Report – Process - Construction site (A5)

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Contents

Average emission values for the construction of residential buildings (phase A5)

The proposed emission values for construction site are based on the results collected from recent Finnish and Swedish studies. All considered studies were case studies based on real construction projects.

The cases that were considered for the determination of the emission values were the seven cases reported in the following studies:

Ahola, R., Liljeström, K. 2018. Rakennuksen elinkaaren hiilijalanjäljen pienentäminen kustannustehokkaasti vuokratalokohteessa. ARA. Asumisen rahoitus- ja kehittämiskeskuksen raportteja 08/2018. 73pp. https://joutsenmerkki.fi/wp-content/uploads/2018/12/Hiilijalanj%C3%A4ljen-pienent%C3%A4minen-kustannustehokkaasti_2018.pdf

Hämäläinen J. 2012. Energy research on construction site. Tampere University of Technology. Master's thesis. Tampere. 87pp. https://www.rakennusteollisuus.fi/globalassets/rakentamisen-kehittaminen/rakennustyomaan-energiatutkimus.pdf

Pöyry, A., Säynäjoki, A., Heinonen, J., Junnonen, J.-M., Junnila, S. 2015. Embodied and construction phase greenhouse gas emissions of alow-energy residential building. Procedia Economics and Finance 21/2015 355 – 365. https://core.ac.uk/reader/82004310

Table 1 The emission values for phase A5 in the considered cases of seven residential buildings

Case		1	2	3	4	5	6	7
Source		Hämäläinen	Hämäläinen	Pöyry	Ahola and Liljeström			
Volume	m3	22500	14161	9645				
Area Gross	m2	6467	3797	3085	8830	6224	11675	8842
Area Net	m2	5830	3417	2777	8029	5670	10697	7553
Electricity	kWh	336970	311640					
	kg CO2e	46839	43318					
	kg CO2e/m2	8	13					
District heat	kWh	597850	178080					
	kg CO2e	89080	26534					
	kg CO2e/m2	15	8					
Fossil	kWh	152180	252280					
	kg CO2e	46567	77197					
	kg CO2e/m2	8	23					
All (A5)	kg CO2e			111000				
	kg CO2e/m2	31	43	36	46	63	55	47
Average	**kg CO2e/m2**	**46**						

Regarding the above table, the emission values were calculated in terms of kg CO2e per net area (m2). When the net area was not reported, it was calculated by assuming that the ratio between net area and gross area is 0.9 (in accordance with the guideline given in Kuittinen (2019)[1].

[1] Kuittinen 2019. Ministry of Environment. Method for the whole life carbon assessment of buildings. 2019. Appendix 4: PITKO-scenario. Publications of the Ministry of the Environment 2019:22. http://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/161761/YM_2019_22_Rakennuksen_vahahiilisyyden_arviointimenetelma.pdf?sequence=1&isAllowed=y

Used emission values for energy sources

Regarding the cases reported by Pöyry and Ahola & Liljeström, the emissions are directly based on the reports. The energy data reported by Hämäläinen for cases 1 and 2 were converted to emissions data by using the following values for different energy sources.

Table 2 GWP values for different energy sources

Electricity	139	g CO2e/kWh
District heat	149	g CO2e/kWh
Fossil fuel	306	g CO2e/kWh

The emission factors used for calculations are based on CO2DATA database and the sources are explained in the background report for energy services.

The values presented in Table 2 are proposed for use in those cases when the site-specific energy consumption is known or can be estimated accurately and there is no need to apply the proposed generic value (in accordance with Table 1).

Variance of energy consumption in phase A5

The proposed generic GWP value for A5 (46 kg CO2e/net m2 as presented in Table 1) may be a high estimate.

The proposed value is significantly bigger than the Swedish results collected and reported by IVL. Larsson et al. (2016) report the energy consumption during construction phase in 5 Swedish construction cases. The energy consumption results of these cases are significantly smaller compared to those reported for example by Hämäläinen (in average 200 kWh/m2).

Table 3 Energy consumption in 5 Swedish building cases in phase A5 as reported by Lanrsson et al. (2016)

	1 Strandparken	2 Boktryckaren	3 Grim	4 Klockstapeln	5 Blå Jungfrun
Electricity kWh/net area	90	53	56	77	135
District heat kWh/net area	0	28	43	96	13
Total kWh/net area	80	91	99	173	148

Lower values have also been reported in few Finnish studies. Rintamäki[2] and Keskisalo[3] present the following results (see also Appendix 1):

[2] Rintamäki, E. 2016. Energy consumption of buildings in the building phase – Case: Renovation and enlargement of a hypermarket. LUT School of Energy Systems. Bachelor's thesis. 34pp. https://lutpub.lut.fi/bitstream/handle/10024/129928/Emilia%20Rintam%C3%A4ki%20-%20Kandidaatinty%C3%B6.pdf?sequence=3

[3] Keskisalo, M. 2020. LCA-report – Kuhmonkadun campus. Karelia University of Applied Sciences. https://www.karelia.fi/puurakentaminen/wp-content/uploads/2020/01/LCA_raportti_Kuhmonkadun-kampus_lopullinen.pdf

Table 4 GWP values for phase A5 as reported by Rintamäki (2016) and Keskisalo (2020)

GWP for A5 (kg/m2)	Source	Remark
20	Rintamäki	building extension in the connection of retail building renovation
32	Keskisalo	wooden school building (the frame based on CLT and glued laminated timber)

Based on researched documents, seasonal variance of energy consumption is significant. Mainly heating and lighting of construction site cause the large increase in energy consumption during winter months. For example, Heinänen (2016)[4] tells in his thesis that at +14 degrees Celsius and above outside temperature, the interior construction heating and drying doesn't require consumption of purchased energy (Ratu 07-3032)[5]. On the basis of the results presented by Karhunen (2011)[6], the factor values for construction site emissions could be something like 1.5 for winter months, 1.2 for spring, 0.8 for fall and 0.3 for summer, when the average temperatures follow typical distribution.

However, season related energy consumption factor was not created based on this information, as there was not enough data to formulate such a factor. Furthermore, construction usually occurs throughout the year encompassing all seasons as the duration of a multi-story building is typically more than 1 year.

In accordance with Hämäläinen (2016)[7], the share of heating energy consumption is around 70 % of total energy consumption (excluding earthworks and transportations) (Table 4).

[4] Heinänen, J. 2016. Energy saving possibilities of the construction. Satakunta University of Applied Sciences. Degree Programme in Construction Engineering. 48pp. https://core.ac.uk/download/pdf/38134672.pdf

[5] Ratu 07-3032. Rakenteiden lämmitys ja kuivatus. 1996. Helsinki: Rakennustieto. https://www.rakennustieto.fi/kortistot/

[6] Karhunen, A. 2011. Energy Consumption Reduction of Site Cabins. Metropolia University of Applied Sciences. Bachelor's thesis. Helsinki. 36pp. https://core.ac.uk/download/pdf/38038291.pdf

[7] Hämäläinen J. 2012. Energy research on construction site. Tampere University of Technology. Master's thesis. Tampere. 87pp. https://www.rakennusteollisuus.fi/globalassets/rakentamisen-kehittaminen/rakennustyomaan-energiatutkimus.pdf

Table 5 Summary of the main outcomes based on the case studies by Hämäläinen (2016).

	Case A	Case B
Building type	Concrete element 6 storeys Residential and office 99 flats, 2-3 offices Including parking spaces	Concrete element 6 storeys Residential 51 flats including parking spaces
Location	Tampere	Tampere
Construction time	8/2010-4/2012	9/2010-1/2012
Conditions	Winters exceptionally harsh	Winters exceptionally harsh
Building volume	22500 m3	14161 m3
Building area	6467 m2	3797 m2
Building area net heated (estimate)	5830 m2	3417 m2
Energy consumption	1087 MWh 168 kWh/m2 186 kWh/m2 (net) 52 kWh/m3 48 kWh/m3 (with parking)	742 MWh 195 kWh/m2 217 kWh/m2 (net) 52 kWh/m3 45 kWh/m3 (with parking)
Main factors	Heating (69%) and drying with the help of ventilation	Heating (75%)
Division of energy consumption by source	District heat 55% Electricity 31% LPG 14%	District heat 42% Electricity 25% LPG 23%
Division of energy consumption by phase	Internal construction 60% Frame construction 40%	Internal construction 58% Frame construction 42% (concreting during winter requires much energy)
Not considered	Combustion engine driven working machines	Combustion engine driven working machines
Division of electricity consumption	Lighting 55% Drying 19% Construction booths 10% Tower crane <1%	
Main conclusions	Energy concumption roughly 50 kWh/m3. Heating and drying are the most important issues for energy. The season may affect significantly. Lifting and internal transport on site can happen very efficiently – towercrane consumed <1% of electricity.	

In summary, the important factors that explain the variation in energy consumption during phase A5 are as follows:

- the outdoor temperatures during winter season as the harshness of winter may vary greatly between years,
- the seasonal time of concreting,
- the degree of prefabrication and use of elements and space elements, and
- the use of overall shelters.

Variance related to the building type

The scope of the referenced studies that have investigated environmental impats of construction process is residential buildings. The proposed values cannot be directly applied for other types of buildings because the ratio between volume and floor area is different.

According to Korteoja, the following conversation values for gross volume and building area can be used for different types of buildings [8]:

- detached, attached and terraced buildings 3,5
- blocks of flats 3
- office buildings 7
- school buildings 5
- kindergartens 4.

By assuming that half of the impact is based on heating and the heating need increases in direct proportion with the ration between volume and area, we get rough estimates for the following additional factors for schools and kindergartens and for office buildings:

- factor 1,3 for schools and kindergartens
- factor 1,7 for office buildings

Emission value for earthwork

The proposed generic GWP value for phase A5 given above is based on data that focuses on electricity and district heat consumption during the construction of building frame and building interior work. It is assumed that the earth work and foundation is not taken into account.

Larsson et al. (2016)[9] have studied the life cycle impacts of a wooden multi-story residential building following the principles of EN 17978. The building has 33 apartments with a heated area of 3982 m2 and 704 m2 garage area. Construction production was divided into electricity consumption, fuel consumption for machines and vehicles, and management of waste generated at the construction site. Diesel consumption for earthworks and construction of the building were documented separately.

Table 6 Total consumption of diesel for earthwork and foundation (Larsson et al. 2016)

Earthwork	2,5	m3
Transportation of earth (10 km, 3400 m3, 2125 ton)	1,4	m3
Piling	1	m3
Foundation (garage)	0,47	m3
Foundation (building)	0,21	m3
Lifting crane	0,6	
Wheel loader	1,9	m3
Total	8100	l
Gross area	4386	m2
Total per gross area	**1,8**	l/m2
Total GWP*	26123	kg CO2e
Total GWP per gross area, garage included	5,7	kg/m2
Total GWP per gross area, garage excluded	6,6	kg/m2

* based on the emission value 3225 g CO2e/l for working machines (including procurement)

In accordance with Rintamäki (2016)[10], the estimate for fuel consumption because of earthwork is 0,4 – 0,8 l per cubic meter. When using the factor 3 as a ratio between volume and gross building area, this corresponds

[8] https://www.theseus.fi/bitstream/handle/10024/42428/1/Korteoja_Otto.pdf mukaan suhde rm3/brm2

[9] Larsson, Mathias, Erlandsson,Martin, Malmqvist, Tove and Kellner, Jhonny. 2016. Byggandets klimatpåverkan Livscykelberäkning av klimatpåverkan för ett nyproducerat flerbostadshus med massiv stomme av trä, IVL B-2260. 67 p. https://www.ivl.se/download/18.29aef808155c0d7f05063/1467900250997/B2260.pdf

[10] Rintamäki, E. 2016. Energy consumption of buildings in the building phase – Case: Renovation and enlargement of a hypermarket. LUT School of Energy Systems. Bachelor's thesis. 34pp.

to 1,2 – 2,4 l/m^2 (gross area), which is of the same order of magnitude than the values reported by Larsson et al. (2016) for the Swedish case (residential buildings).

In addition, the background report for stabilizers (Sirje Vares, VTT) suggests the use of the following value for stabilization work.

Table 7 GWP for stabilization process A5 in terms of kg CO2e per the consumption of stabilizer

GWP	Remark
0.039 kg CO2e/kg stabilizer	General column and mass-stabilization work. Data based on the assessment of stabilization work for Malmi airport (Ramboll / Malmin lentokentän selvitys).

Alternatively, when the use of working machines can be estimated more accurately based on the long-term monitoring of the process related use of resources by the contractor, the following values can be used for the working machine related services at building site:

LIPASTO database[11] by VTT defines emission values for working machines.

Table 8The average emission values (g CO2e/l) of working machines based on LIPASTO

Drivable machines, diesel	**Average power [kW]**	**Average load factor**	**CO2e [gCO2e/l]**
Cranes	99	0,26	2673
Other lifts, diesel	33	0,30	2672
Forklifts, diesel	88	0,30	2672
Bulldozers	112	0,40	2674
Rollers	45	0,30	2672
Wheel loaders	94	0,33	2673
Backhoe loaders	74	0,33	2672
Miniexcavators	22	0,40	2672
Excavators, skid steer	104	0,31	2672
Excavators, rubber tire	88	0,32	2672
Tractors in industry	67	0,29	2675
Other tractors	58	0,27	2679
Harvesters	149	0,40	2674
Forwarders (forest tractors)	105	0,30	2673
Dumpers	153	0,30	2672
Sid steer loaders	50	0,25	2672
Telehandlers	78	0,28	2672
Lawn tractor, diesel	12	0,30	2672
Other drivable machines, diesel	89	0,36	2672
Average			**2673**

https://lutpub.lut.fi/bitstream/handle/10024/129928/Emilia%20Rintam%C3%A4ki%20-%20Kandidaatinty%C3%B6.pdf?sequence=3

[11] LIPASTO database is available through the following link http://lipasto.vtt.fi/yksikkopaastot/muut/tyokoneet/tyokoneet.htm

The proposal is to apply the average value and add the impact because of procurement of fuels by applying the results presented by JRC[12]:

In accordance with the JRC report, the procurement related emssion is

- 15,4 g CO_2e/MJ_{fuel} (min 13,8, max 17,0 g CO_2e/MJ_{fuel}).

In addition, the JRC report Appendix 4 gives the following values for the density and heating value.

Table 9 Density and heating value of diesel.

		Diesel
Density	kg/l	0,832
LHV	MJ/kg	43,1

Based on these values, it can be calculated that the procurement related emission is as follows:

- Emission per MJ is 15,4 g/MJ
- Emission per kg is 15,4 *43,1=663,74 g/kg
- Emission per l is 0,832*663,74=552 g/l

Thus the total emission related to the use of work machines at building site is

- (2673 + 552) g CO_2e/l = 3225 g $CO2_e/l$

LIPASTO also defines emissions values assessed in terms of working hours.

Average emission factors for all working machines are as follows:

- Average of drivable diesel machines 21,26 [CO_2e kg/h]
- Average of main working machines (excavators, loaders, bulldozers) 26,4 kg CO_2e kg/h

When considering the GHG because of procurement of fuels, the values are as follows:

- Average of drivable diesel machines 27,2 kg CO_2e kg/h
- Average of main working machines (excavators, loaders, bulldozers) 32,6 kg CO_2e kg/h.

Summary of the proposed values

The proposed GWP values for phase A5 are as follows:

Table 10 Proposed GWP for building process

Scope	GWP	Unit	Remark
A 5 residential building	46	kg CO2e/m2 (net)	excluding earth work
A 5 kinder gartens and schools	60	kg CO2e/m2 (net)	excluding earth work
A5 office building	78	kg CO2e/m2 (net)	excluding earth work
A 5 earth work	7	kg CO2e/m2 (net)	base case
A 5 stabilization	0,04	kg CO2e/kg of stabilizer	when relevant

[12] JRC Technical reports.) WELL-TO-TANK. Report Version 4.a JEC WELL-TO-WHEELS ANALYSIS. Authors: Robert EDWARDS (JRC), Jean-François LARIVÉ (CONCAWE), David RICKEARD (CONCAWE), Werner WEINDORF (LBST). WTT Appendix 4 (Version 4.a) – Description, results and input data per pathway.
Available: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/well-tank-report-version-4a-jec-well-wheels-analysis

			Note, the value is given per the amount of stibilizer
A 5 earth work / working machine related service	3,23	kg CO2e/l	when the estimate can be based on monitored consumption based on earlier similar cases Note, the value is given per estimated amount of fuel.

Appendix 1

	Unit									
Case		Case A	Case B			Case A	Case B	Case C	Case D	
Source		Hämäläinen	Hämäläinen	Rintamäki	Pöyry	Ahola et al.				Keskisalo
Building type		Concrete	Concrete		Concrete					
Building type		Residential	Residential	Retail	Residential	Residential	Residential	Residential	Residential	School
Volume	m3	22500	14161		9645					
Area Gross	m2	6467	3797	401	3085	8830	6224	11675	8842	2919
Area Net	m2	5830	3417	361	2777	8029	5670	10697	7553	2627
Area Living	m2				2081					
Electricity	kWh	336970	311640	20081						
	kg CO2e	46839	43318	2791						
	kg CO2e/m2	8	13	8						
District heat	kWh	597850	178080	27290						
	kg CO2e	89080	26534	4066						
	kg CO2e/m2	15	8	11						
Fossil	kWh	152180	252280	4119						
	kg CO2e	46567	77197	350						
	kg CO2e/m2	8	23	1						
All (A5)	kg CO2e				111000					42395
	kg CO2e/m2	31	43	20	36	46	63	55	47	16
Transport A4	kg CO2e				25900					54151
	kg CO2e/m2				8	11	9	10	13	21
Energy use	kWh/m2	186	217							

Emission	Emission	Emission
electricity	DH	fossil
g CO2e/kWh	g CO2e/kWh	g/MJ
139	149	85
		g/kWh 306