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Estimation of base-values for Grey Energy, Primary Energy, Global Warming Potential (GWP 100A) and *Umweltbelastungspunkte* (UBP 2006) for Swiss constructions from before 1920 until today

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Abstract

This paper presents a framework to estimate base-values for embodied energy and CO_2 emissions of the Swiss building stock. These values are estimated for existing, renovated and future constructions. Using the approach of Fonseca et al. (2014), the impacts of standing and future buildings at the urban scale can be calculated from these values. The framework allows to quickly estimate the environmental impact of a set of buildings from its year of construction or renovation, saving the effort of a thorough examination of buildings properties. The work was done as part of the so called INDUCITY Project by ETH Zürich, Siemens A.G. and WERZ institute (2014), which compared the impacts of embodied energy in buildings for the sustainable transformation of an urban area in Switzerland.

Keywords: Trends in Grey Energy and Emissions, Building sector

1. Introduction

The world's population shifts increasingly towards urban areas (United Nations, 2014). Those new arrivals need places for living, working and leisure. Hence cities grow (United Nations, 2014) and new residential, commercial and industrial buildings are needed. Meanwhile, old buildings are refurbished in order to accord with changing requirements and standards (McGraw-Hill Construction, 2009). But can this evolution be mastered in a sustainable manner?

Important sustainability-indicators of constructions are their Grey Energy and Grey Emissions. The Swiss Society of Engineers and Architects SIA (2004) defines Grey Energy as a "number in energy units (MJ or kWh) that contains the cumulated energy expenditure for the production of a good". Grey Emissions are the defined by the Swiss environmental department BAFU (2007) as the "emitted pollutants, caused by the production of goods […] and the disposal of their waste products".

This paper presents a methodology to estimate values for Grey Energy (GE), Primary Energy (PE), Global Warming Potential (GWP 100A) and *Umweltbelastungspunkte* (UBP 2006) for Swiss constructions from the database of Holliger Consultant (2002), a large state-supported official database of construction materials and designs. This database contains detailed compositions of many base-constructions in Switzerland. The building components, such as walls, floors, roofs, windows, etc. are shown with the above-named values of GE, PE, GWP 100A and

UBP 2006, which are all calculated according to the SIA standard 2032 (SIA, 2010). The Global Warming Potential here stands for the Grey Emissions in CO_2-equivalents, accounted for 100 years (Holliger Consultant, 2002).

Swiss constructions and renovations are categorized in blocks according to their time of construction/renovation, and the building type.

In order to receive the GE, PE, GWP 100A and UBP 2006 of the buildings, typical compositions of construction or renovation building components such as exterior walls, roofs, slab-floors etc. are identified. For constructions, this is done according to the Intelligent Energy Project TABULA (2014), a database which lists typical buildings with construction-periods from as early as 1850 for European countries. Switzerland is not included in the database; however conclusions are drawn from constructions in Germany and Austria under the assumption of vast similarities with Switzerland. Data for the most recently constructed buildings is taken in from the database of Holliger Consultant (2002). For renovations, the typical measures are estimated from TFT TIE Kinetix GmbH (2014), a study on major weaknesses of constructions from the different periods. From these and the base constructions for each period, the renovation building components are estimated.

From these typical construction and renovation building components, base-designs for Swiss buildings and renovation measures are defined. Knowing the base-designs and the GE, PE, GWP 100A and UBP 2006 of the used materials from Holliger Consultant (2002), these four indicators are then calculated for the Swiss buildings according to their time of construction/renovation and building type.

Many existing studies, e. g. Enerdata (2012) and (U.S. DOE, 2008), have addressed the temporal development of yearly energy-use and emissions of the building sector due to operation. In order to reduce the energy-use and emissions of buildings, governments have passed standards, such as the MINERGIE standard in Switzerland for new constructions and renovations. However, when analyzing buildings yearly energy-use and emissions, one should also consider the buildings yearly Grey Energy and Grey Emissions, which is done by dividing the total Grey Energy and Grey Emissions by the buildings lifetime. This can't be done without knowledge of the Grey Energy and Grey Emissions of existing buildings. The here presented framework presents a basis for estimating the Grey Energy and Grey Emissions of old buildings from their year of construction and renovation.

Therefore, this framework provides additional information for evaluating the temporal development of the environmental impact of the building sector.

The results of this paper give valuable information about the ecological impact of the building sector in Switzerland, being an important input for policy makers, the building industry as well as real estate owners. This work represents a part of the so called INDUCITY Project (see ETH Zürich, Siemens A.G. and WERZ institute, 2014).

This project elaborated different scenarios for the transformation of a Swiss city quarter and examined them in terms of their environmental impacts.

Applying a similar methodology to other countries would give great input for evaluating trend of the ecological impact of the building sector and support advances towards a more sustainable urban development.

2. Method

Based on the approach of Girardin et al. (2012), we classify Swiss buildings in five construction periods. The five different categories are constructions before 1920, between 1920 and 1970, between 1970 and 1980, between 1980 and 2005 and between 2005 and 2020 (new constructions). Likewise, renovation measures in these periods are examined, however, renovation of buildings before 1920 is not considered, due to the very poor availability of data for this time. Hence, the analysis that is described in the following is performed for all these time-periods.

First, we assign buildings to certain categories, of which the main categories are industrial, residential and commercial buildings. The latter two are divided into several sub-categories. Residential buildings are divided in multiple dwelling units, hotels, and single dwelling units. The category commercial buildings includes administrative, commercial, educational, fitness/sports, supermarkets, public/other, restaurants, hospitals, swimming halls, server rooms, icerings, deposit/parking and cooling-rooms. Cooling-rooms as well as server rooms are usually part of other types of buildings. In some special cases, however, they might exist as stand-alone services, why they were assigned own categories

In the next step, for each category, base case building components (layers and thicknesses) for exterior walls above ground, exterior walls below ground, floors/ceilings, supporting interior walls, non-supporting interior walls, roofs, slab floors and windows are defined. In order to find appropriate base case building components for Swiss buildings constructed before 2005, we correlate them to those of the German and Austrian building stocks provided by the Intelligent Energy Project TABULA (2014). For Swiss buildings constructed after 2005, we first define base case building components by comparing common constructions in (Verein MINERGIE (AMI), 2012) and the Holliger Consultant (2002) database.

The embodied energy is then found by entering the defined case building components into the calculation tool of the Holliger Consultant (2002) database, which then delivers the components' GE, PE, GWP 100A and UBP 2006 according SIA (2010). In many cases it is assumed that the categories multiple dwelling units, hotel, administrative, education, hospital and public/other share similar properties. Some Similarities are also assumed for commercial, supermarkets, restaurants, fitness-sport, swimming hall, icering and cooling-rooms. Furthermore, in many cases, similarities are assumed between Industrial buildings and deposit/parking.

2.1 Base-values of pure materials and general construction components

We estimate the composition of base constructions (layers and thicknesses) for every time period, category and sub-category of buildings. Then we use the database of building materials (Holliger Consultant, 2002) to determine the values of GE, PE, GWP 100A and UBP 2006. The relevant values of pure construction materials from Holliger Consultant (2002) are listed in Table 1.

Material	Grey Energy [MJ/m²]	GWP 100A [kg/m²]	Primary Energy [MJ/m²]	UBP 2006 [Pt/m²]
Brick	27.33	2.57	30.05	1899.13
Concrete wall	35.18	3.78	41.85	5707
Concrete roof	31.88	3.59	35.1	5211.43
Wood	25.84	1.45	141.05	5030.81
Plaster	35	2.19	38.34	3369.15
Cellulose	3.72	0.2	5	635.64
EPS/XPS	30.74	3.25	31.09	2055.53
Mineral fiber	9.13	0.63	10.17	646.48
Glass wool	13.73	0.45	14.89	672.05
PUR/PIR	30.4	2.03	31.19	1830.03
Foam glass	21.64	1.28	29.11	992.82

Table 1: Base-values for Grey Energy, Global Warming Potential, Primary Energy and Umweltbelastungspunkte for different pure construction materials per centimeter thickness extracted from Holliger Consultant (2002)

Using the articles of Eicke-Hennig, W. (2011a and 2011b) on insulation materials described in, we assign the type of insulation materials used in buildings according to its construction period in the following way: In the construction period from 1920 until 1970, an insulation material mix of 60 % wood-fiber, 15 mineral-fiber, 15 % glass wool, 10 % EPS/XPS is assumed. From 1970 until 1980, 45 % mineral-fiber, 35 % glass wool and 20 % EPS/XPS is assumed. For the years between 1980 and 2005, we assume an insulation material mix of 40 % mineral-fiber, 30 % glass wool, 25 % EPS/XPS, 2 % PUR/PIR, 1.5 % cellulose and 1.5 % foam glass. The insulation material mix for new constructions, hence for the period between 2005 and 2020 is approximated to 35 % EPS/XPS, 28 % mineral-fiber, 22 % glass wool, 3.5 % foam glass and 3.5 % cellulose. With these assumptions and the values for pure insulation materials listed in Table 1, base-values for the insulation mix in the respective time-periods can be calculated. As an example, Formula (1) shows, how the base value for Grey Energy of the insulation mix for the period between 1970 and 1980 is calculated.

$$GE_{insulation-mix} = 0.45 \cdot GE_{mineral-fiber} + 0.35\, GE_{glass\,wool} + 0.2\, GE_{EPS/XPS} \quad (1)$$

Construction-period	Grey Energy [MJ/m²]	GWP 100A [kg/m²]	Primary Energy [MJ/m²]	UBP 2006 [Pt/m²]
1920-1970	8.71	0.55	9.87	773.44
1970-1980	15.06	1.09	16.01	937.24
1980-2005	16.44	1.26	17.44	1035.12
2005-2020	19.65	1.63	20.69	1251.7

Table 2: Average base-values for Grey Energy, Global Warming Potential, Primary Energy and Umweltbelastungspunkte of the typical insulation mix of different time-periods (Holliger Consultant, 2002, Eicke-Hennig, W. 2011a and 2011b)

The values of GE, PE, GWP 100A and UBP 2006 for the relevant window types arise from SIA (2010). In the next chapter we specify the main window types for the respective construction periods. Other important construction components are stream breaks and sealing-sheetings. Table 3 lists the typical GE, PE, GWP 100A and UBP 2006 of steam breaks and sealing-sheetings (Holliger Consultant, 2002).

Construction elements	Grey Energy [MJ/m²]	GWP 100A [kg/m²]	Primary Energy [MJ/m²]	UBP 2006 [Pt/m²]
steam break	30.19	2.19	31.72	1957.44
sealing sheeti	174.66	12	178.29	9786.81

Table 3: Average base-values for Grey Energy, Global Warming Potential, Primary Energy and Umweltbelastungspunkte of typical construction components (Holliger Consultant, 2002)

In order to now calculate the embodied energy of the construction components for the different time-periods, we define representative base case construction components for every considered time-period in the following section.

2.2 Description of new buildings per construction-period

2.2.1 Construction time before 1920

Solid brick was the main construction material for all types of walls. Here, the building types differ mostly in layer thickness. Concrete, brick and wood were used for slab floors, floors and ceilings. Roofs were generally built of wood Straw and cork were the main insulation materials [3]. Since both of them only need low energy input, insulation materials are ignored in this analysis for constructions from before 1920. The window-type for all constructions is assumed to be single-glazed windows with wooden frame and 25 % frame fraction (TABULA ,2014).

2.2.2 Construction time between 1920 and 1970

In this construction period, exterior walls both below and above ground were mainly built of hollow or honeycomb bricks with a cladding of wood or plaster. The building types differ mostly in layer thickness, however plaster is assumed to not have been used for cladding of industrial walls. Interior walls consisted mainly of hollow bricks or wood. Concrete, wood and plaster were the main materials for slab floors, floors and ceilings. Roofs consisted basically of a wood-beam structure or concrete, insulated with a 5 cm layer of the insulation material mix listed in Table 2.2. Industrial roofs are the exception, generally being built of concrete only. The main window-type was double-glazed windows with a wooden frame and 25 % of frame fraction (TABULA ,2014).

2.2.3 Construction time between 1970 and 1980

Between 1970 and 1980, hollow or honeycomb bricks with a plaster-cladding and a thin insulation layer was the base composition of exterior walls of most building types. However, for industrial and commercial buildings, a high share of concrete walls with a thin insulation layer and plastering was used as well. Interior walls were mainly built of plastered hollow or honeycomb bricks and again, for a high fraction of commercial and industrial buildings, the bricks were replaced by concrete (TABULA, 2014, Eicke-Hennig, W. ,2011a and 2011b).

Interior walls of most building types were made of plastered hollow or honeycomb bricks. For commercial and industrial buildings, a high share of concrete was used interior walls as well. Floors and ceilings were generally made of concrete and for some building types, an insulation layer for soundproofing was used. Roofs mainly consisted of concrete as well, with an additional insulation layer for most of the building types. The main window type used was the double-glazed plastic frame window with 25 % of frame fraction. An exception are the double-glazed wooden frame windows with 25 % frame fraction, in single dwelling units and administrative (TABULA, 2014).

2.2.4 Construction time between 1980 and 2005

The first basic exterior wall type in this construction period consisted of plastered one- or two-layered brickwork with an insulation layer. For walls below ground, steam break and sealing as listed in Table 2.3 are added (TABULA ,2014). The second basic type was the sandwich panel wall, used mainly in industrial and commercial buildings (Holliger Consultant, 2002).

Supporting interior walls were generally plastered brick or pure concrete for industrial and commercial buildings. Slab floors were basically made of concrete. Floors and ceilings were made of concrete with an additional layer of sound insulation for most building types. For industrial and some commercial types, steel-sheeted concrete was used for floors and ceilings. The main roof types were insulated and sealed wood-beam roofs for small buildings, insulated and sealed concrete flat-roofs for larger buildings and profiled sheeting flat roofs for industrial and some commercial buildings. Furthermore, mainly double-glazed windows with plastic or aluminum frame of 10 % frame-fraction were used (TABULA ,2014).

2.2.5 Construction time after 2005

In this construction-period the variety of different construction compositions (TABULA, 2014) make it difficult to define real base-constructions. However, comparing different recent compositions with the database of Holliger Consultant (2002), most of the general compositions do not differ much in their values for GE, PE, GWP 100A and UBP 2006. Therefore, the following examples are used for the different categories.

The basic type of exterior walls above ground are exposed concrete walls with exterior insulation and plastering. For industrial and some commercial buildings, insulated sandwich panel walls are used. Exterior walls below ground are generally sealed, plastered and insulated concrete walls. For part of industrial and commercial cases, simple water-proof concrete walls without insulation are used.
Supporting interior walls were mainly cladded concrete and exposed concrete for industrial and commercial buildings respectively. For base non-supporting interior walls, either plastered and sound insulated steel sheets, or sound insulated wood-stud walls (as in the Baloon-frame building style) are used.

The typical floors and ceilings consist in a structural slab of concrete with sound insulation and steam break. In industrial and some commercial buildings, steel-sheeted concrete floors and ceilings are used. Base Slab floors consist of sealed and insulated concrete with a cement layer. For part of the industrial and some commercial buildings, only water-proof concrete is used (e.g. for the parking areas).

For most of the buildings either slanted insulated and sealed wood-beam roofs with a layer of bricks, or flat insulated and sealed concrete roofs with a layer of gravel are used. For the roofs of Industrial and some Commercial buildings, either slanted, insulated sandwich panel roofs or profiled sheeting flat roofs are used.

All the above listed compositions arise from comparison of the databases of Holliger Consultant (2002), TABULA (2014) and the Minergie certified elements in Verein Minergie (2012).

From the assumptions and base-construction components defined in the sections 2.2.1 – 2.2.5, now the GE, PE, GWP 100A and UBP 2006 is calculated for the different building types. The results are described in the next section.

2.3 Results for new buildings

The results are obtained for each building type and construction component, for all of the considered time periods. As an example, Table 4 shows the results for multiple dwelling units. The results for all the other building types are available upon request.

Multiple dwelling unit		Exterior wall above ground	Exterior wall below ground	Floor / ceiling	Interior wall (supporting)	Interior wall (non-supporting)	Roof	Slab floor	Windows
2005-2020	Grey Energy [MJ/m²]	1241	1633	673	662	305	992	1642	1273
	GWP 100A [kg/m²]	112	188	75	73	16	78	180	85
	Primary Energy [MJ/m²]	1390	1790	771	799	960	1574	1715	1492
	UBP 2006 [Pt/m²]	127078	178583	90545	105908	29498	103889	198852	98936
1980-2005	Grey Energy [MJ/m²]	786	991	829	377	240	1122	1155	1055
	GWP 100A [kg/m²]	57	71	91	34	21	113	104	69
	Primary Energy [MJ/m²]	835	1045	939	414	264	1216	1217	1104
	UBP 2006 [Pt/m²]	50012	61756	114773	27108	17613	149528	150845	81694
1970-1980	Grey Energy [MJ/m²]	407	392	994	377	240	1032	1029	1957
	GWP 100A [kg/m²]	36	35	110	34	21	113	113	123
	Primary Energy [MJ/m²]	446	430	1093	414	264	1133	1131	2045
	UBP 2006 [Pt/m²]	28983	28046	158686	27108	17613	161029	162055	151080
1920-1970	Grey Energy [MJ/m²]	388	388	1048	353	213	534	1048	926
	GWP 100A [kg/m²]	34	34	113	32	20	57	113	62
	Primary Energy [MJ/m²]	427	427	1322	388	256	366	1322	1546
	UBP 2006 [Pt/m²]	29198	29198	168943	23944	17588	58086	168943	91052
Before 1920	Grey Energy [MJ/m²]	601	601	659	410	342	517	440	688
	GWP 100A [kg/m²]	57	57	68	39	32	29	39	47
	Primary Energy [MJ/m²]	661	661	810	451	376	564	935	1268
	UBP 2006 [Pt/m²]	41781	41781	82696	28487	23739	100616	49537	73839

Table 4: The Table shows the four environmental impact indicators Grey Energy, GWP 100A, Primary Energy and UBP 2006 for multiple dwelling units in Switzerland for different times of construction.

The values for GE, PE, GWP 100A and UBP 2006 listed in Table 4 can now be examined in terms of their development over time. This examination is done as an example again for one building type. Hence, Figure 1 illustrates the temporal development of the embodied Grey Energy of Swiss multiple dwelling units. As the figure shows, the Grey Energy for the different wall types has been increasing since 1920, whereas the Grey Energy of floors / ceilings and roof seems to have decreased during the last decades. The development of the Grey Energy of the wall types can probably be explained with the more and more growing use of EPS as an insulation material (Eicke-Hennig, W., 2011a and 2011b). The very sharp increase in Grey Energy and Grey Emissions of exterior walls and slap floors is particularly noticeable.

Figure 1 furthermore shows a peak in Grey Energy embodied in windows between 1970 and 1980. The Grey Energy of windows then decreased again, but started to increase again after 2005. This development might be explained by the decrease of frame-fraction after 1980 arising from the database TABULA (2014) which led to a decreasing Grey Energy. The increase after 2005 could be explained by the shift from double- to triple glazed windows (TABULA, 2014).

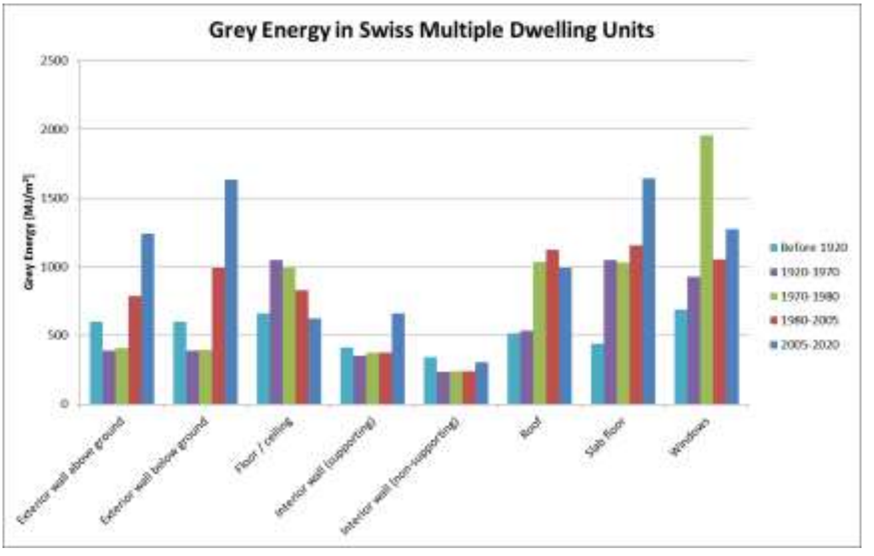

Figure 1: The Figure illustrates the trend of the Grey Energy embodied in new constructed multiple dwelling units in Switzerland.

The same examination is done for Grey Emissions (GWP 100A). The bar chart in Figure 2 illustrated the results, which are qualitatively similar to the results in Figure 1. This analogy is not surprising, since the energy-use and caused emissions depend on one another.

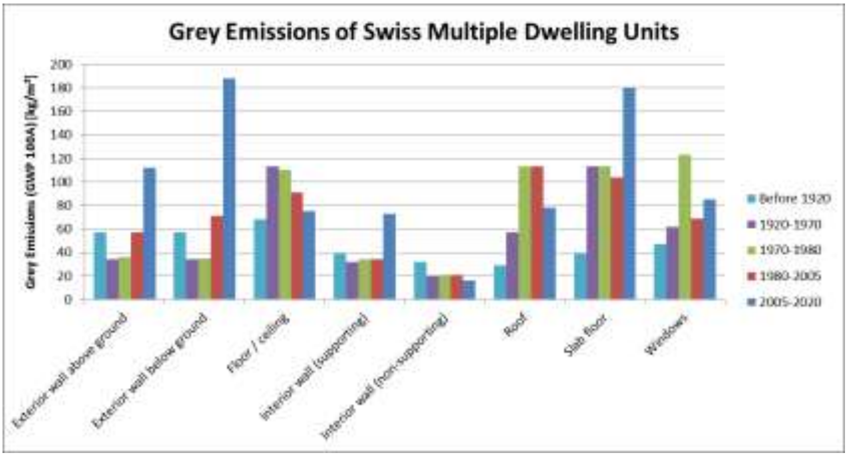

Figure 2: The Figure illustrates the temporal development of the Grey Emissions of new constructed multiple dwelling units in Switzerland.

In the following section, the same analysis is now done for refurbishments.

2.4 Description of refurbishments per construction-period

2.4.1 Refurbishment time before 1920

The main faults of existing buildings in that time period were degrading wooden, straw and cork parts and cracks in the brick and concrete parts of the buildings (Eicke-Hennig, W., 2011a). It is assumed here, that common refurbishment measures for these faults were rather rudimentary and hence caused only negligible GE, PE, GWP 100A and UBP 2006 impacts. Refurbishment measures for improvement of the thermal envelopes of the constructions have been done by adding the contemporary insulation materials straw and cork (Eicke-Hennig, W., 2011a) that due to their low energy input are ignored in this analysis as well. It is therefore assumed that refurbishment measure before 1920 didn't cause additional GE, PE, GWP 100A and UBP 2006.

2.4.2 Refurbishment time between 1920 and 1970

For this very long construction-period it is assumed that refurbishments were undertaken most likely at the end of the period. Therefore, the following estimated refurbishment measures are rather typical for the later years of the period from 1920 until 1970.

During that time-period, the major refurbishment measures were an addition of a layer of the typical insulation material mix (Table 2) to roofs and exterior walls (Eicke-Hennig, W., 2011b), which as well worked against the problem of water leaking into the buildings (TFT TIE Kinetix GmbH, 2014). It is assumed, that the added insulation layer is of the same thickness as the contemporary insulation layer for new constructions in the respective building-type. Furthermore, old and untight windows were replaced by the contemporary window-type, i. e. double-glazed windows with a wooden frame and 25 % of frame fraction. It is assumed here, that these two measures were only done in part of the industrial buildings, as thermal insulation was rather untypical for this building type in the respective time-period (Eicke-Hennig, W., 2011b). Another important refurbishment measure was the repairing of cracks in plaster, concrete and roof covering and the replacement of degraded wooden parts (TFT TIE Kinetix GmbH, 2014).

2.4.3 Refurbishment time between 1970 and 1980

Between 1970 and 1980 the most common refurbishment measure was an addition of the contemporary insulation layer to the building envelope, in order to overcome the water condensation problems (Eicke-Hennig, W., 2011a). Furthermore, the windows were replaced by the typical type for that time-period, i.e. plastic-framed, double glazed windows with 25 % frame fraction (Eicke-Hennig, W., 2011b).

Repairing cracks in plaster, concrete and roof covering and the replacement of degraded wooden parts were common, as well as the addition of soundproofing to floors/ceilings of some constructions (TFT TIE Kinetix GmbH, 2014).

2.4.4 Refurbishment time between 1980 and 2005

During this time-period, the refurbishment measures were similar to the ones between 1970 and 1980, with a new insulation mix (Eicke-Hennig, W., 2011a). The window-type for replacement changed to double-glazed plastic-frame windows with 10 % of frame-fraction. Furthermore, steam-breaks and sealing sheetings were added to roofs, exterior walls below ground, some floors and ceilings and slab floors. Soundproofing was now also added to parts of the interior walls. (TABULA, 2014)

2.4.5 Refurbishment time between 2005 and 2020

Refurbishments after 2005 were very similar to the ones between 1980 and 2005, with the only differences that the insulation-material mix changed and due to stricter regulations (Eicke-Hennig, W., 2011b), the thickness of the insulation layers increased in order to obtain better thermal insulation. The basic window-type changed to a mix of plastic-framed, wood-framed and aluminum-framed, triple-glazed windows with 10 % frame-fraction. (TABULA, 2014)

2.5 Results for refurbishments

Again, the results are obtained for each building type and construction component, for all of the considered time periods. As an example, Table 5 shows the results for multiple dwelling units. The results for all the other building types are available upon request.

Hospital		Exterior wall above ground	Exterior wall below ground	Floor / ceiling	Interior wall (supporting)	Interior wall (non-supporting)	Roof	Slab floor	Windows
2005-2020	Grey Energy [MJ/m²]	467	672	109	90	90	598	551	1273
	GWP 100A [kg/m²]	38	52	8	6	6	47	44	85
	Primary Energy [MJ/m²]	494	704	230	99	99	624	576	1492
	UBP 2006 [Pt/m²]	30906	42651	13208	7248	7248	36778	30983	98936
1980-2005	Grey Energy [MJ/m²]	167	371	93	44	44	336	302	1055
	GWP 100A [kg/m²]	12	26	7	3	3	24	23	69
	Primary Energy [MJ/m²]	178	388	214	49	49	350	315	1104
	UBP 2006 [Pt/m²]	11650	23394	12229	4016	4016	20025	21096	81694
1970-1980	Grey Energy [MJ/m²]	95	95	75	35	35	107	142	1957
	GWP 100A [kg/m²]	7	7	5	2	2	9	11	123
	Primary Energy [MJ/m²]	102	102	80	38	38	115	153	2045
	UBP 2006 [Pt/m²]	7118	7118	4686	3369	3369	9898	13267	151080
1920-1970	Grey Energy [MJ/m²]	114	114	91	53	53	107	91	928
	GWP 100A [kg/m²]	7	7	5	3	3	10	5	62
	Primary Energy [MJ/m²]	126	126	269	58	58	120	269	1546
	UBP 2006 [Pt/m²]	10662	10662	12600	5054	5054	14346	12600	91052

Table 5: The Table shows the four environmental impact indicators Grey Energy, GWP 100A, Primary Energy and UBP 2006 for refurbishment measures in Swiss hospitals for different times of refurbishment.

The values listed in Table 5 can now again be examined in terms of their temporal development. This examination is done here exemplary for hospitals. Figure 3 shows the development of the respective Grey Energy, Figure 4 shows it for Grey Emissions (GWP 100A).

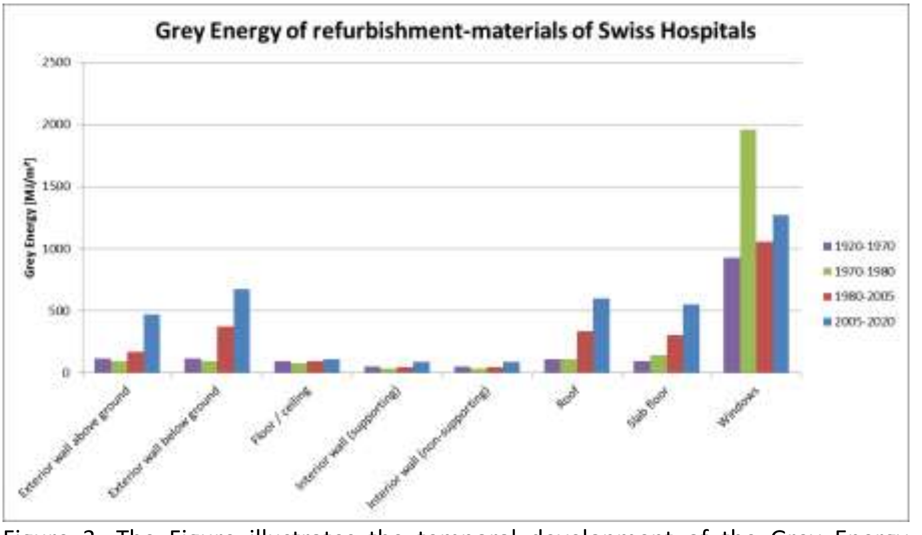

Figure 3: The Figure illustrates the temporal development of the Grey Energy embodied in the materials used for refurbishing multiple dwelling units in Switzerland.

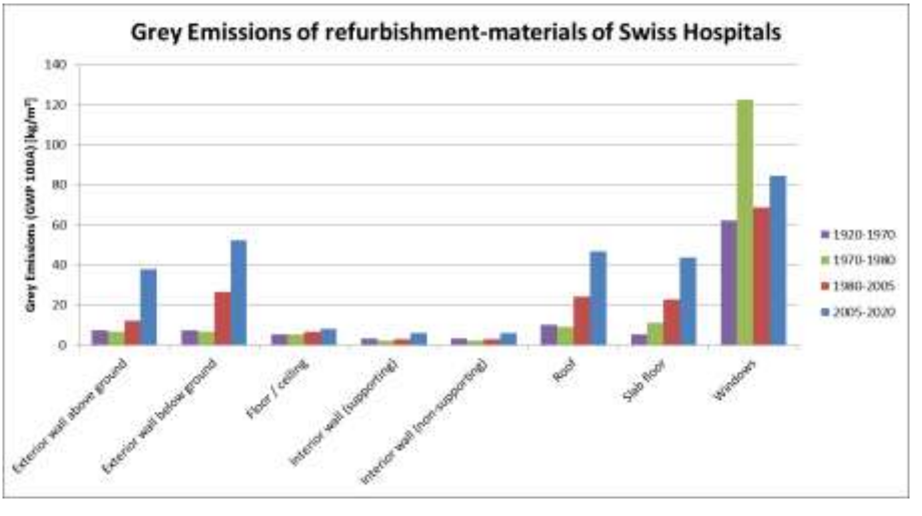

Figure 4: The Figure illustrates the temporal development of the Grey Emissions included in the materials used for refurbishing multiple dwelling units in Switzerland.

Qualitatively, Figure 3 and 4 look very similar. From the figures it can be concluded, that the Grey Energy and Grey Emissions of refurbishment materials have generally increased over time for all the different types of building components, except for windows. Similar to the results in section 2.3, the Grey Energy and Grey Emissions from window refurbishment peaked between 1970 and 1980.

3. Conclusion and Discussion

With the here presented framework, base values for Grey Energy (GE), Primary Energy (PE), Global Warming Potential (GWP 100A) and *Umweltbelastungspunkte* (UBP 2006) were calculated per square meter of the respective component of the building (i. e. for exterior walls above ground, exterior walls below ground, floors/ceilings, supporting interior walls, non-supporting interior walls, roofs, slab floors and windows). The analysis was performed for the Swiss building stock, for different time-periods, whereat building-types (e.g. multiple dwelling units, hotels, offices, etc.) were assigned to different categories.

With knowledge of the geometry and the year of construction and renovation, now the total values of these four indicators can be calculated for a specific building. An application of the database created in this manuscript is presented in Fonseca et al. (2014). The authors use the presented framework to identify the contribution of the embodied energy of buildings into the whole energy consumption of a city quarter. It further lead to evaluate how this fraction might change under different planning scenarios and then find a correlation to future forms of urban development. Figure 5 shows a picture of the four different scenarios they assessed for a city quarter in Switzerland.

Figure 5: The four pictures show four different planning scenarios for a city quarter in Switzerland, developed within the INDUCITY project by ETH Zürich, Siemens A.G. and WERZ institute (2014).

Fonseca et al. (2014) compared the four different scenarios “Business-as-usual”, “Campus”, “High End Business” and “Urban Condenser” with the status quo of the city quarter, selecting and amortization age of 60 years for the analysis. After that period, emissions for previous retrofits or the construction itself are considered to be totally offset. In between this period, all embodied energy due to construction and previous retrofits are considered to be accumulated.

The results of the calculation for each future urban scenario are presented in Figure 6. As it can be seen in Figure 6, the amount of embodied energy and related grey emissions in buildings will increase substantially from scenario to scenario as a result of the new built areas and retrofit strategies planned for the site. A peak of these values is found for the high-end-and business scenario, where modern structures with high use of concrete, glass and aluminum are foreseen (Fonseca et al., 2014).

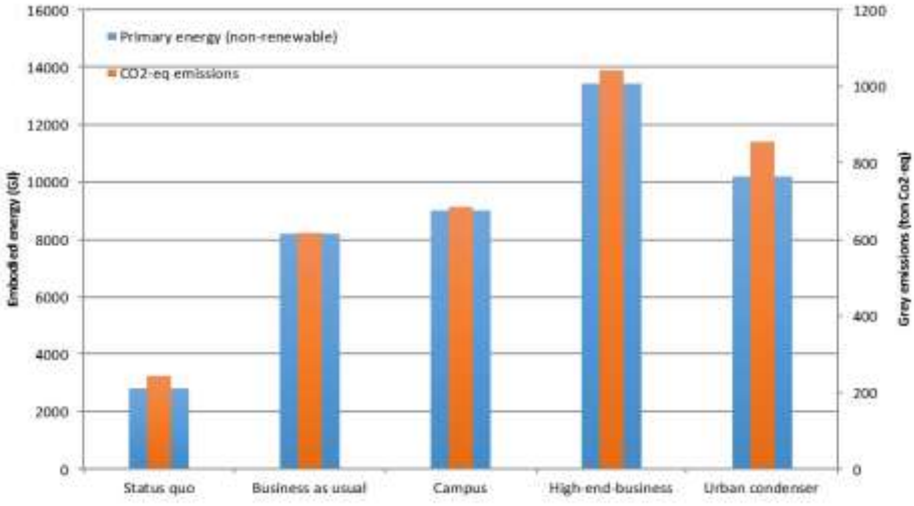

Figure 6: The bar chart compares the yearly embodied energy and related emissions in buildings for the four different scenarios with the status quo.

Applying the here presented framework and the model by Fonseca et al. (2014) to other regions, large sets of buildings can quickly be analyzed in terms of their embodied energy and related emissions.

Examining the development of the environmental impact of buildings over time can as well be useful for policy makers in order to decide on new regulating laws for the construction industry. The results of an application of this framework can help to identify the building types and construction components with the highest environmental impact.

In this paper, a generally increasing tendency of Grey Energy and Grey Emissions in Swiss buildings was identified. Taking into account the global trend towards renewable energy sources and the long lifetime of buildings, it is counterproductive to push the building industry towards energy-intense insulation materials. These insulation materials are produced today, using today's environmentally harmful energy sources (e. g. power from coal-fired power plants) and on the contrary reduce the usage of future clean energy. Harvey L. D. D. (2010) suggests the use of less energy intense insulation materials, such as cellulose, which has a slightly poorer insulating performance, but much less of an environmental impact.

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