

Computer-aided supporting tool for LCA evaluation of energy efficiency of the buildings – assessment method and case studies

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University of Ljubljana
Faculty of Mechanical Engineering





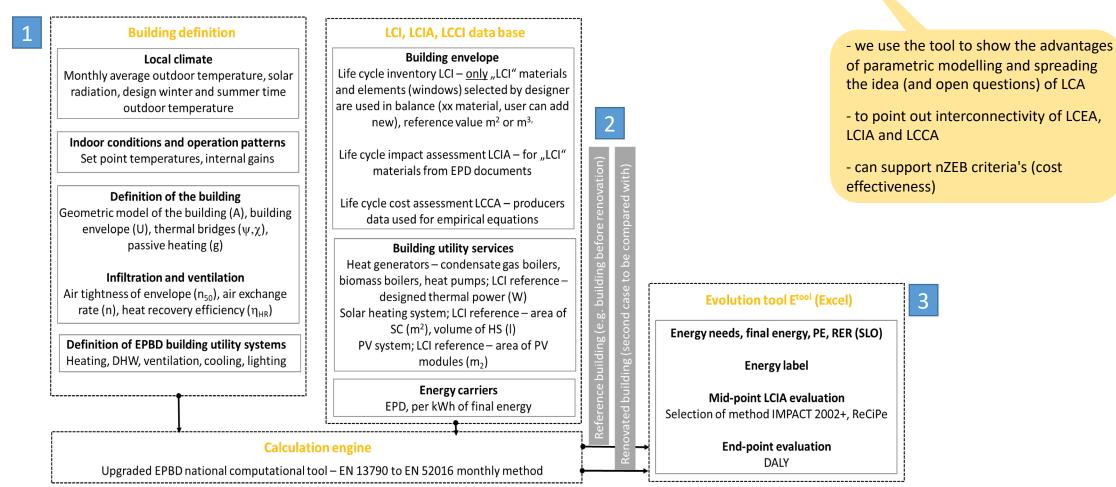


Modest attempt to bring LCA to students and engineering practice to promote the potential of the BIM.

Computer tool (Etool) for LCA assessment includes: LCE(energy)A, LCI(environment)A and LCC(cost)A indicators.

Consists of three modules:

yet another?



PROJEKT		Projekt				Spisek projektov		
Odpri		Osnovni podatki M	leteorološki podatki			Projekt	Datum	^
CONE	Ê	Naziv projekta	Hiša Bled - obnova			Černetova 5 - troslojna zasteklite	e 19.05.2016	
Odpri		Ulica	Cesta Gornjskega odred	da 15a		Černetova 5 - dvoslojna zasteklit	ti 19.05.2016	
ZONOTOLIKOLIE		Kraj	Bled			Černetova 5 - obstoječe, stara o	19.05.2016	
Zunanje		Katastrska občina	ŽELEČE			Pasivna - ZP + PV	29.04.2016	
Streha		1 Lokacija kraja	Y 430897	X 135327		Pasivna - ZP + SSE	29.04.2016	
Tla Okna vrata		Parcelna številka	914/7	ID oznaka stavbe		Pasivna - TČ	29.04.2016	
Toplotni mostovi		Etažnost	2			Pasivna - biomasa	29.04.2016	
Notranje	_	Investitor	-			Bolnica Petra Držaja - obnova	29.04.2016	
ANALIZA	1	Projektant	-			Bolnica Petra Držaja	29.04.2016	
Konstrukcije		Projektivno podjetje				Vestanovanjski objekt POLJE4	25.04.2016	
Cone Stavbe		Št. Elaborata				Hiša Bled - obnova	25.04.2016	
		Elaborat izdelal	-					
SISTEMI	- 12		Fakulteta za strojništvo	, Univerza v Ljubljani		Hiša Bled - referenčni projekt	25.04.2016	
Prezračevanje		Odgovorna oseba izd. EI	Branko Širok	Št. pooblastila 25		POŠ Mlinše - prenova	20.04.2016	
Ogrevanje Topla voda		Izdelovalec EI	Suzana Domjan	Št. pooblastila 44		POŠ Mlinše - obstoječe stanje	20.04.2016	
Hlajenje		Vrsta	O Novogradnja	Večja prenova		REFERENČNI PROJEKT	14.04.2016	
Razsvetljava OVE		Status projekta	🔾 za PGD 🍥 Izved	deno 🦳 Merjena EI 🐧		TESTNI PROJEKT	17.01.2011	
Drugi sistemi		Več kot ena cona	Da Ne					_ ~
ZKAZ	1						Briši Izv	
Stavbe					Naprej na cone 😜	Nov Spremeni	DIISI 12)	vozi
						0 program	ıu	
Primeri in navodila	?					Poslovni parti	nerii	

Reference (i.e. before renovation) and current building are evaluated at the same time.

1 Building description

Each building structures **can** consist one or more LCA layers.

Windows and doors can also be marked as LCA element.

Meanwhile LCEA will be performed for any building, only elements marked as "LCA" will be taken into account in LCIA and LCCA.

PROJEKT		Projekt				Spisek projektov		
Odpri	_	Osnovni podatki	leteorološki podatki			Projekt	Datum	^
CONE	Ê	Naziv projekta	Hiša Bled - obnova			Černetova 5 - troslojna zasteklit	e 19.05.2016	
Odpri		Ulica	Cesta Gornjskega odreda	15a		Černetova 5 - dvoslojna zastekli	ti 19.05.2016	
KONSTRUKCIJE		Kraj	Bled			Černetova 5 - obstoječe, stara o	19.05.2016	
Zunanje		Katastrska občina	ŽELEČE			Pasivna - ZP + PV	29.04.2016	
Streha		1 Lokacija kraja	Y 430897	X 135327		Pasivna - ZP + SSE	29.04.2016	
Tla Okna vrata		Parcelna številka	914/7	ID oznaka stavbe		Pasivna - TČ	29.04.2016	
Toplotni mostovi		Etažnost	2			Pasivna - biomasa	29.04.2016	
Notranje	4	Investitor	-			Bolnica Petra Držaja - obnova	29.04.2016	
ANALIZA	1	Projektant				Bolnica Petra Držaja	29.04.2016	
Konstrukcije Cone		Projektivno podjetje				Vestanovanjski objekt POLJE4	25.04.2016	
Stavbe		Št. Elaborata				Hiša Bled - obnova	25.04.2016	
SISTEMI	L3	Elaborat izdelal	Suzana Domjan Fakulteta za strojništvo, U	lnivaras v Liubliani		Hiša Bled - referenčni projekt	25.04.2016	
Prezračevanje		Odgovorna oseba izd. EI		Št. pooblastila 25		POŠ Mlinše - prenova	20.04.2016	
Ogrevanje Topla voda		Izdelovalec EI		Št. pooblastila 44		POŠ Mlinše - obstoječe stanje	20.04.2016	
Hlajenje		Vrsta	Novogradnja Već	čja prenova		REFERENČNI PROJEKT	14.04.2016	
Razsvetljava OVE		Status projekta	a PGD Izveden	o Merjena EI		TESTNI PROJEKT	17.01.2011	
Drugi sistemi		Več kot ena cona	Da ○ Ne			TESTIVE TROSERT	17.01.2011	~
	-							
ZKAZ					Naprej na cone 😞	Nov Spremeni	Briši Iz	vozi
Stavbe								
						O progran	nu	
Primeri in navodila	?					Poslovni part	nerji	

1 Building description

Elements of building service systems can also be marked as "LCA" elements.

- biomass boilers,
- gas condensate boilers,
- oil boilers,
- HP (geosonde-W, S-W, W-W, A-W),
- SC (flat, vacuum) and
- PV (mono, poly, CdTe, CuInGaSe) and
- water heat storage.

PROJEKT		Projekt				Spisek projektov		
Odpri	_	Osnovni podatki N	leteorološki podatki			Projekt	Datum	^
CONE	Ê	Naziv projekta	Hiša Bled - obnova			Černetova 5 - troslojna zasteklit	te 19.05.2016	
Odpri		Ulica	Cesta Gornjskega odreda 15a	3		Černetova 5 - dvoslojna zastekli	t 19.05.2016	
KONSTRUKCIJE		Kraj	Bled			Černetova 5 - obstoječe, stara o	ol 19.05.2016	
Zunanje		Katastrska občina	ŽELEČE			Pasivna - ZP + PV	29.04.2016	
Streha		O Lokacija kraja	Y 430897	X 135327		Pasivna - ZP + SSE	29.04.2016	
Tla Okna vrata		Parcelna številka	914/7	ID oznaka stavbe		Pasivna - TČ	29.04.2016	
Toplotni mostovi		Etažnost	2			Pasivna - biomasa	29.04.2016	
Notranje	-	Investitor	-			Bolnica Petra Držaja - obnova	29.04.2016	
ANALIZA	1	Projektant	-			Bolnica Petra Držaja	29.04.2016	
Konstrukcije		Projektivno podjetje				Vestanovanjski objekt POLJE4	25.04.2016	_
Cone Stavbe		Št. Elaborata				Hiša Bled - obnova	25.04.2016	
		Elaborat izdelal						
SISTEMI		Izdajatelj EI	Fakulteta za strojništvo, Univ	erza v Ljubljani		Hiša Bled - referenčni projekt	25.04.2016	
Prezračevanje		Odgovorna oseba izd. EI	Branko Širok	Št. pooblastila 25		POŠ Mlinše - prenova	20.04.2016	
Ogrevanje Topla voda		Izdelovalec EI	Suzana Domjan	Št. pooblastila 44		POŠ Mlinše - obstoječe stanje	20.04.2016	
Hlajenje		Vrsta	O Novogradnja O Večja	prenova		REFERENČNI PROJEKT	14.04.2016	
Razsvetljava OVE		Status projekta	🔾 za PGD 🍥 Izvedeno	Merjena EI 🐧		TESTNI PROJEKT	17.01.2011	
Drugi sistemi		Več kot ena cona	Da ○ Ne					
IZKAZ	1							
Stavbe					Naprej na cone 😜	Nov Spremeni	Briši Izv	vozi
Stavbe	h	7						
						O program	iu	
Primeri in navodila	1					Poslovni part	nerji	

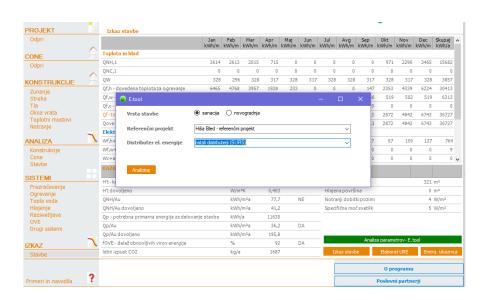
Generic LCA data of energy carriers is used except for the electricity, for which local distributer can be selected

There is a large difference in Environment Product Data among distributors in SLO.

After the description of the building is completed, following will happened:

Using Taguchi matrix L50, the **energy needs** for heating $Q_{h,nd}$ and cooling $Q_{c,nd}$ ae determined in 50 loop simulations

One of two Taguchi matrix: for new and renovated building can be selected; this one is for new buildings



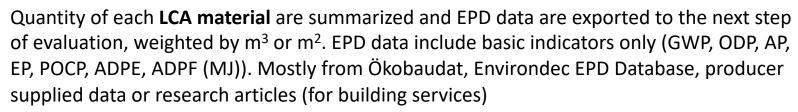
Parameters (12)	Levels	(5) – n	ew bui	ldings	
Degree days (DD Kday/y)	two le		signed buildi	ng)	
Thermal transmittance of walls structures (U w/m²K)	0.08 (2/7 U _{max})	0.14 (1/2 U _{max})	0.20 (5/7 U _{max})	0.24 (6/7 U _{max})	0.28 (U _{max})
Thermal transmittance of roof structures	0.07 (2/7 U _{max})	0.10	0.143	0.171	0.20 (U _{max})
Thermal tran. of structure in contact with ground	0.07 (2/7 U _{max})	0.10	0.143	0.171	0.20 (U _{max})
Thermal transmittance of windows and doors	0.46 (2/7 U _{max})	0.80	1.14	1.37	1.60
Total solar transmittance of glazing (g)	0.65	0.55	0.45	0.35	0.25
Thermal bridge impact factor ($\Delta U \text{ w/m}_2 \text{K}$)	0	0.03	0.06 suggested)	0.08	0.10
Air tightness of envelope (n ₅₀ h ⁻¹)	0.6 (PHPP)	1.0	2.0 (n ₅₀ max)	2.5	3.5
Heat recovery of ventilation system (η_{hx} -)	0.40	0.65		0.90	0.95
Set point temperature for heating $(T_{i,h}$ °C)	18	19	20	22	24
Internal heat gains (w/m²)	0	2 (su	4 ggested)	6	8
Air exchange rate (n h-1)	0.38	0.5 minimum)	8.0	1.0	1.2

Final energy demand per energy carriers is determined for both current and reference building, taking into account user defined data.

Embodied energy in LCA elements is determined.



Beside energy demand related data, following data are **exported to E**^{tool}:



EPD Data for **LCA windows and door** are exported.

EPD data of **LCA building systems** are exported. Data are weighted by design heat load (kW,), area (m²: SC, PV) and volume (HS). EPD data are determined by approximation polynomials:

$$\begin{split} \text{ODP}_{\text{gen}} &= a_{0,\text{gen}} + a_{1,\text{gen}} \cdot \boxed{P_{\text{gen}}} + a_{2,\text{gen}} \cdot P_{\text{gen}}^2 \quad \left(\text{kg CFC } 11_{\text{eq}}\right) \\ \text{ODP}_{\text{sol}} &= 1.25 \cdot a_{1,\text{sol}} \cdot \boxed{A_{\text{sc}}} \left(\text{kg CFC } 11_{\text{eq}}\right) \\ \text{ODP}_{\text{hs}} &= a_{0,\text{hs}} + a_{1,\text{hs}} \cdot \boxed{V_{\text{hs}}} + a_{2,\text{hs}} \cdot V_{\text{hs}}^2 \quad \left(\text{kg CFC } 11_{\text{eq}}\right) \\ \text{ODP}_{\text{pv}} &= a_{1,\text{pv}} \cdot \boxed{A_{\text{pv}}} \quad \left(\text{kg CFC } 11_{\text{eq}}\right) \end{split}$$

LCA EPD data of **energy carriers** based on defined building service systems are exported. (probably this will be the only data for reference project).

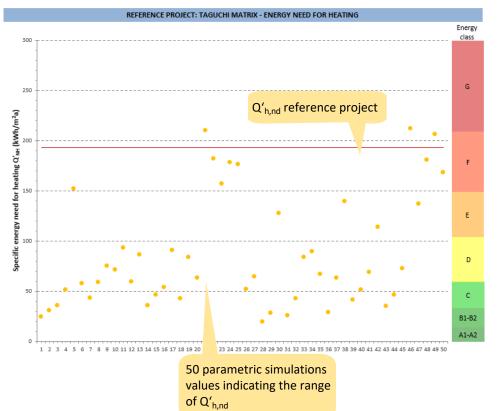
kW		a2,gen	a1,gen	a0,gen
GWP	kg eq CO2	0,028	1,272	1566,316
ODP	kg eq CFC11	2,74E-13	1,24E-11	6,42E-08
AP	kg eq SO2	1,03E-04	4,67E-03	7,161
EP	kg eq (PO4)3-	9,27E-06	4,18E-04	0,601
POCP	kg eq eten	1,45E-05	6,64E-04	0,768
ADPE	kg Sb	2,33E-09	7,37E-08	0,054
ADPF	MJ	0,319	14,443	18151
Heat ger	nerator - konden	s.		
kW		a2,gen	a1,gen	a0,gen
GWP	kg eq CO2	0,0035	10,166	618,4
ODP	kg eq CFC11	-1,00E-13	6,00E-10	6,00E-08
AP	kg eq SO2	5,00E-06	4,86E-02	3,6074
EP	kg eq (PO4)3-	6,00E-07	4,00E-03	0,2837
POCP	kg eq eten	1,00E-06	4,10E-03	0,2605
ADPE	kg Sb	9,00E-07	1,60E-03	0,0835
ADPF	MJ	4,33E-02	1,25E+02	7548,7

ROJEKT	ILRUI .	stavbe														
Odpri				Jan kWh/m	Feb kWh/m	Mar kWh/m	Apr kWh/m	Maj kWh/m	Jun kWh/m	Jul kWh/m	Avg kWh/m	Sep kWh/m	Okt kWh/m	Nov kWh/m	Dec kWh/m	Skupaj kWh/a
ONE	Toplota	in hlad														
Odpri	QNH,1			3614	2613	2015	715	0	0	0	0	0	971	2290	3465	15682
^	QNC,1			0	0	0	0	0	0	0	0	0		0	0	
ONSTRUKCIJE	QW			328	296	328	317	328	317	328	328	317	328	317	328	
Zunanje		vedena toplota za	ogrevanje	6465	4768	3957	1928	233	0	0	0	147	2353	4339	6224	
Streha		E.tool										× 6	519 0	502	519	
Tla Okna vrata	Qf,c - Qf-to	Vrsta stavbe	•	sanacija	○ nov	ogradnja						0	2872	4842	6743	
Toplotni mostovi	Qove	VISCO SCOVE										3	2872	4842	6743	
Notranje	Elekt	Referenčni pro	ojekt Hi	ša Bled - re	eferenčni j	projekt					~		2072	10 12	07 10	50727
NALIZA	Wf,h+	Distributer el.	energije	tali distribu	terii (SHR	5)					~	7	67	109	137	764
Konstrukcije	Wf,w4	Distributer ei.	ellergije	cair distribu	telji (SON	<u> </u>						0	0	0	0	
Cone	Wc+a											0	0	0	0	(
Stavbe	KAZA	Analizirai														
STEMI																
Prezračevanje	H't-k	W			W/m	N/C	0,403			Ulata	na površ				321	m² m²
Ogrevanje	QNH/Au	jeno			kWh/		77,7		VE.			ina kipozimi				W/m²
Topla voda Hlajenje		dovoljeno			kWh/		41,2		***		fična mo					W/m²
Razsvetljava			ergija za delovanj	e stavbe	kWh/		11630			op acc						
OVE	Qp/Au				kWh/		36,2		DA							
Drugi sistemi	Qp/Au do	voljeno			kWh/	m²a	195,8			_						
ZKAZ	fOVE - de	elež obnovljivih vir	rov energije		%		92		DA			Anali	za param	etrov-E.	ool	
Stavbe	letni izpu	st CO2			kg/a		1687			Iz	kaz stavb	e	Elabor	at URE	Ener	rg. izkazn
										-						
rimeri in navodila										Ļ			O pr	ogramu		
Univerza v Ljubljani Fakulteta za strojništvo										L			Poslovi			
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Univerza v Ijubljani Fakulteta za sirvjuštiro		ļ				Name	nce proj	ect Hiši		referen	čni proje	ekt				
Univerza e Ijubljuni Pakulteta zu srvgništro						Name A	nce proj	Hiša	321	m²	čni proje	ekt				
Entiverza v Ijobijuni Pikulica za strepulitro	_					Name A Q _{NH}	nce proj	Hiša	321 61.993	m² kWh/a	čni proje	ekt				
Univerza e Ijubijani Paksheta za savojnimo		tool				Name A Q _{NH} Q _p	nce proj	Hiš:	321 61.993 14.803	m² kWh/a kWh/a	čni proj	ekt		•		
Taketra a spoljam Pakelteta za sangustico		tool				Name A Q _{NH}	nce proj	Hiš:	321 61.993	m² kWh/a kWh/a	čni proje	≘kt				
Universa - Jaddjuni Fakulteta sa surgustiro		tool				Name A Q _{NH} Q _o CO ₂ Current	nce project	Hiši	321 61.993 14.803 27.361	m² kWh/a kWh/a kg/a	čni proj	ekt				
Univerza e Ijubijuni Pakulten. za sregotitro		tool				Name A Q _{NH} Q _o CO ₂ Current Name		Hiši	321 61.993 14.803 27.361	m² kWh/a kWh/a kg/a obnova	čni proj	ekt				
Universa e Japigam Fakulteta za sarguiliro		tool				Name A Q _{NH} Q _o CO ₂ Current Name A		Hiša 1 Hiša	321 61.993 14.803 27.361 a Bled - 321	m² kWh/a kWh/a kg/a obnova m²	čni proji	ekt				
Valverza v Ijadými Pákulteta za surguitiro		tool				Name A Q _{NH} Q _o CO ₂ Curren Name A Q _{NH}		Hiša 1 Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326	m² kWh/a kWh/a kg/a obnova m² kWh/a	čni proje	ekt				
Vaiverza v Ijubijuni rakultea za strejutitro		tool				Name A Q _{NH} Q _p CO ₂ Current Name A Q _{NH} Q _p		Hiša 1 Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816	m² kWh/a kWh/a kg/a obnova m² kWh/a	čni proje	ekt				
Univerza e Ijubijuni rikohen in srepetitro		tool				Name A Q _{NH} Q _o CO ₂ Curren Name A Q _{NH}		Hiša 1 Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326	m² kWh/a kWh/a kg/a obnova m² kWh/a	čni proje	ekt				
tuiverza » Ijubijuni Päkulteta zu surepulitro		tool				Name A Q _{NH} Q _p CO ₂ Current Name A Q _{NH} Q _p	t project	Hiša 1 Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816 1.577	m² kWh/a kWh/a kg/a obnova m² kWh/a kWh/a		ekt				
Valverza v Ipolijami Pakulteta za sareguiliro		tool				Name A Q _{NH} Q _p CO ₂ Current Name A Q _{NH} Q _p CO ₂	t project	Hišá Hišá	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816 1.577	m² kWh/a kWh/a kg/a obnova m² kWh/a kWh/a		ekt				
Fakulteta za strojništvo		tool				Name A Q _{NH} Q _p CO ₂ Current Name A Q _{NH} Q _p CO ₂	t project	Hiša Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816 1.577	m² kWh/a kWh/a kg/a obnova m² kWh/a kWh/a		ekt				
Fakulteta za strojniliro Authors Suzana Domjar Ciril Arkar		tool				Name A Q _{00H} Q _p CO ₂ Curren Name A Q _{00H} Q _p CO ₂	t project	Hišá Hišá	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816 1.577	m² kWh/a kWh/a kg/a obnova m² kWh/a kWh/a		ekt				
Fakulteta za strajnilitro Authors Suzana Domjar		tool				Name A Q _{SSH} Q _p CO ₂ Curren Name A Q _{SSH} Q Q SSH Q SSH Q SSH Q SSH Q SSH Q SSH SSH	t project	Hiša Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816 1.577	m² kWh/a kWh/a kg/a obnova m² kWh/a kWh/a		ekt				
Fakulteta za sregiriliro Authors Suzana Domjar Ciri Arkar		tool				Name A Q _{NSH} Q _p CO ₂ Curren Name A Q _{NSH} Q _p CO ₂ curren Name A Q _{NSH} Q _p CO ₂ dd	t project	Hiša Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816 1.577	m² kWh/a kWh/a kg/a obnova m² kWh/a kWh/a		ekt				
Fakulteta za sregiriliro Authors Suzana Domjar Ciri Arkar		tool				Name A Q _{b0H} Q _p CO ₂ Current Name A Q _{s0H} Q _p CO ₂ 44 38 32 22 32 31	t project	Hiša Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816 1.577	m² kWh/a kWh/a kg/a obnova m² kWh/a kWh/a		ekt				
Fakulteta za sregiriliro Authors Suzana Domjar Ciri Arkar		tool				Name	t project	Hiša Hiša	321 61.993 14.803 27.361 3 Bled - 321 14.326 9.816 1.577	m² kWh/a kWh/a kg/a obnova m² kWh/a kWh/a	n√m²a)					

LCC data are exported for "LCA" elements based on market cost of energy caries or approximation models for LCA elements.

this is how occupant behaviour influence the energy demand for heating (i.e. the way how the buildings is ventilated has highest impact on energy demand for heating

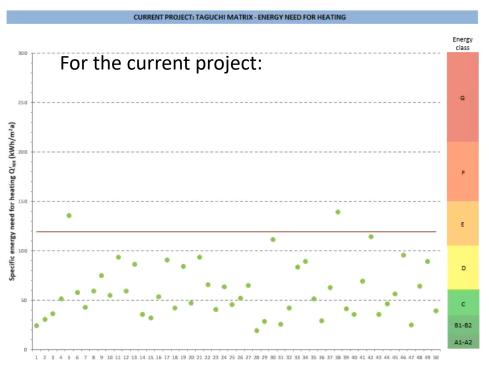
ENERGY EVALUATION OF ENERGY EFFICIENCY MEASURES



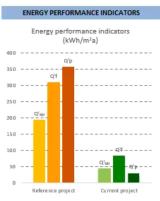
- - impact of the control parameters (i.e. U of walls and U floor should be improved for this buildings fist

- Following results are available in E^{tool}: for the reference building:
 - range of energy needs $Q_{h,nd}$ and $Q_{c,nd}$ is shown according to values defined in Taguchi matrix; designer can evaluate to what extend energy efficiency of the building could be improved.
 - statistically evaluated impacts of individual influence parameter is shown; designer can evaluate what **measures to take first** for particular building.







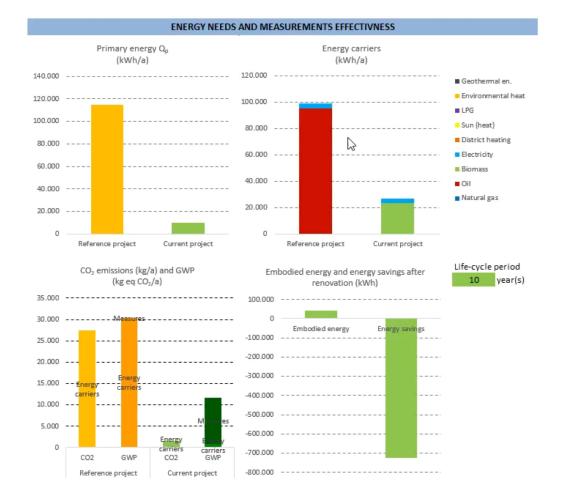


influence parameters included in approximation model (k=12)

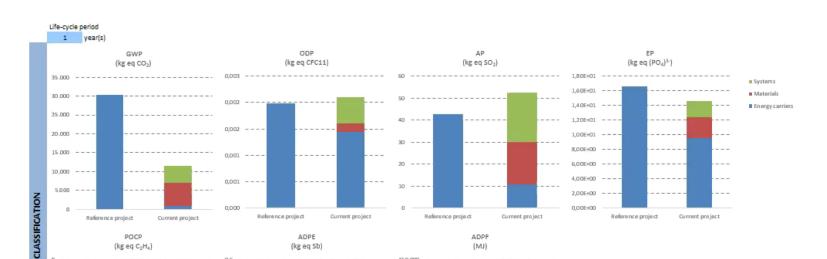
Following results are available in E^{tool}: for the current building:

Based on Taguchi matrix approximation model of energy needs $Q_{h,nd}$ and $Q_{c,nd}$ of current building are produced for parametric analyse in form:

$$Q_{h,nd}' = b_0 + \sum_{i=1}^{12} (b_{1,i} \cdot k_i + b_{2,i} \cdot k_1^2)$$
 (kWh/m²a)



- As part of the LCEA following results for reference and current project are shown:
 - primary energy demand
 - final energy use per energy carriers
 - CO₂ and GW gas emissions resulting from energy use, built-in "LCA" materials and "LCA" building service elements
 - embodied energy of "LCA"
 components is compared with energy savings in selected time range.



350.000 --

Reference project

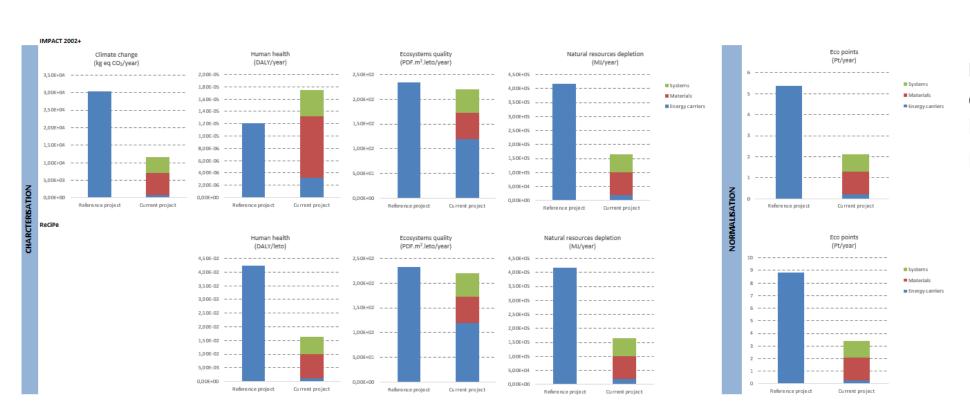
Re nce project

As part of the LCIA EPD indicators are compared for reference and current building.

For the current building EPD indicators which are the results of energy demand, built-in "LCA" materials and "LCA" building service materials are show separately.

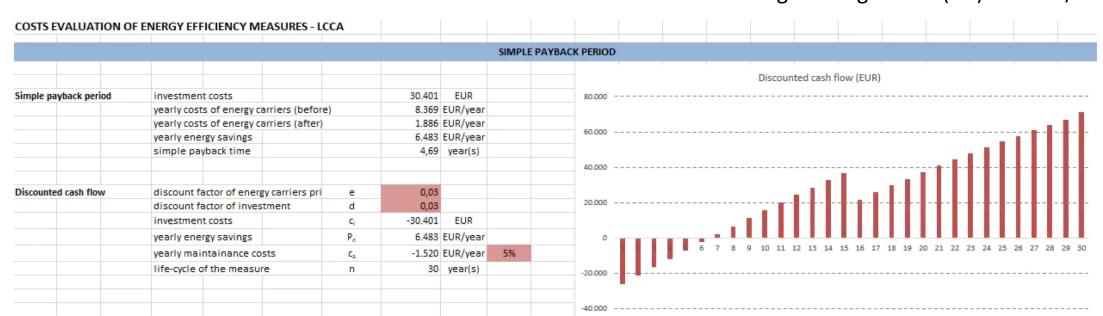
Designer can see which EPD indicator is **most critical** and indicates whether the selection of "LCA" materials or elements **should be modified**.

- Damage categories included in IMPACT 2002+ are analysed:
 - by normalization phase
 - by grouping and weighting



End-point single score environmental impact can be evaluated by Eco Points per year (PT/y).

- As part of the LCCA simple return period and cash flow diagram is presented for the current building. Parametric analysis can be performed according to:
 - the yearly **energy carries increase cost rate**
 - investment discount rate
 - yearly maintenance cost
 - CO₂ emissions global (environmental) cost (as defined in Commission delegated regulation (EU) No. 244/2012)



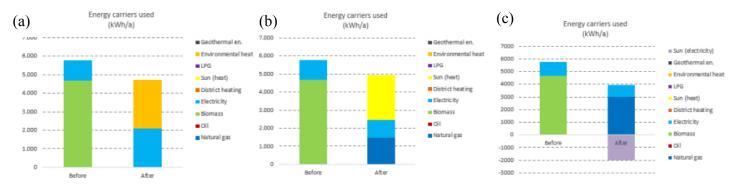






The LCA for following cases are shown in the paper:

- renovation of the municipality hospital
- single family passive house



pellet boiler with HS (reference object) is compared to (a) A-W HP with HS, (b) NG condensing boiler + solar heating system (7.5 m²) and (c) NG condensing boiler + 1.75 kW_p PV

- renovation of the multi-family building

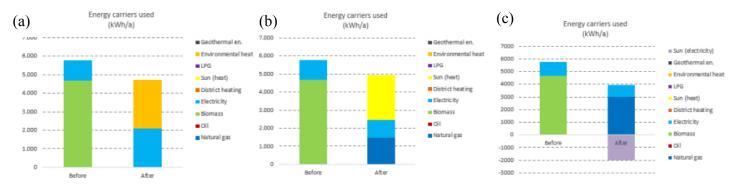






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Thank you for your attention