel on Climate Change (IPCC) uses a baseline scenario of 100 years (IPCC 2007, p.212).

Indicator:	Global Warming Potential 100 years (GWP ₁₀₀)
Unit:	kg CO ₂ -equivalent
Main cause:	Incineration of fossil fuels (CO ₂), agriculture (CH ₄), industrial processes (CF ₄ , SF ₆ , N ₂ O)
Effects:	Rise of sea level, floods, expansion of deserts, crop failure

Stratospheric Ozone Depletion

The ozone layer is situated in the lower part of the stratosphere, at around 20 to 30 km above the earth's surface (Fahey & Hegglin 2010, p.Q4). The ozone absorbs about 99% of the sun's UV radiation, which is harmful to humans, animals, and plants. Halogenic molecules in the stratosphere destroy the ozone (Molina & Rowland 1974, p.810). This leads to a decline of ozone concentration in general, and to local phenomena called ozone holes. Two main groups of substances are responsible: chlorofluorocarbons (CFCs) and nitric oxides (NO_x) (König et al. 2009, p.46). A number of man-made substances emit these molecules, most commonly halocarbon refrigerants and foam-blowing agents.

Indicator:	Ozone Depletion Potential (ODP)
Unit:	kg R11-equivalent

Main cause: CFCs, HCFCs, NO_x

Effects: Skin cancer (humans and animals), crop failure

Acidification of soil and water

Acidification relates to an increased concentration of hydrogen ions (H⁺) in the air, water, and soil (JRC European commission 2010b, p.56). Anthropogenically-derived air pollutants like sulphur and nitrogen compounds react to acids, which fall to the ground as 'acid rain'. The pH level of soil and waters falls and causes a decline in the health of forests and kills fish. Other effects include the acidification of the oceans, which is also caused by natural absorption of CO₂ and leads to a decline in coral growth, for example. In addition, acid rain harms historical buildings made of natural stone.

Indicator: Acidification Potential (AP)

Unit: kg SO₂-equivalent

Main cause: Sulphur and nitrogen compounds from the burning of fossil fuels, volcanic ash, CO₂

Effects: Fish and tree mortality, decline of coral reefs

Eutrophication

Eutrophication describes the oversupply of nutrients in rivers, lakes, oceans, or soil (Klöppfer & Grahl 2014, p.261). The main cause is the addition of phosphate from detergents, fertilizers, or sewage, and nitrogen compounds from burning fossil fuels. The effects of aquatic eutrophication are, for example, algae growth and increased fish mortality. Terrestrial eutrophication decreases plants' resistance to diseases. Plants adapted to a low nutrient content are endangered because they are overgrown by more competitive species that can take advantage of higher nitrogen levels.

Indicator: Eutrophication Potential (EP)

Unit: kg PO₄³⁻-equivalent

Main cause: Detergents, fertilizers, sewage, fossil fuels

Effects: Algae growth, fish and plant mortality

Formation of Photo Oxidants

Photo-oxidant formation is the formation of reactive chemical compounds by the action of sunlight (Guinée et al. 2001, p.65). It is also known as photochemical smog or summer smog. Aggressive pollutants, such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs), react under the influence of sunlight and create ozone. While ozone is beneficial in the stratosphere, it has a toxic influence on humans at ground level. In addition to ozone, other toxic substances are produced, forming the group of photooxidants. Summer smog greatly depends on regional and meteorological factors (Klöpffer & Grahl 2014, p.252).

Indicator: Photochemical Ozone Creation Potential (POCP)

Unit: kg C₂H₄-equivalent

Main cause: Nitrogen oxides, traffic, burning of fossil fuels

Effects: Toxic for humans, breathing difficulties

Abiotic resource depletion

Udo de Haes (1996, p.19) lists abiotic resource depletion in input-related impact categories. In contrast, EN 15804:2012 and EN 15978:2012 list it as an output-related parameter. These standards employ two indicators for abiotic resource depletion: Abiotic resource depletion potential elements (ADPe) and abiotic resource depletion potential fossil (ADPf).

According to Oers et al. "abiotic resource depletion is the decrease of availability of functions, both in the environment and the economy" (Oers et al. 2002, p.29). These two indicators describe the loss of natural element availability and fossil fuel availability. The indicator ADPe is defined by relating each element to the world's available reserves which can be exploited economically currently and possibly in future. The annual extraction is divided by the reserves squared. The result is related to the reference element antimony (Sb) through dividing it by the same ratio of availability and current annual extraction. By including the annual extraction rate the current importance of a given resource is captured (JRC European commission 2011, p.100). ADPf is calculated analogously, but instead of the mass of material the lower heating value of the fossil fuel is used. Therefore, the unit is MJ.

Indicator: Abiotic resource depletion potential element (ADPe) /
Abiotic resource depletion potential fossil (ADPf)

Unit: kg Sb-equivalent / MJ

B. Normalization and weighting in DGNB

The calculation process for the environmental criteria related to LCA of DGNB¹ is shown here using the example of the 2015 version for new residential buildings with more than six apartments. The DGNB systems consists of 37 individual criteria. For each criterion, evaluation points (*Bewertungspunkte*, BP) are awarded. These are weighted and added together to provide the overall score a building achieves. DGNB employs two criteria related to LCA: ENV1.1 for output-related impacts and ENV2.1 for the primary energy demand. They make up 7.9% and 5.6% respectively of all BP that can be achieved. This indicates that, with 13.5% of the total, the LCA-related criteria have a great importance for the DGNB system. With exception of ADPe and ADPf, DGNB employs all output-related indicators defined in EN 15978:2012. To compensate for neglecting certain small building components due to the simplification, DGNB adds 10% to the results at the end. The functional unit in DGNB is always 1 m² of net floor area (NFA) and 1 year of operation. The calculation of BP is based on the so-called *check list points* (CLP) for each criterion. To calculate the CLP for both criteria (ENV1.1 and ENV2.1.) four steps are necessary: Normalization of the LCA results, calculation of sub-points called *Teilpunkte* (TP), weighting of TP, and the aggregation into CLP.

Normalization

The reference values for normalization (R) are provided separately for the operational impact (R_{Nref}) and the embodied impact (R_{Kref}). Reference values for embodied impact are shown in Table 1 and Table 2.

Table 1: Reference values for embodied impact (R_{Kref}) according to DGNB ENV1.1 residential buildings 2015

GWP_{Kref} [kg CO ₂ e/m ² _{NFA} ×a]	ODP_{Kref} [kg R11e/m ² _{NFA} ×a]	$POCP_{Kref}$ [kg C ₂ H ₄ e/m ² _{NFA} ×a]	AP_{Kref} [kg SO ₂ e/m ² _{NFA} ×a]	EP_{Kref} [kg PO ₄ ³⁻ e/m ² _{NFA} ×a]
9.4	5.3E-07	0.0042	0.037	0.0047

Table 2: Reference values for embodied impact (R_{Kref}) according to DGNB ENV2.1 residential buildings 2015

$PENRT_{Kref}$ [MJ / m ² _{NFA} ×a]	PET_{Kref} [MJ / m ² _{NFA} ×a]	$PET/PENRT_{Kref}$ [%]
123	151	-

¹ The DGNB criteria catalogue can be requested at <http://www.dgnb-system.de/en/services/request-dgnb-criteria/> (accessed March 21st 2016)

The reference values for operational impact depend on the results for the energy demand of the reference building according to EnEV 2014. The reference values are provided separately for electricity demand and heating demand and then summed up. The reference values are shown in Table 3 and Table 4. S_{ref} refers to the electricity demand and W_{ref} to the heating demand. Both refer to the final energy demand and are declared in kWh/m²_{NFA}×a.

Table 3: Reference values for operational impact (R_{Nref}) according to DGNB ENV1.1 residential buildings 2015

	GWP _{Nref} [kg CO ₂ e/m ² _{NFA} ×a]	ODP _{Nref} [kg R11e/m ² _{NFA} ×a]	POCP _{Nref} [kg C ₂ H ₄ e/m ² _{NFA} ×a]	AP _{Nref} [kg SO ₂ e/m ² _{NFA} ×a]	EP _{Nref} [kg PO ₄ ³⁻ e/m ² _{NFA} ×a]
Sref	0.62	3.07E-09	7.60E-05	1.03E-03	9.92E-05
Wref	0.25	1.80E-11	3.10E-05	2.70E-04	1.90E-05

Table 4: Reference values for operational impact (R_{Nref}) according to DGNB ENV2.1 residential buildings 2015

	PENRT _{Nref} [MJ / m ² _{NFA} ×a]	PET _{Nref} [MJ / m ² _{NFA} ×a]	PERT/PET _{Nref} [%]
Sref	8.80	10.30	-
Wref	3.8	3.90	-

Calculation of TP

The TP range between 0 and 100 points. They are awarded for undercutting the reference value (R) multiplied by a factor provided in Table 5 to Table 7. For example, if the GWP of a building design is lower than $0.88 \times GWP_{ref}$, this design achieves 70 TP for the indicator GWP.

Table 5: Factors for the calculation of TP according to DGNB ENV1.1 residential buildings 2015

TP	GWP	ODP	POCP	AP	EP
10	1.40	10.0	2.00	1.700	2.00
20	1.30	7.75	1.75	1.525	1.75
30	1.20	5.50	1.50	1.350	1.50
40	1.10	3.25	1.25	1.175	1.25
50	1.00	1.00	1.00	1.00	1.00
60	0.94	0.94	0.94	0.94	0.94
70	0.88	0.88	0.88	0.88	0.88
80	0.82	0.82	0.82	0.82	0.82
90	0.76	0.76	0.76	0.76	0.76
100	0.70	0.70	0.70	0.70	0.70

Table 6: Factors for the calculation of TP for PENRT according to DGNB ENV2.1 residential buildings 2015

TP	PENRT
10	1.40
20	1.30
30	1.20
40	1.10
50	1.00
60	0.94
70	0.88
80	0.82
90	0.76
100	0.70

Table 7: Factors for the calculation of TP for PERT/PET according to DGNB ENV2.1 residential buildings 2015

TP	PERT/PET
5	2%
10	4%
15	6%
20	8%
25	10%
30	12%
35	14%
40	16%
45	18%
50	20%

Table 8: Factors for the calculation of TP for PET according to DGNB ENV2.1 residential buildings 2015

TP	PET
5	1.40
10	1.30
15	1.20
20	1.10
25	1.00
30	0.94
35	0.88
40	0.82
45	0.76
50	0.70
55	0.67
60	0.64
65	0.61
70	0.58
75	0.55
80	0.52
85	0.49
90	0.46
95	0.43
100	0.40

Weighting

The TP are weighted by the weighting factors (G) provided in Table 9 and Table 10.

Table 9: Weighting factors according to DGNB ENV1.1 residential buildings 2015

G _{GWP}	G _{ODP}	G _{POCP}	G _{AP}	G _{EP}
40%	15%	15%	15%	15%

Table 10: Weighting factors according to DGNB ENV2.1 residential buildings 2015

G _{PENRT}	G _{PET}	G _{PET/PET}
60%	40%	20%

Calculation of CLP

In the last step the CLP for ENV1.1 and ENV2.1 are calculated by summing up the TP multiplied by the weighting factors (G), see Equations B1 and B2.

$$CLP = TP_{GWP} \times G_{GWP} + TP_{ODP} \times G_{ODP} + TP_{POCP} \times G_{POCP} + TP_{AP} \times G_{AP} + TP_{EP} \times G_{EP} \quad (B1)$$

$$CLP = TP_{PENRT} \times G_{PENRT} + TP_{PET} \times G_{PET} + TP_{PERT/PET} \times G_{PERT/PET} \quad (B2)$$

A maximum of 100 CLP can be achieved for both criteria ENV1.1 and ENV2.1.

Calculation of BP

For both criteria ENV1.1 and ENV2.1 BP equals CLP divided by 10. As such a maximum of 10 BP can be achieved for both criteria.

C. Environmental data of modified components for Concretecube

Table 11 to Table 13 show the environmental data of the modified building components for Concretecube.

Table 11: Environmental data for concrete exterior wall

	#	Name	Amount	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [M]	PERT [MJ]
Production	1	Plaster	32.00 kg	11.9723	3.22E-07	0.0034148	0.0243	0.0046385	123.41	9.24
	2	EPS	0.18 m ³	15.6505	4.70E-07	5.55E-03	0.034	3.68E-03	479.27	2.13
	3	Concrete	0.18 m ³	4.88	9.46E-07	6.42E-03	0.0631	8.96E-03	182.14	3.31
	4	Reinforcement	28.26 kg	24.7093	2.22E-06	7.74E-03	0.0464	3.92E-03	351.05	27.85
	5	Gypsum Plaster	24.00 kg	3.8609	1.87E-07	0.0004509	0.0048268	0.0005321	54.18	1.16
	Sum per m²				61.0698	4.143E-06	0.0235815	0.1726268	0.0217313	1190.0491
Replacement	1	Plaster	1	12.6141	3.27E-07	0.0038345	0.0269	0.0049883	128.54	9.58
	2	EPS	1	23.6654	-1.53E-09	4.60E-03	0.0238	2.81E-03	308.38	-0.11
	3	Concrete	0							
	4	Reinforcement	0							
	5	Gypsum Plaster	0							
	Sum per m²				36.2795	3.257E-07	0.0084328	0.0507	0.0077969	436.9184
EOL	1	Plaster	32.00 kg	0.6418	5.29E-09	0.0004197	0.0026414	0.0003498	5.13	0.34
	2	EPS	0.18 m ³	8.0149	-4.72E-07	-0.000952	-0.0102	-0.000875	-170.89	-2.24
	3	Concrete	0.18 m ³	14.5696	-1.57E-07	2.12E-03	0.0284	4.16E-03	19.82	-0.68
	4	Reinforcement	28.26 kg	0.9869	-1.06E-08	1.43E-04	1.92E-03	2.82E-04	1.34	-0.05
	5	Gypsum Plaster	24.00 kg	0.8382	-9.04E-09	1.22E-04	1.63E-03	2.39E-04	1.14	-0.04
	Sum per m²				25.0514	-6.43E-07	0.001848	0.0243997	0.0041512	-143.4586
LC	Sum per m²			122.4007	3.826E-06	0.0338623	0.2477265	0.0336795	1483.5089	50.4938

Table 12: Environmental data for concrete ceiling with parquet floor

	#	Name	Amount	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [M]	PERT [MJ]
Production	1	Wooden flooring	1.00 m ²	-40.810	1.00E-06	0.0038	0.0219	0.0033	216.72	502.49
	2	Dry screed	2.60 kg	-0.250	8.40E-08	0.0012	0.0113	0.0015	83.29	67.62
	3	Separating foil	0.80 kg	-0.510	8.98E-08	0.0003	0.0034	0.0009	11.53	24.53
	4	Dry screed	2.60 kg	-0.250	8.40E-08	0.0012	0.0113	0.0015	83.29	67.62
	5	Impact sound insulation	3.90 kg	-0.380	1.26E-07	0.0018	0.0169	0.0023	124.93	101.43
	6	Filling	60.00 kg	28.460	3.19E-07	0.0049	0.0454	0.0053	397.48	1.70
	7	Separating foil	0.80 kg	-0.510	8.98E-08	0.0003	0.0034	0.0009	11.53	24.53
	8	Concrete	0.19 m ³	36.810	9.99E-07	0.0068	0.0666	0.0095	192.26	3.50
	9	Reinforcement	29.83 kg	26.080	2.34E-06	0.0082	0.0490	0.0041	370.55	29.39
	10	Wooden cladding	0.02 m ³	-20.410	8.36E-07	0.0021	0.0214	0.0025	145.20	279.53
	Sum per m²			28.230	5.968E-06	0.0306	0.2506	0.0318	1636.78	1102.34
Replacement	1	Wooden flooring	0							
	2	Dry screed	0							
	3	Separating foil	0							
	4	Dry screed	0							
	5	Impact sound insulation	0							
	6	Filling	0							
	7	Separating foil	0							
	8	Concrete	0							
	9	Reinforcement	0							
	10	Wooden cladding	0							
	Sum per m²			0	0	0	0	0	0	0
EOL	1	Wooden flooring	11.50 kg	13.530	-2.59E-07	0.0000	0.0095	0.0025	-117.93	-1.23
	2	Dry screed	2.60 kg	1.080	-1.37E-07	-0.0003	-0.0020	-0.0003	-58.58	-0.65
	3	Separating foil	0.80 kg	0.650	-5.97E-08	-0.0001	-0.0011	-0.0001	-22.08	-0.29
	4	Dry screed	2.60 kg	1.080	-1.37E-07	-0.0003	-0.0020	-0.0003	-58.58	-0.65
	5	Impact sound insulation	3.90 kg	1.610	-2.05E-07	-0.0004	-0.0030	-0.0004	-87.87	-0.97
	6	Filling	60.00 kg	1.200	9.92E-09	0.0008	0.0050	0.0007	9.61	0.64
	7	Separating foil	0.80 kg	0.650	-5.97E-08	-0.0001	-0.0011	-0.0001	-22.08	-0.29
	8	Concrete	440.4 kg	14.410	-2.82E-07	0.0020	0.0278	0.0041	6.15	-1.27
	9	Reinforcement								
	10	Wooden cladding	13.22 kg	13.150	-4.31E-07	-0.0008	-0.0054	0.0000	-180.97	-2.05
	Sum per m²			47.360	-1.56E-06	0.0008	0.0277	0.0061	-532.33	-6.76
LC	Sum per m²			75.590	4.407E-06	0.0314	0.2783	0.0379	1104.45	1095.58

Table 13: Environmental data for concrete ceiling bathroom

	#	Name	Amount	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [M]	PERT [MJ]
Production	1	Tiles	10.00 kg	2.830	1.10E-07	0.0003	0.00555	0.0005	47.54	0.52
	2	Tile adhesive	3.75 kg	1.030	2.75E-08	0.0003	0.00195	0.0003	7.17	0.64
	3	Dry screed	2.60 kg	-0.250	8.40E-08	0.0012	0.01127	0.0015	83.29	67.62
	4	Separating foil	0.80 kg	-0.510	8.98E-08	0.0003	0.00338	0.0009	11.53	24.53
	5	Dry screed	2.60 kg	-0.250	8.40E-08	0.0012	0.01127	0.0015	83.29	67.62
	6	Impact sound insulation	3.90 kg	-0.380	1.26E-07	0.0018	0.01691	0.0023	124.93	101.43
	7	Filling	60.00 kg	28.460	3.19E-07	0.0049	0.04539	0.0053	397.48	1.70
	8	Separating foil	0.80 kg	-0.510	8.98E-08	0.0003	0.00338	0.0009	11.53	24.53
	9	Concrete	0.19 m ³	36.810	9.99E-07	0.0068	0.06662	0.0095	192.26	3.50
	10	Reinforcement	29.83 kg	26.080	2.34E-06	0.0082	0.04899	0.0041	370.55	29.39
	11	Wooden cladding	0.02 m ³	-20.410	8.36E-07	0.0021	0.02141	0.0025	145.20	279.53
	Sum per m²				61.0698	4.143E-06	0.0235815	72.900	5.105E-06	0.0274
Replacement	1	Tiles	0							
	2	Tile adhesive	0							
	3	Dry screed	0							
	4	Separating foil	0							
	5	Dry screed	0							
	6	Impact sound insulation	0							
	7	Filling	0							
	8	Separating foil	0							
	9	Concrete	0							
	10	Reinforcement	0							
	11	Wooden cladding	0							
	Sum per m²				0	0	0	0	0	0
EOL	1	Tiles	10.00 kg	0.200	1.65E-09	0.00010	0.00080	0.0001	1.60	0.11
	2	Tile adhesive	3.75 kg	0.080	6.20E-10	0.00000	0.00030	0.0000	0.60	0.04
	3	Dry screed	2.60 kg	1.080	-1.37E-07	-0.00030	-0.00200	-0.0003	-58.58	-0.65
	4	Separating foil	0.80 kg	0.650	-5.97E-08	-0.00010	-0.00110	-0.0001	-22.08	-0.29
	5	Dry screed	2.60 kg	1.080	-1.37E-07	-0.00030	-0.00200	-0.0003	-58.58	-0.65
	6	Impact sound insulation	3.90 kg	1.610	-2.05E-07	-0.00040	-0.00300	-0.0004	-87.87	-0.97
	7	Filling	60.00 kg	1.200	9.92E-09	0.00080	0.00500	0.0007	9.61	0.64
	8	Separating foil	0.80 kg	0.650	-5.97E-08	-0.00010	-0.00110	-0.0001	-22.08	-0.29
	9	Concrete	440.4 kg	14.410	-2.82E-07	0.00200	0.02780	0.0041	6.15	-1.27
	10	Reinforcement								
	11	Wooden cladding	13.22 kg	13.150	-4.31E-07	-0.00080	-0.00540	0.0000	-180.97	-2.05
	Sum per m²				34.110	-1.3E-06	0.00090	0.01930	0.0037	-412.2
LC	Sum per m²			107.010	3.806E-06	0.02830	0.25542	0.0330	1062.57	595.63

D. Detailed results for verification of embodied impact

Here, the result for the embodied impact are shown. First of all, the results of the original study are provided in Table 15. Some components, e.g. the elevator, have not been modelled with CAALA. Therefore, the results for the study with reduced building components are shown in Table 16. These values serve as references for the following comparisons.

For both reference buildings, Woodcube and Concretcube, the analysis consists of two steps. In the first step, the results from the original study by Hartwig are compared to those of the modified areas in order to investigate the influence of differences in area in the geometric model on the results. In the second step, the results of the modified areas are compared to those provided study by CAALA, in order to find out if the algorithms calculate correctly. The results are provided in different tables. An overview of the individual tables is provided in Table 14.

Table 14: Overview on tables with results for verification

	Results	Table
Woodcube	Original study	Table 15
	Reduced study (Hartwig)	Table 16
	Method results (CAALA)	Table 17
	Difference between CAALA – Hartwig	Table 18
	Deviation between CAALA – Hartwig	Table 19
	Method results with modified areas (CAALA modified)	Table 20
	Difference between CAALA modified – Hartwig	Table 21
	Deviation between CAALA modified – Hartwig	Table 22
Concretcube	Original areas	Table 23
	Modified areas	Table 24
	Difference between modified areas – reduced study	Table 25
	Deviation between modified areas – reduced study	Table 26
	Results of CAALA	Table 27
	Difference between CAALA - modified areas	Table 28
	Deviation between CAALA - modified areas	Table 29

Table 15: Results for embodied impact, original study by Hartwig (2012)

Name	Area [m ² / pieces]	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Wooden exterior wall	741.95	-82808	2.39E-03	12.500	99.990	21.980	-475189	3074486
Exterior wall basement	183.01	17203	6.67E-04	3.730	31.560	3.920	123979	6763
Exterior wall staircase above roof	20.04	2846	6.44E-05	1.030	9.420	1.260	30905	36505
Interior wall staircase	208.15	22358	8.85E-04	4.910	41.470	5.130	164552	9146
Interior wall staircase basement	52.78	6050	2.00E-04	1.680	14.830	1.880	53201	33424
Interior wall elevator	135.61	15174	6.00E-04	3.330	28.140	3.480	111675	6207
Interior wall	498.29	7177	3.57E-04	1.430	13.510	2.290	119248	46265
Interior partition wall	93.84	2492	1.24E-04	0.630	5.470	0.980	42063	20333
Interior wall basement	52.46	1708	2.87E-05	0.290	2.320	0.310	13927	669
Bottom slab	228.01	37507	1.45E-03	8.125	68.819	8.541	270313	14745
Roof above staircase	24.00	4698	1.10E-04	1.000	7.290	0.900	46503	1177
Wooden roof	204.00	-5549	4.59E-04	4.070	24.340	4.840	32389	543547
Wooden ceiling with parquet floor	612.67	-45386	1.99E-03	14.080	115.160	21.850	61081	2161445
Wooden ceiling bathroom	55.61	-2197	1.44E-04	1.090	9.060	1.680	2982	165605
Basement ceiling with parquet floor	121.62	3438	1.03E-03	5.770	55.520	7.850	123839	443555
Concrete ceiling staircase	36.36	3092	1.22E-04	0.680	5.730	0.710	22756	1265
Basement ceiling entrance interior	19.90	562.56	1.68E-04	0.940	9.090	1.280	20263	72576
Basement ceiling entrance exterior	22.67	2024	7.85E-05	0.440	3.710	0.460	14590	796
Basement ceiling bathroom	13.82	1751	5.81E-05	0.450	4.010	0.520	17785	9055
Wooden balcony	99.69	-22137	6.33E-04	7.290	17.570	4.490	-146468	730650
Small window	13 pc.	752	4.21E-05	0.530	3.600	0.500	9180	3495
Medium window	12 pc.	1136	5.44E-05	0.710	5.380	0.750	13525	4362
Large window	28 pc.	5240	2.08E-04	2.850	24.350	3.460	61226	15032
Entrance door	1 pc.	859	2.42E-05	0.330	3.820	0.560	9905	1006
Apartment door	9 pc.	-177	1.22E-05	0.040	0.360	0.070	-593	8419
Balcony door	13 pc.	10410	3.00E-04	4.110	46.380	6.820	120028	12840
Basement interior door	4 pc.	303	1.22E-05	0.100	0.670	0.060	4022	231
Interior door	31 pc.	-608	4.19E-05	0.130	1.240	0.220	-2043	29000
Terrace	0 pc.	0	0.00E+00	0.000	0.000	0.000	0	0
Pile foundation	40 pc.	24026	9.32E-04	5.200	44.080	5.470	173155	9445
District heating connection	40 kW	432	4.33E-05	0.090	0.970	0.300	6298	368
Elevator	1 pc.	13388	1.05E-03	4.110	52.650	18.490	172783	17200
Sum		25764	1.43E-02	91.665	750.509	131.051	1217880	7479612

Table 16: Results for embodied impact, Woodcube, reduced study

Name	Area [m ²]	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Wooden exterior wall	741.95	-82808	2.39E-03	12.500	99.990	21.980	-475189	3074486
Exterior wall basement	183.01	17203	6.67E-04	3.730	31.560	3.920	123979	6763
Exterior wall staircase above roof	20.04	2846	6.44E-05	1.030	9.420	1.260	30905	36505
Interior wall staircase	208.15	22358	8.85E-04	4.910	41.470	5.130	164552	9146
Interior wall staircase basement	52.78	6050	2.00E-04	1.680	14.830	1.880	53201	33424
Interior wall elevator	135.61	15174	6.00E-04	3.330	28.140	3.480	111675	6207
Interior wall	498.29	7177	3.57E-04	1.430	13.510	2.290	119248	46265
Interior partition wall	93.84	2492	1.24E-04	0.630	5.470	0.980	42063	20333
Interior wall basement	52.46	1708	2.87E-05	0.290	2.320	0.310	13927	669
Bottom slab	228.01	37507	1.45E-03	8.125	68.819	8.541	270313	14745
Roof above staircase	24.00	4698	1.10E-04	1.000	7.290	0.900	46503	1177
Wooden roof	204.00	-5549	4.59E-04	4.070	24.340	4.840	32389	543547
Wooden ceiling with parquet floor	612.67	-45386	1.99E-03	14.080	115.160	21.850	61081	2161445
Wooden ceiling bathroom	55.61	-2197	1.44E-04	1.090	9.060	1.680	2982	165605
Basement ceiling with parquet floor	121.62	3438	1.03E-03	5.770	55.520	7.850	123839	443555
Concrete ceiling staircase	36.36	3092	1.22E-04	0.680	5.730	0.710	22756	1265
Basement ceiling entrance interior	19.90	563	1.68E-04	0.940	9.090	1.280	20263	72576
Basement ceiling entrance exterior	22.67	2024	7.85E-05	0.440	3.710	0.460	14590	796
Basement ceiling bathroom	13.82	1751	5.81E-05	0.450	4.010	0.520	17785	9055
Wooden balcony	99.69	-22137	6.33E-04	7.290	17.570	4.490	-146468	730650
Small window	6.37	752	4.21E-05	0.530	3.600	0.500	9180	3495
Medium window	10.83	1136	5.44E-05	0.710	5.380	0.750	13525	4362
Large window	54.88	5240	2.08E-04	2.850	24.350	3.460	61226	15032
Entrance door	9.89	859	2.42E-05	0.330	3.820	0.560	9905	1006
Apartment door	18.00	-177	1.22E-05	0.040	0.360	0.070	-593	8419
Balcony door	119.60	10410	3.00E-04	4.110	46.380	6.820	120028	12840
Basement interior door	8.00	303	1.22E-05	0.100	0.670	0.060	4022	231
Interior door	55.80	-608	4.19E-05	0.130	1.240	0.220	-2043	29000
Sum	3707.85	-12082	1.23E-02	82.265	652.809	106.791	865644	7452599

Table 17: Results for embodied impact, Woodcube, CAALA

Name	Area [m ²]	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Wooden exterior wall	713.58	-79642	2.30E-03	12.022	96.167	21.140	-457019	2956900
Exterior wall basement	183.01	17203	6.67E-04	3.730	31.560	3.920	123980	6763
Exterior wall staircase above roof	14.05	1996	4.50E-05	0.722	6.606	0.884	21671	25598
Interior wall staircase	259.87	27914	1.11E-03	6.130	51.775	6.405	205442	11419
Interior wall staircase basement	52.73	6045	2.00E-04	1.679	14.817	1.878	53154	33395
Interior wall elevator	137.56	15392	6.09E-04	3.378	28.545	3.530	113284	6296
Interior wall	549.62	7916	3.94E-04	1.577	14.902	2.526	131531	51031
Interior partition wall	100.71	2675	1.33E-04	0.676	5.871	1.052	45144	21822
Interior wall basement	62.91	2049	3.40E-05	0.348	2.782	0.372	16702	802
Bottom slab	228.01	37507	1.45E-03	8.125	68.819	8.541	270313	14745
Roof above staircase	25.14	4921	1.15E-04	1.048	7.637	0.943	48714	1233
Wooden roof	202.87	-5518	4.56E-04	4.047	24.205	4.813	32209	540534
Wooden ceiling with parquet floor	736.35	-56115	2.46E-03	17.409	142.382	27.015	75521	2672418
Wooden ceiling bathroom	63.71	-2517	1.65E-04	1.249	10.379	1.925	3416	189718
Basement ceiling with parquet floor	156.21	4416	1.32E-03	7.411	71.309	10.082	159056	569692
Concrete ceiling staircase	36.16	3075	1.21E-04	0.676	5.698	0.706	22630	1258
Basement ceiling entrance interior	11.21	317	9.50E-05	0.529	5.120	0.721	11413	40878
Basement ceiling entrance exterior	21.15	1889	7.30E-05	0.411	3.461	0.429	13612	743
Basement ceiling bathroom	16.74	2121	7.00E-05	0.545	4.857	0.630	21540	10967
Wooden balcony	90.68	-20136	5.76E-04	6.631	15.982	4.084	-133228	664603
Small window	6.37	752	4.20E-05	0.530	3.600	0.500	9180	3495
Medium window	10.83	1136	5.40E-05	0.710	5.380	0.750	13525	4362
Large window	54.88	5240	2.08E-04	2.850	24.350	3.460	61226	15032
Entrance door	9.89	859	2.40E-05	0.332	3.819	0.561	9905	1006
Apartment door	18.21	-179	1.20E-05	0.040	0.364	0.071	-600	8518
Balcony door	128.57	11190	3.23E-04	4.418	49.859	7.332	129030	13803
Basement interior door	8.09	306	1.20E-05	0.101	0.678	0.061	4069	234
Interior door	55.80	-608	4.20E-05	0.130	1.240	0.220	-2043	29000
Sum	3954.93	-9797	1.31E-02	87.455	702.163	114.549	1003378	7896264

Table 18: Differences of embodied impact, Woodcube, Hartwig - CAALA

Name	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Wooden exterior wall	-3166	9.10E-05	0.478	3.823	0.840	-18170	117600
Exterior wall basement	0	0.00E+00	0.000	0.000	0.000	-1	0
Exterior wall staircase above roof	850	1.90E-05	0.308	2.814	0.376	9234	10907
Interior wall staircase	-5556	-2.20E-04	-1.220	-10.305	-1.275	-40890	-2273
Interior wall staircase basement	5	0.00E+00	0.001	0.013	0.002	47	29
Interior wall elevator	-219	-9.00E-06	-0.048	-0.405	-0.050	-1609	-89
Interior wall	-739	-3.70E-05	-0.147	-1.392	-0.236	-12283	-4766
Interior partition wall	-183	-9.00E-06	-0.046	-0.401	-0.072	-3081	-1489
Interior wall basement	-340	-5.00E-06	-0.058	-0.462	-0.062	-2775	-133
Bottom slab	0	0.00E+00	0.000	0.000	0.000	0	0
Roof above staircase	-223	-5.00E-06	-0.048	-0.347	-0.043	-2211	-56
Wooden roof	-31	3.00E-06	0.023	0.135	0.027	180	3013
Wooden ceiling with parquet floor	10729	-4.71E-04	-3.329	-27.224	-5.165	-14440	-511000
Wooden ceiling bathroom	320	-2.10E-05	-0.159	-1.319	-0.245	-434	-24113
Basement ceiling with parquet floor	-978	-2.93E-04	-1.641	-15.789	-2.232	-35217	-126137
Concrete ceiling staircase	17	1.00E-06	0.004	0.032	0.004	126	7
Basement ceiling entrance interior	246	7.30E-05	0.411	3.970	0.559	8850	31698
Basement ceiling entrance exterior	136	5.00E-06	0.029	0.249	0.031	978	53
Basement ceiling bathroom	-370	-1.20E-05	-0.095	-0.847	-0.110	-3755	-1912
Wooden balcony	-2001	5.70E-05	0.659	1.588	0.406	-13240	66047
Small window	0	0.00E+00	0.000	0.000	0.000	0	0
Medium window	0	0.00E+00	0.000	0.000	0.000	0	0
Large window	0	0.00E+00	0.000	0.000	0.000	0	0
Entrance door	0	0.00E+00	0.000	0.000	0.000	0	0
Apartment door	2	0.00E+00	0.000	-0.004	-0.001	7	-99
Balcony door	-781	-2.30E-05	-0.308	-3.479	-0.512	-9002	-963
Basement interior door	-4	0.00E+00	-0.001	-0.008	-0.001	-47	-3
Interior door	0	0.00E+00	0.000	0.000	0.000	0	0
Sum	-2285	-8.56E-04	-5.19	-49.36	-7.76	-137734	-443678

Table 19: Deviation of embodied impact, Woodcube, Hartwig - CAALA

Name	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Wooden exterior wall	3.824	3.808	3.824	3.824	3.824	3.824	3.825
Exterior wall basement	-0.001	0.000	-0.001	-0.001	-0.001	-0.001	-0.001
Exterior wall staircase above roof	29.877	29.688	29.877	29.877	29.877	29.877	29.877
Interior wall staircase	-24.849	-24.859	-24.849	-24.849	-24.849	-24.849	-24.849
Interior wall staircase basement	0.088	0.000	0.088	0.088	0.088	0.088	0.088
Interior wall elevator	-1.441	-1.500	-1.441	-1.441	-1.441	-1.441	-1.441
Interior wall	-10.301	-10.364	-10.301	-10.301	-10.301	-10.301	-10.301
Interior partition wall	-7.324	-7.258	-7.324	-7.324	-7.324	-7.324	-7.324
Interior wall basement	-19.927	-17.241	-19.927	-19.927	-19.927	-19.927	-19.927
Bottom slab	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Roof above staircase	-4.754	-4.545	-4.754	-4.754	-4.754	-4.754	-4.754
Wooden roof	0.554	0.654	0.554	0.554	0.554	0.554	0.554
Wooden ceiling with parquet floor	-23.640	-23.668	-23.640	-23.640	-23.641	-23.640	-23.642
Wooden ceiling bathroom	-14.560	-14.583	-14.560	-14.560	-14.560	-14.560	-14.560
Basement ceiling with parquet floor	-28.438	-28.447	-28.438	-28.438	-28.438	-28.438	-28.438
Concrete ceiling staircase	0.555	0.820	0.555	0.555	0.555	0.555	0.555
Basement ceiling entrance interior	43.676	43.452	43.676	43.676	43.676	43.676	43.676
Basement ceiling entrance exterior	6.702	6.410	6.702	6.702	6.702	6.702	6.702
Basement ceiling bathroom	-21.114	-20.690	-21.114	-21.114	-21.114	-21.114	-21.114
Wooden balcony	9.039	9.005	9.039	9.039	9.039	9.039	9.039
Small window	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Medium window	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Large window	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Entrance door	0.000	0.000	-0.037	0.001	-0.009	0.000	-0.001
Apartment door	-1.173	0.000	-1.172	-1.173	-1.173	-1.173	-1.173
Balcony door	-7.500	-7.667	-7.500	-7.500	-7.500	-7.500	-7.500
Basement interior door	-1.173	0.000	-1.173	-1.173	-1.173	-1.173	-1.173
Interior door	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum	18.909	-6.987	-6.306	-7.561	-7.264	-15.911	-5.953

Table 20: Results for embodied impact, Woodcube, CAALA modified

Name	Area [m ²]	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Wooden exterior wall	741.95	-82808	2.39E-03	12.500	99.990	21.980	-475189	3074500
Exterior wall basement	183.01	17203	6.67E-04	3.730	31.560	3.920	123979	6763
Exterior wall staircase above roof	20.04	2846	6.40E-05	1.030	9.420	1.260	30905	36505
Interior wall staircase	208.15	22358	8.85E-04	4.910	41.470	5.130	164552	9146
Interior wall staircase basement	52.78	6050	2.00E-04	1.680	14.830	1.880	53201	33424
Interior wall elevator	135.61	15174	6.00E-04	3.330	28.140	3.480	111675	6207
Interior wall	498.29	7177	3.57E-04	1.430	13.510	2.290	119248	46265
Interior partition wall	93.84	2492	1.24E-04	0.630	5.470	0.980	42063	20333
Interior wall basement	52.46	1708	2.90E-05	0.290	2.320	0.310	13927	669
Bottom slab	228.01	37507	1.45E-03	8.125	68.819	8.541	270313	14745
Roof above staircase	24.00	4698	1.10E-04	1.000	7.290	0.900	46503	1177
Wooden roof	204.00	-5549	4.59E-04	4.070	24.340	4.840	32389	543547
Wooden ceiling with parquet floor	612.67	-45386	1.99E-03	14.080	115.158	21.850	61081	2161418
Wooden ceiling bathroom	55.61	-2197	1.44E-04	1.090	9.060	1.680	2982	165605
Basement ceiling with parquet floor	121.62	3438	1.03E-03	5.770	55.520	7.850	123839	443555
Concrete ceiling staircase	36.36	3092	1.22E-04	0.680	5.730	0.710	22756	1265
Basement ceiling entrance interior	19.90	563	1.68E-04	0.940	9.090	1.280	20263	72576
Basement ceiling entrance exterior	22.67	2024	7.80E-05	0.440	3.710	0.460	14590	796
Basement ceiling bathroom	13.82	1751	5.80E-05	0.450	4.010	0.520	17785	9055
Wooden balcony	99.69	-22137	6.33E-04	7.290	17.570	4.490	-146468	730650
Small window	6.37	752	4.20E-05	0.530	3.600	0.500	9180	3495
Medium window	10.83	1136	5.40E-05	0.710	5.380	0.750	13525	4362
Large window	54.88	5240	2.08E-04	2.850	24.350	3.460	61226	15032
Entrance door	9.89	859	2.40E-05	0.332	3.819	0.561	9905	1006
Apartment door	18.00	-177	1.20E-05	0.040	0.360	0.070	-593	8419
Balcony door	119.60	10410	3.00E-04	4.110	46.380	6.820	120028	12840
Basement interior door	8.00	303	1.20E-05	0.100	0.670	0.060	4022	231
Interior door	55.80	-608	4.20E-05	0.130	1.240	0.220	-2043	29000
Sum	3707.85	-12082	1.23E-02	82.267	652.807	106.791	865644	7452586

Table 21: Differences of embodied impact, Woodcube, Hartwig – CAALA modified

Name	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Wooden exterior wall	0.000	0.00E+00	0.000	0.000	0.000	0.000	-14.000
Exterior wall basement	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Exterior wall staircase above roof	0.000	4.00E-07	0.000	0.000	0.000	0.000	0.000
Interior wall staircase	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior wall staircase basement	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior wall elevator	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior wall	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior partition wall	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior wall basement	0.000	-3.00E-07	0.000	0.000	0.000	0.000	0.000
Bottom slab	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Roof above staircase	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Wooden roof	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Wooden ceiling with parquet floor	0.128	0.00E+00	0.000	0.002	0.000	-0.161	27.255
Wooden ceiling bathroom	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Basement ceiling with parquet floor	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Concrete ceiling staircase	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Basement ceiling entrance interior	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Basement ceiling entrance exterior	0.000	5.00E-07	0.000	0.000	0.000	0.000	0.000
Basement ceiling bathroom	0.000	1.00E-07	0.000	0.000	0.000	0.000	0.000
Wooden balcony	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Small window	0.000	1.00E-07	0.000	0.000	0.000	0.000	0.000
Medium window	0.000	4.00E-07	0.000	0.000	0.000	0.000	0.000
Large window	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Entrance door	-0.002	2.00E-07	-0.002	0.001	-0.001	0.108	-0.129
Apartment door	0.000	2.00E-07	0.000	0.000	0.000	0.000	0.000
Balcony door	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Basement interior door	0.000	2.00E-07	0.000	0.000	0.000	0.000	0.000
Interior door	0.000	-1.00E-07	0.000	0.000	0.000	0.000	0.000
Sum	0.126	1.70E-06	-0.002	0.002	0.000	-0.053	13.126

Table 22: Deviation of embodied impact, Woodcube, Hartwig - CAALA modified

Name	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Wooden exterior wall	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Exterior wall basement	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Exterior wall staircase above roof	0.000	0.621	0.000	0.000	0.000	0.000	0.000
Interior wall staircase	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior wall staircase basement	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior wall elevator	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior wall	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior partition wall	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior wall basement	0.000	-1.045	0.000	0.000	0.000	0.000	0.000
Bottom slab	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Roof above staircase	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wooden roof	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wooden ceiling with parquet floor	0.000	0.000	-0.001	0.002	0.002	0.000	0.001
Wooden ceiling bathroom	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Basement ceiling with parquet floor	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Concrete ceiling staircase	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Basement ceiling entrance interior	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Basement ceiling entrance exterior	0.000	0.637	0.000	0.000	0.000	0.000	0.000
Basement ceiling bathroom	0.000	0.172	0.000	0.000	0.000	0.000	0.000
Wooden balcony	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Small window	0.000	0.238	0.000	0.000	0.000	0.000	0.000
Medium window	0.000	0.735	0.000	0.000	0.000	0.000	0.000
Large window	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Entrance door	0.000	0.826	-0.633	0.016	-0.148	0.001	-0.013
Apartment door	0.000	1.639	0.000	0.000	0.000	0.000	0.000
Balcony door	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Basement interior door	0.000	1.639	0.000	0.000	0.000	0.000	0.000
Interior door	0.000	-0.239	0.000	0.000	0.000	0.000	0.000
Sum	-0.001	0.014	-0.003	0.000	0.000	0.000	0.000

Table 23: Results for embodied impact, Concretecube, Hartwig

Name	Area [m ²]	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Concrete exterior wall	741.95	90815	2.84E-03	25.124	183.801	24.988	1100689	37464
Exterior wall basement	183.01	17203	6.67E-04	3.730	31.560	3.920	123979	6763
Exterior wall staircase above roof	20.04	2846	6.44E-05	1.030	9.420	1.260	30905	36505
Interior wall staircase	208.15	22358	8.85E-04	4.910	41.470	5.130	164552	9146
Interior wall staircase basement	52.78	6050	2.00E-04	1.680	14.830	1.880	53201	33424
Interior wall elevator	135.61	15174	6.00E-04	3.330	28.140	3.480	111675	6207
Interior wall	498.29	7177	3.57E-04	1.430	13.510	2.290	119248	46265
Interior partition wall	93.84	2492	1.24E-04	0.630	5.470	0.980	42063	20333
Interior wall basement	52.46	1708	2.87E-05	0.290	2.320	0.310	13927	669
Bottom slab	228.01	37507	1.45E-03	8.125	68.819	8.541	270313	14745
Roof above staircase	24.00	4698	1.10E-04	1.000	7.290	0.900	46503	1177
Wooden roof	204.00	-5549	4.59E-04	4.070	24.340	4.840	32389	543547
Concrete ceiling with parquet floor	612.67	46312	2.70E-03	19.238	170.475	23.220	676663	671229
Concrete ceiling bathroom	55.61	5951	2.12E-04	1.574	14.204	1.835	59090	33123
Basement ceiling with parquet floor	121.62	3438	1.03E-03	5.770	55.520	7.850	123839	443555
Concrete ceiling staircase	36.36	3092	1.22E-04	0.680	5.730	0.710	22756	1265
Basement ceiling entrance interior	19.90	563	1.68E-04	0.940	9.090	1.280	20263	72576
Basement ceiling entrance exterior	22.67	2024	7.85E-05	0.440	3.710	0.460	14590	796
Basement ceiling bathroom	13.82	1751	5.81E-05	0.450	4.010	0.520	17785	9055
Wooden balcony	99.69	-22137	6.33E-04	7.290	17.570	4.490	-146468	730650
Small window	6.37	752	4.21E-05	0.530	3.600	0.500	9180	3495
Medium window	10.83	1136	5.44E-05	0.710	5.380	0.750	13525	4362
Large window	54.88	5240	2.08E-04	2.850	24.350	3.460	61226	15032
Entrance door	9.89	859	2.42E-05	0.330	3.820	0.560	9905	1006
Apartment door	18.00	-177	1.22E-05	0.040	0.360	0.070	-593	8419
Balcony door	119.60	10410	3.00E-04	4.110	46.380	6.820	120028	12840
Basement interior door	8.00	303	1.22E-05	0.100	0.670	0.060	4022	231
Interior door	55.80	-608	4.19E-05	0.130	1.240	0.220	-2043	29000
Sum	3707.85	261388	1.35E-02	100.531	797.079	111.325	3113212	2792879

Table 24: Results for embodied impact, Concretecube, CAALA

Name	Area [m ²]	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Concrete exterior wall	713.58	87343	2.73E-03	24.163	176.773	24.033	1058600	36031
Exterior wall basement	183.01	17203	6.67E-04	3.730	31.560	3.920	123980	6763
Exterior wall staircase above roof	14.05	1996	4.50E-05	0.722	6.606	0.884	21671	25598
Interior wall staircase	259.87	27914	1.11E-03	6.130	51.775	6.405	205442	11419
Interior wall staircase basement	52.73	6045	2.00E-04	1.679	14.817	1.878	53154	33395
Interior wall elevator	137.56	15392	6.09E-04	3.378	28.545	3.530	113284	6296
Interior wall	549.62	7916	3.94E-04	1.577	14.902	2.526	131531	51031
Interior partition wall	100.71	2675	1.33E-04	0.676	5.871	1.052	45144	21822
Interior wall basement	62.91	2049	3.40E-05	0.348	2.782	0.372	16702	802
Bottom slab	228.01	37507	1.45E-03	8.125	68.819	8.541	270313	14745
Roof above staircase	25.14	4921	1.15E-04	1.048	7.637	0.943	48714	1233
Wooden roof	202.87	-5518	4.56E-04	4.047	24.205	4.813	32209	540534
Concrete ceiling with parquet floor	736.35	57260	3.34E-03	23.786	210.776	28.709	836627	829908
Concrete ceiling bathroom	63.71	6817	2.42E-04	1.803	16.272	2.102	67693	37946
Basement ceiling with parquet floor	156.21	4416	1.32E-03	7.411	71.309	10.082	159056	569692
Concrete ceiling staircase	36.16	3075	1.21E-04	0.676	5.698	0.706	22630	1258
Basement ceiling entrance interior	11.21	317	9.50E-05	0.529	5.120	0.721	11413	40878
Basement ceiling entrance exterior	21.15	1889	7.30E-05	0.411	3.461	0.429	13612	743
Basement ceiling bathroom	16.74	2121	7.00E-05	0.545	4.857	0.630	21540	10967
Wooden balcony	90.68	-20136	5.76E-04	6.631	15.982	4.084	-133228	664603
Small window	6.37	752	4.20E-05	0.530	3.600	0.500	9180	3495
Medium window	10.83	1136	5.40E-05	0.710	5.380	0.750	13525	4362
Large window	54.88	5240	2.08E-04	2.850	24.350	3.460	61226	15032
Entrance door	9.89	859	2.40E-05	0.332	3.819	0.561	9905	1006
Apartment door	18.21	-179	1.20E-05	0.040	0.364	0.071	-600	8518
Balcony door	128.57	11190	3.23E-04	4.418	49.859	7.332	129030	13803
Basement interior door	8.09	306	1.20E-05	0.101	0.678	0.061	4069	234
Interior door	55.80	-608	4.20E-05	0.130	1.240	0.220	-2043	29000
Sum	3954.93	279897	1.45E-02	106.527	857.055	119.314	3344380	2981113

Table 25: Differences of embodied impact, Concretecube, Hartwig - CAALA

Name	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Concrete exterior wall	3472.51	1.09E-04	0.961	7.028	0.955	42089.43	1432.51
Exterior wall basement	-0.19	0.00E+00	0.000	0.000	0.000	-1.35	-0.07
Exterior wall staircase above roof	850.27	1.94E-05	0.308	2.814	0.376	9233.61	10906.74
Interior wall staircase	-5555.81	-2.20E-04	-1.220	-10.305	-1.275	-40889.61	-2272.69
Interior wall staircase basement	5.31	0.00E+00	0.001	0.013	0.002	46.66	29.32
Interior wall elevator	-218.64	-9.00E-06	-0.048	-0.405	-0.050	-1609.12	-89.44
Interior wall	-739.24	-3.70E-05	-0.147	-1.392	-0.236	-12283.32	-4765.59
Interior partition wall	-182.51	-9.00E-06	-0.046	-0.401	-0.072	-3080.59	-1489.14
Interior wall basement	-340.39	-5.30E-06	-0.058	-0.462	-0.062	-2775.19	-133.31
Bottom slab	0.00	0.00E+00	0.000	0.000	0.000	0.00	0.00
Roof above staircase	-223.32	-5.00E-06	-0.048	-0.347	-0.043	-2210.68	-55.95
Wooden roof	-30.76	3.00E-06	0.023	0.135	0.027	179.56	3013.28
Concrete ceiling with parquet floor	-10948.10	-6.38E-04	-4.548	-40.300	-5.489	-159963.29	-158678.60
Concrete ceiling bathroom	-866.46	-3.04E-05	-0.229	-2.068	-0.267	-8603.67	-4822.84
Basement ceiling with parquet floor	-977.72	-2.93E-04	-1.641	-15.789	-2.232	-35217.01	-126137.01
Concrete ceiling staircase	17.17	1.00E-06	0.004	0.032	0.004	126.35	7.02
Basement ceiling entrance interior	245.70	7.30E-05	0.411	3.970	0.559	8850.00	31698.05
Basement ceiling entrance exterior	135.67	5.50E-06	0.029	0.249	0.031	977.80	53.35
Basement ceiling bathroom	-369.70	-1.19E-05	-0.095	-0.847	-0.110	-3755.18	-1911.90
Wooden balcony	-2001.06	5.70E-05	0.659	1.588	0.406	-13239.89	66046.68
Small window	0.00	1.00E-07	0.000	0.000	0.000	0.00	0.00
Medium window	0.00	4.00E-07	0.000	0.000	0.000	0.00	0.00
Large window	0.00	0.00E+00	0.000	0.000	0.000	0.00	0.00
Entrance door	0.00	2.00E-07	-0.002	0.001	-0.001	0.11	-0.14
Apartment door	2.07	2.00E-07	0.000	-0.004	-0.001	6.96	-98.77
Balcony door	-780.72	-2.30E-05	-0.308	-3.479	-0.512	-9002.10	-963.00
Basement interior door	-3.55	2.00E-07	-0.001	-0.008	-0.001	-47.18	-2.71
Interior door	0.00	-1.00E-07	0.000	0.000	0.000	0.00	0.00
Sum	-18509.47	-1.01E-03	-5.997	-59.976	-7.990	-231167.71	-188234.23

Table 26: Deviation of embodied impact, Concretecube, Hartwig - CAALA

Name	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Concrete exterior wall	3.824	3.825	3.824	3.824	3.824	3.824	3.824
Exterior wall basement	-0.001	0.000	-0.001	-0.001	-0.001	-0.001	-0.001
Exterior wall staircase above roof	29.877	30.124	29.877	29.877	29.877	29.877	29.877
Interior wall staircase	-24.849	-24.859	-24.849	-24.849	-24.849	-24.849	-24.849
Interior wall staircase basement	0.088	0.000	0.088	0.088	0.088	0.088	0.088
Interior wall elevator	-1.441	-1.500	-1.441	-1.441	-1.441	-1.441	-1.441
Interior wall	-10.301	-10.364	-10.301	-10.301	-10.301	-10.301	-10.301
Interior partition wall	-7.324	-7.258	-7.324	-7.324	-7.324	-7.324	-7.324
Interior wall basement	-19.927	-18.467	-19.927	-19.927	-19.927	-19.927	-19.927
Bottom slab	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Roof above staircase	-4.754	-4.545	-4.754	-4.754	-4.754	-4.754	-4.754
Wooden roof	0.554	0.654	0.554	0.554	0.554	0.554	0.554
Concrete ceiling with parquet floor	-23.640	-23.625	-23.640	-23.640	-23.640	-23.640	-23.640
Concrete ceiling bathroom	-14.560	-14.342	-14.560	-14.560	-14.560	-14.560	-14.560
Basement ceiling with parquet floor	-28.438	-28.447	-28.438	-28.438	-28.438	-28.438	-28.438
Concrete ceiling staircase	0.555	0.820	0.555	0.555	0.555	0.555	0.555
Basement ceiling entrance interior	43.676	43.452	43.676	43.676	43.676	43.676	43.676
Basement ceiling entrance exterior	6.702	7.006	6.702	6.702	6.702	6.702	6.702
Basement ceiling bathroom	-21.114	-20.482	-21.114	-21.114	-21.114	-21.114	-21.114
Wooden balcony	9.039	9.005	9.039	9.039	9.039	9.039	9.039
Small window	0.000	0.238	0.000	0.000	0.000	0.000	0.000
Medium window	0.000	0.735	0.000	0.000	0.000	0.000	0.000
Large window	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Entrance door	0.000	0.826	-0.671	0.017	-0.157	0.001	-0.014
Apartment door	-1.173	1.639	-1.172	-1.173	-1.173	-1.173	-1.173
Balcony door	-7.500	-7.667	-7.500	-7.500	-7.500	-7.500	-7.500
Basement interior door	-1.173	1.639	-1.173	-1.173	-1.173	-1.173	-1.173
Interior door	0.000	-0.239	0.000	0.000	0.000	0.000	0.000
Sum	-7.081	-7.515	-5.965	-7.525	-7.177	-7.425	-6.740

Table 27: Results for embodied impact, Concretecube, CAALA modified

Name	Area [m ²]	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Concrete exterior wall	741.95	90815	2.84E-03	25.124	183.801	24.988	1100700	37464
Exterior wall basement	183.01	17203	6.67E-04	3.730	31.560	3.920	123979	6763
Exterior wall staircase above roof	20.04	2846	6.40E-05	1.030	9.420	1.260	30905	36505
Interior wall staircase	208.15	22358	8.85E-04	4.910	41.470	5.130	164552	9146
Interior wall staircase basement	52.78	6050	2.00E-04	1.680	14.830	1.880	53201	33424
Interior wall elevator	135.61	15174	6.00E-04	3.330	28.140	3.480	111675	6207
Interior wall	498.29	7177	3.57E-04	1.430	13.510	2.290	119248	46265
Interior partition wall	93.84	2492	1.24E-04	0.630	5.470	0.980	42063	20333
Interior wall basement	52.46	1708	2.90E-05	0.290	2.320	0.310	13927	669
Bottom slab	228.01	37507	1.45E-03	8.125	68.819	8.541	270313	14745
Roof above staircase	24.00	4698	1.10E-04	1.000	7.290	0.900	46503	1177
Wooden roof	204.00	-5549	4.59E-04	4.070	24.340	4.840	32389	543547
Concrete ceiling with parquet floor	612.67	46312	2.70E-03	19.238	170.475	23.220	676663	671229
Concrete ceiling bathroom	55.61	5951	2.12E-04	1.574	14.204	1.835	59090	33123
Basement ceiling with parquet floor	121.62	3438	1.03E-03	5.770	55.520	7.850	123839	443555
Concrete ceiling staircase	36.36	3092	1.22E-04	0.680	5.730	0.710	22756	1265
Basement ceiling entrance interior	19.90	563	1.68E-04	0.940	9.090	1.280	20263	72576
Basement ceiling entrance exterior	22.67	2024	7.80E-05	0.440	3.710	0.460	14590	796
Basement ceiling bathroom	13.82	1751	5.80E-05	0.450	4.010	0.520	17785	9055
Wooden balcony	99.69	-22137	6.33E-04	7.290	17.570	4.490	-146468	730650
Small window	6.37	752	4.20E-05	0.530	3.600	0.500	9180	3495
Medium window	10.83	1136	5.40E-05	0.710	5.380	0.750	13525	4362
Large window	54.88	5240	2.08E-04	2.850	24.350	3.460	61226	15032
Entrance door	9.89	859	2.40E-05	0.332	3.819	0.561	9905	1006
Apartment door	18.00	-177	1.20E-05	0.040	0.360	0.070	-593	8419
Balcony door	119.60	10410	3.00E-04	4.110	46.380	6.820	120028	12840
Basement interior door	8.00	303	1.20E-05	0.100	0.670	0.060	4022	231
Interior door	55.80	-608	4.20E-05	0.130	1.240	0.220	-2043	29000
Sum	3707.85	261388	1.35E-02	100.533	797.078	111.326	3113223	2792879

Table 28: Differences of embodied impact, Concretecube, Hartwig – CAALA modified

Name	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Concrete exterior wall	0.000	-4.29E-07	0.000	0.000	0.000	-10.572	0.000
Exterior wall basement	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Exterior wall staircase above roof	0.000	4.00E-07	0.000	0.000	0.000	0.000	0.000
Interior wall staircase	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior wall staircase basement	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior wall elevator	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior wall	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior partition wall	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Interior wall basement	0.000	-3.00E-07	0.000	0.000	0.000	0.000	0.000
Bottom slab	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Roof above staircase	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Wooden roof	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Concrete ceiling with parquet floor	0.000	1.10E-07	0.000	0.000	0.000	0.000	0.000
Concrete ceiling bathroom	0.000	-3.54E-07	0.000	0.000	0.000	0.000	0.000
Basement ceiling with parquet floor	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Concrete ceiling staircase	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Basement ceiling entrance interior	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Basement ceiling entrance exterior	0.000	5.00E-07	0.000	0.000	0.000	0.000	0.000
Basement ceiling bathroom	0.000	1.00E-07	0.000	0.000	0.000	0.000	0.000
Wooden balcony	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Small window	0.000	1.00E-07	0.000	0.000	0.000	0.000	0.000
Medium window	0.000	4.00E-07	0.000	0.000	0.000	0.000	0.000
Large window	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Entrance door	-0.002	2.00E-07	-0.002	0.001	-0.001	0.108	-0.129
Apartment door	0.000	2.00E-07	0.000	0.000	0.000	0.000	0.000
Balcony door	0.000	0.00E+00	0.000	0.000	0.000	0.000	0.000
Basement interior door	0.000	2.00E-07	0.000	0.000	0.000	0.000	0.000
Interior door	0.000	-1.00E-07	0.000	0.000	0.000	0.000	0.000
Sum	-0.002	1.03E-06	-0.002	0.001	-0.001	-10.464	-0.129

Table 29: Deviation of embodied impact, Concretecube, Hartwig – CAALA modified

Name	GWP [kg CO ₂ e]	ODP [kg R11e]	POCP [kg C ₂ H ₄ e]	AP [kg SO ₂ e]	EP [kg PO ₄ ³ e]	PENRT [MJ]	PERT [MJ]
Concrete exterior wall	0.000	-0.015	0.000	0.000	0.000	-0.001	0.000
Exterior wall basement	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Exterior wall staircase above roof	0.000	0.621	0.000	0.000	0.000	0.000	0.000
Interior wall staircase	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior wall staircase basement	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior wall elevator	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior wall	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior partition wall	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Interior wall basement	0.000	-1.045	0.000	0.000	0.000	0.000	0.000
Bottom slab	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Roof above staircase	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wooden roof	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Concrete ceiling with parquet floor	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Concrete ceiling bathroom	0.000	-0.167	0.000	0.000	0.000	0.000	0.000
Basement ceiling with parquet floor	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Concrete ceiling staircase	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Basement ceiling entrance interior	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Basement ceiling entrance exterior	0.000	0.637	0.000	0.000	0.000	0.000	0.000
Basement ceiling bathroom	0.000	0.172	0.000	0.000	0.000	0.000	0.000
Wooden balcony	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Small window	0.000	0.238	0.000	0.000	0.000	0.000	0.000
Medium window	0.000	0.735	0.000	0.000	0.000	0.000	0.000
Large window	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Entrance door	0.000	0.826	-0.633	0.016	-0.148	0.001	-0.013
Apartment door	0.000	1.639	0.000	0.000	0.000	0.000	0.000
Balcony door	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Basement interior door	0.000	1.639	0.000	0.000	0.000	0.000	0.000
Interior door	0.000	-0.239	0.000	0.000	0.000	0.000	0.000
Sum	0.000	0.008	-0.002	0.000	-0.001	0.000	0.000

E. Data for Example 1

Physical properties of existing building

The physical properties of the existing building to be refurbished are shown in Table 30.

Table 30: Physical properties of existing building

Component	Layers	Thickness [m]	λ [W/mK]	U-value
Exterior wall	Lime sand plaster	0.020	0.800	1.77
	Brick	0.300	0.860	
	Lime plaster	0.015	0.700	
Roof living area	Roof tiles	0.020	1.000	2.22
	Wood beams / air	0.120	0.621	
	Gypsum board	0.025	0.250	
Roof unconditioned	Roof tiles	0.020	1.000	2.22
	Wood beams /air	0.120	0.621	
	Gypsum board	0.025	0.250	
Uppermost ceiling	Wooden floor	0.030	0.130	0.89
	Wood beams / filling	0.260	0.571	
	Wooden cladding	0.030	0.130	
Basement ceiling	Wooden floor	0.030	0.130	0.87
	Wood beams / filling	0.265	0.569	
	Brick	0.115	0.860	
Window	Double glazing 4/16/4			2.8

Combined data

The combined data including physical properties, environmental data and RSL for insulation materials employed for possible refurbishment solutions are provided in Table 31. Table 32 provides the combined data for the windows and Table 33 the environmental data for energy carriers.

Table 31: Combined data for insulation materials

Insulation	Unit	Physical properties		Environmental data									RSL
				A1-A3 + C3-C4									
		ρ	λ	PET	PERT	PENRT	GWP	ODP	AP	EP	POCP	ADPE	
		[MJ]	[MJ]	[MJ]	[kg CO2-equiv.]	[kg R11-equiv.]	[kg SO2-equiv.]	[kg PO43-equiv.]	[kg C2H4-equiv.]	[kg Sb-equiv.]	[a]		
EPS	1 kg	15.5	0.035	85.78	0.54	85.24	2.99	9.9E-08	0.00645	0.00068	0.01677	5.4E-07	40
XPS	1 kg	32.0	0.035	97.65	1.97	95.68	3.27	1.7E-05	0.00690	0.00064	0.00285	0.00086	40
PUR	1 kg	30.0	0.030	93.88	1.63	92.25	4.47	7.3E-08	0.01417	0.00147	0.00237	0.00034	40
GW	1 kg	60.0	0.035	31.57	2.43	29.14	1.80	3.8E-09	0.00366	0.00063	0.00042	7.0E-05	40
SW	1 kg	90.0	0.040	16.41	2.45	13.96	0.92	3.6E-08	0.00682	0.00116	0.00042	2.5E-07	40
FG	1 kg	117.0	0.042	28.86	8.80	20.05	1.30	4.2E-10	0.00282	0.00035	0.00024	7.1E-06	40
WFIB	1 kg	200.0	0.040	36.12	22.87	13.26	-1.55	1.8E-06	0.00117	0.00015	0.00025	1.2E-07	40
CIB	1 kg	80.0	0.040	44.82	16.10	28.72	0.85	9.4E-06	0.00636	0.00125	0.00046	0.00023	40
VIP	1 kg	145.0	0.007	235.97	47.85	188.11	9.33	1.3E-06	0.02989	0.00299	0.00253	0.00034	30

Table 32: Combined data for windows

Window	Unit	Physical properties		Environmental data									RSL
				A1-A3 + C3-C4									
		U	g	PET	PERT	PENRT	GWP	ODP	AP	EP	POCP	ADPE	
		[MJ]	[MJ]	[MJ]	[kg CO2-equiv.]	[kg R11-equiv.]	[kg SO2-equiv.]	[kg PO43-equiv.]	[kg C2H4-equiv.]	[kg Sb-equiv.]	[a]		
Double PVC-U	1 m ²	1.30	0.60	1314.2	45.40	1268.8	70.59	3.1E-06	0.34672	0.07527	0.02010	0.00214	40
Triple PVC-U	1 m ²	0.80	0.50	1533.2	52.63	1480.5	84.19	3.6E-06	0.40237	0.07875	0.02399	0.00235	40
Double wood	1 m ²	1.30	0.60	866.9	266.88	599.9	31.92	7.3E-07	0.17873	0.03050	0.02782	0.00087	40
Triple wood	1 m ²	0.80	0.50	1085.9	274.12	811.8	45.53	1.3E-06	0.23438	0.03399	0.03170	0.00108	40

Table 33: Environmental data of energy carriers

Energy carrier	Unit	Environmental data										
		B6										
		PET	PERT	PENRT	GWP	ODP	AP	EP	POCP	ADPE		
		[MJ]	[MJ]	[MJ]	[kg CO2-equiv.]	[kg R11-equiv.]	[kg SO2-equiv.]	[kg PO43-equiv.]	[kg C2H4-equiv.]	[kg Sb-equiv.]		
Gas	1 kWh			4.29	0.01	4.28	0.2606	1.1E-11	0.00021	3E-05	3.3E-05	1.3E-08
Electricity mix	1 kWh			10.26	1.49	8.77	0.6230	3.1E-09	0.00103	9.9E-05	7.6E-05	5.1E-08
Electricity wind	1 kWh			9.15	9.01	0.14	0.0118	4.1E-11	0.00003	2.5E-06	4.5E-06	-2.2E-07

Data for supplementary example of multi-criteria optimization

Table 34: GWP and costs of insulation materials

Insulation materials	ρ [kg/m ³]	λ_i [W/mK]	C [J/kg K]	GWP [kg CO ₂ -e/m ³]	Cost [€/m ³]
Glass wool (GW30)	30	0.035	810	45.2	88.00
Glass wool (GW50)	50	0.032	810	75.3	152.00
Glass wool (GW100)	100	0.035	810	150.6	285.00
Stone wool (SW40)	40	0.035	1030	52.0	143.80
Stone wool (SW50)	50	0.400	1030	104.0	269.00
Stone wool (SW100)	100	0.036	1030	124.8	226.00
Stone wool (SW34)	34	0.036	1030	156.0	196.50
Expanded polystyrene (EPS15)	15	0.038	1400	110.4	112.00
Expanded polystyrene (EPS30)	30	0.035	1500	220.9	174.00
Polyurethane foam (PUR)	30	0.027	1480	203.6	250.00
Wood fibre insulation board (WFIB50)	50	0.039	2100	21.6	150.00
Wood fibre insulation board (WFIB110)	110	0.040	2100	47.5	272.00
Wood fibre insulation board (WFIB140)	140	0.043	2100	60.4	299.00
Wood fibre insulation board (WFIB190)	190	0.045	2100	77.7	410.00
Cellulose (CE)	50	0.040	2150	19.6	100.00
Calcium silicate (CS115)	115	0.046	1300	48.4	339.00
Hemp fibre insulation board (HE)	40	0.040	1600	3.1	170.00
Vacuum insulation panels (VIP)	200	0.007	800	744.0	7500.00
Phenolic foam board (PF)	40	0.023	1400	260.3	335.00

Table 35: GWP and costs for types of constructions

Construction	RSL [a]	Δ GWP [kg CO ₂ -e/m ²]	GWP'(d) [kg CO ₂ -e/m ³]	Cost [€/m ²]	Cost(d) [€/m ³]
Interior Insulation vapour barrier (INTVB)	30	5.04	3.12	55.00	28.00
Interior Insulation capillary active (INTCA)	30	6.60	0.00	70.00	0.00
Exterior thermal insulation composite systems (ETICS)	30	11.00	0.00	85.00	0.00
Ventilated façade, wood cladding, wood substructure (VFW)	40	0.75	3.12	100.00	28.00
Ventilated façade, fibre cement cladding, aluminium substructure (VFA)	40	21.22	2084.88	115.00	20.00
Double brick cavity wall (DBCW)	60	59.00	0.00	135.00	0.00

F. Data for Example 2

Table 36: Heating system 1, gas fuelled heat pump + floor heating

	Layer name	Name in Ökobau.dat	Amount
1	Gas fuelled heat pump (Air)	Gaswärmepumpe (Luft) 20-70 kW	157 kg
2	Floor heating	Fußbodenheizung PP (200 mm Abstand)	1/1 m ²

Table 37: Heating system 2, electricity powered heat pump (earth) + floor heating

	Layer name	Name in Ökobau.dat	Amount
1	Electricity powered heat pump (earth)	Strom-Wärmepumpe (Sole-Wasser, Erdkollektor) 20 kW	4692 kg
2	Floor heating	Fußbodenheizung PP (200 mm Abstand)	1/1 m ²

Table 38: Heating system 3, gas condensing boiler + floor heating

	Layer name	Name in Ökobau.dat	Amount
1	Gas condensing boiler	Gas-Brennwertgerät 20-120 kW (Standgerät)	283 kg
2	Floor heating	Fußbodenheizung PP (200 mm Abstand)	1/1 m ²

Table 39: Heating system 4, gas condensing boiler + radiators

	Layer name	Name in Ökobau.dat	Amount
1	Gas condensing boiler	Gas-Brennwertgerät 20-120 kW (Standgerät)	283 kg
2	Radiator	Heizkörper Typ 22 h=600mm	1/20 m ²

Table 40: Heating system 5, wood chip boiler + floor heating

	Layer name	Name in Ökobau.dat	Amount
1	Wood chip boiler	Hackschnitzelkessel 20-120 kW	921 kg
2	Floor heating	Fußbodenheizung PP (200 mm Abstand)	1/1 m ²

Table 41: Heating system 6, district heating + floor heating

	Layer name	Name in Ökobau.dat	Amount
1	District heating	Übergabestation Fernwärme	20 kg
2	Floor heating	Fußbodenheizung PP (200 mm Abstand)	1/1 m ²

Table 42: Overview of building material combinations

Variant	Exterior wall	Roof	Ceiling	Interior wall	Slab
M1: ETICS	3: ETICS	1: Concrete	1: Concrete	2: Lime-sand stone	1: Concrete
M2: Brick	1: Poroton	1: Concrete	1: Concrete	3: Brick	1: Concrete
M3: Concrete	4: Concrete	1: Concrete	1: Concrete	1: Concrete	1: Concrete
M4: Wood	12: Wood frame	3: Wooden beams	6: Wooden beams	4: Wood frame	1: Concrete
M5: Ventilated facade	6: Ventilated facade	1: Concrete	1: Concrete	2: Lime-sand stone	1: Concrete
M6: Double shell	14: Double shell	3: Wooden beams	1: Concrete	4: Wood frame	1: Concrete

Table 43: Exterior wall 1, Poroton

	Layer name	Name in Ökobau.dat	Thickness [cm]		
1	Plaster	Oberputze Leichtputz RK 2mm - Alligator	2.00		
2	Insulated brick	Mineralwollgefüllte Ziegel - Deutsche POROTON	16	26	51
3	Plaster	Oberputze Leichtputz RK 2mm - Alligator	2.00		

Table 44: Exterior wall 3, external thermal insulation composite systems (ETICS) on lime sand stone

	Layer name	Name in Ökobau.dat	Thickness [cm]		
1	Plaster	Kunstharzputz - VDL	0.20		
2	Fibre glas reinforcement grid	Glasarmierungsgitter - Vitruvan	0.05		
3	Synthetic resin	Armierung (Kunstharzspachtel)	0.04		
4	EPS	EPS PS 15	7	13	25
5	Plaster	Armierung (Kunstharzspachtel)	0.20		
6	Lime sand stone	Kalksandstein - Bundesverband Kalksandstein	24.00		
7	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50		

Table 45: Exterior wall 4, concrete

	Layer name	Name in Ökobau.dat	Thickness [cm]		
1	Plaster	Kunstharzputz - VDL	0.20		
2	Fibre glas reinforcement grid	Glasarmierungsgitter - Vitrolan	0.05		
3	Synthetic resin	Armierung (Kunstharzspachtel)	0.04		
4	EPS	EPS PS 15	8	13	26
5	Synthetic resin	Armierung (Kunstharzspachtel)	0.20		
6	Concrete C20/25	Transportbeton C20/25	15.00		
7	Reinforcement	Bewehrungsstahl	0.3 (2 Vol%)*		

Table 46: Exterior wall 6, ventilated facade

	Layer name	Name in Ökobau.dat	Thickness [cm]		
1	Wooden cladding	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	2.40		
2	Wooden laths 40/60 mm	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	0.048*		
3	Sheathing membrane	Unterspannbahn PP	0.08		
4	Rock wool	Steinwolle Flachdachdämmplatte (140 mm)	6	11	23
5	Lime sand stone	Kalksandstein - Bundesverband Kalksandstein	24.00		
6	Plaster	Oberputze Leichtputz K2-3mm, RK 3mm - Alligator	1.50		

Table 47: Exterior wall 12, wood frame

	Layer name	Name in Ökobau.dat	Thickness [cm]		
1	Wooden cladding	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	0.20		
2	Wooden laths 40/60 mm	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	0.048*		
3	Wood fibre board	Holzfaserverplatte DFF - Egger	3.00		
4	Gypsum plaster board	Gipskartonplatte (Brandschutz)	0.95		
5	Wooden beam 12/18 cm	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	2.16*		
6	Wood fibre insulation board	Holzfaserdämmplatte (Trockenverfahren) Thermowall-gf - GUTEX	5	11	26
7	OSB board	OSB Eurostrand - Egger	1.80		
8	Gypsum plaster board	Gipskartonplatte	1.50		

Table 48: Exterior wall 14, double shell

	Layer name	Name in Ökobau.dat	Thickness [cm]		
1	Facing brick	Vormauerziegel	12.50		
2	Cellulose insulation boards	Zellulosefaserplatten	1	6	17
3	Brick	Mauerziegel Durchschnitt - Poroton	24.00		
4	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50		

Table 49: Roof 1, concrete

	Layer name	Name in Ökobau.dat	Thickness [cm]		
1	Gravel 2/32	Kies 2/32 getrocknet	4.00		
2	Bitumen sheeting	Bitumenbahnen G 200 S4	0.80		
3	XPS	XPS-Dämmstoff	12	18	25
4	Vapor barrier PA	Dampfbremse PA	0.30		
5	Concrete C20/25	Transportbeton C25/30	20.00		
6	Reinforcement	Bewehrungsstahl	0.8 (4 Vol%)*		
7	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50		

Table 50: Roof 3, wooden beams

	Layer name	Name in Ökobau.dat	Thickness [cm]		
1	Bitumen sheeting	Bitumenbahnen G 200 S4	0.80		
2	Wood fibre insulation board	Holzfaserdämmplatte (Trockenverfahren) Thermosafe-homogen - GUTEX	12	18	25
3	Vapor barrier PA	Dampfbremse PA	0.30		
4	Wooden planking	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	2.40		
5	Wooden beam 12/18 cm	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	2.16*		

Table 51: Slab 1, concrete

	Layer name	Name in Ökobau.dat	Thickness [cm]
1	Tiles	Steinzeugfliesen glasiert	1.00
2	Tile adhesive	Fliesenkleber	0.80
3	Cement screed	Zementestrich - IWM	6.00
4	Vapor barrier PE	Dampfbremse PE	0.02
5	XPS	XPS-Dämmstoff	6 10 25
6	Bitumen sheeting	Bitumenbahnen G 200 S4	0.40
7	Concrete C20/25	Transportbeton C25/30	25.00
8	Reinforcement	Bewehrungsstahl	1.00 (4 Vol%)*
9	Lean concrete	Transportbeton C25/30	8.00

Table 52: Ceiling 1, concrete

	Layer name	Name in Ökobau.dat	Thickness [cm]
1	Tiles	Steinzeugfliesen glasiert	1.00
2	Tile adhesive	Fliesenkleber	0.80
3	Cement screed	Zementestrich - IWM	6.00
4	Vapor barrier PE	Dampfbremse PE	0.02
5	Concrete C20/25	Transportbeton C25/30	18.00
6	Reinforcement	Bewehrungsstahl	0.72 (4 Vol%)*
7	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50

Table 53: Ceiling 6, wooden beams

	Layer name	Name in Ökobau.dat	Thickness [cm]
1	Parquet floor	Stabparkett	2.00
2	Dry screed	Trockenestrich (Gipsfaserplatte)	2.50
3	Wood fibre footstep sound insulation	Holzfaserdämmplatte (Trockenverfahren) Thermosafe-homogen - GUTEX	2.00
4	Chipboard	Spanplatte (Durchschnitt)	2.50
5	Wood beam 12/18 cm	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	2.16
6	Vapor barrier PE	Dampfbremse PE	0.02
7	Wooden laths 30/60 mm	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	0.036*
8	Wooden cladding	Schnittholz Fichte (12% Feuchte/10,7% H ₂ O)	2.40

Table 54: Interior wall 1, concrete

	Layer name	Name in Ökobau.dat	Thickness [cm]	
1	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50	
2	Concrete C20/25	Transportbeton C25/30	15.00	10.00
3	Reinforcement (2 %)	Bewehrungsstahl	0.30*	0.20*
4	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50	

Table 55: Interior wall 2, lime sand stone

	Layer name	Name in Ökobau.dat	Thickness [cm]	
1	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50	
2	Lime sand stone	Kalksandstein - Bundesverband Kalksandstein	17.50	11.50
3	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50	

Table 56: Interior wall 3, brick

	Layer name	Name in Ökobau.dat	Thickness [cm]	
1	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50	
2	Brick	Mauerziegel Durchschnitt - Poroton	17.50	11.50
3	Gypsum plaster	Gipsputz (Gips-Kalk-Putz)	1.50	

Table 57: Interior wall 4, wood frame

	Layer name	Name in Ökobau.dat	Thickness [cm]	
1	OSB board	OSB Eurostrand - Egger	1.80	
2	Wooden beam 6/10 cm	Wooden beam 6/8cm Schnittholz Fichte (12% Feuchte/10,7% H2O)	3.75*	3.00*
3	Rock wool	Steinwolle Flachdachdämmplatte (140 mm)	7.50	
7	OSB board	OSB Eurostrand - Egger	0.90	