Lolli Nicola, Selamawit Mamo Fufa, Marianne Rose Inman

A parametric tool for the assessment of operational energy use, embodied energy and embodied material emissions in building SINTEF Building and Infrastructure



A1: Raw Material Supply	A1-3
A2: Transport to Manufacturer	Product
A3: Manufacturing	Stage
A4: Transport to building site	Constr
A5: Installation into building	1-5 ruction s Stage
B1: Use	
B2: Maintenance (incl. transport)	
B3: Repair (incl. transport)	B1-
B4: Replacement (incl. transport)	7 Use St
B5: Refurbishment (incl. transport)	age
B6: Operational energy use	
B7: Operational water use	
C1: Deconstruction / demolition	
C2: Transport to end of life	C1-4 En
C3: Waste Processing	d of Life
C4: Disposal	•
D: Reuse, recovery, recycling	D Benefits and Ioads

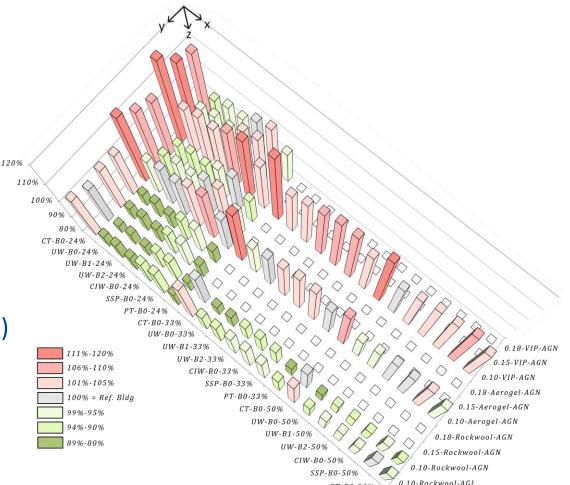
Lifecycle modules according to EN 15978: 2011

- Current effort for **energy and emission abatement** in the building sector requires considering **energy** use in building in a **lifecycle perspective**.
- Energy Performance of Buildings Directive Recast (Directive 2010/31/EU)
- EU 2020 climate & energy package, Effort Sharing Decisions (406/2009/EC)
- Lifecycle assessment (LCA) evaluates resource inputs (energy and mass use) to calculate the building/component environmental impacts.



A comparative study of different technical and the architectural retrofitting alternatives. Lifecycle emissions relative to the reference building. Lolli, N., Life cycle analyses of CO2 emissions of alternative retrofitting measures, NTNU, 2014.

- LCA is a typically comparative study (multiple scenario analysis) and very time consuming.
- Optimization on operational energy and embodied energy/emissions may



- Miffer existing LCA tools do not offer multiple scenario analysis.
- LCA and building energy calculations are often performed separately in existing tools.



This study focused on developing a **tool** that combines:

- Building energy modelling
- Environmental LCA method for buildings
- Allows multiple scenario analysis and comparison
- Multiple outputs (building embodied energy, lifecycle GHG emissions and energy use)



-EnergyPlus Weather Converter V7.1.0.010
Statistics for NOR_Oslo.Fornebu.014880_IWEC
Location OSLO/FORNEBU - NOR
{N 59- 54'} {E 10- 37'} {GMT +1.0 Hours}
Elevation 17m above sea level
Standard Pressure at Elevation 101121Pa
Data Source IWEC Data
WMO Station 014880
- Displaying Design Conditions from "Climate Design Data 2009 ASHRAE Handbook"
- ASHRAE design conditions are carefully generated from a period of record
- (typically 30 years) to be representative of that location and to be suitable
- for use in heating/cooling load calculations.

Part 1

Calculation of **monthly energy demand** (space heating and cooling, electricity for appliances, lighting and ventilation) ISO 13790:

- Uses standard weather files format (.EPW)
- Different geographical locations



-EnergyPlus \	Weather Conve	rter V7.1.0.010				
Statistics for	NOR_Oslo.Forr	nebu.014880_IW	'EC			
Location O	SLO/FORNEBU	- NOR				
{N 59- 54	'}{E 10-37'}{	GMT +1.0 Hours}				
Elevation	17m above sea	a level				
Standard Pre	essure at Elevati	ion 101121Pa				
Data Source	IWEC Data					
WMO Station	n 014880					
						1
emperature	Weekday [C]	Weekend [C]	Night [C]	Day hours [h]	Night hours [h]
Heating	21	21	19	18	6	
Cooling	26	26	10	10	6	

Cooling	26	26	19	18	6	24.25						
	Jan	Feb	Mar	Apr	Мау	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Cooling	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Temperature set point schedule

- Workdays/weekend operative temperature
- Day/night hours of operations
- Monthly YES/NO scheduled operation



-EnergyPlus Weather Converter V7.1.0.0	10									
Statistics for NOR_Oslo.Fornebu.014880	_IWEC									
Location OSLO/FORNEBU - NOR	Location OSLO/FORNEBU - NOR									
{N 59- 54'} {E 10- 37'} {GMT +1.0 Hot										
Elevation 17m above sea level										
Standard Pressure at Elevation 101121	Pa									
Data Source IWEC Data										
WMO Station 014880										
			_1							
mi Internal Heat Gains			'[h]	Setpoint [C]						
_				20.5						
People	Weekday	Weekend		24.25		4	6	<u> </u>		0
- Number of People	2	3		Jun YES	Jul	Aug YES	Sep YES	Oct YES	Nov YES	Dec YES
Activity Level	Light manual work	Resting		YES	YES	YES	YES	YES	YES	YES
Occupancy (hours)	16	16								
Internal Heat Gain: People [W]	171	167								
		107								
Internal Heat Gain: People [W]	339									

Internal heat gains from people

- Activity level
- Weekdays/weekend hours of activity



	us Weather Converter V7.1.0.010				
Statistics f	for NOR_Oslo.Fornebu.014880_IWEC				
Location	- OSLO/FORNEBU - NOR				
{N 59-	54'} {E 10-37'} {GMT +1.0 Hours}				
Elevation -	17m above sea level				
Standard F	Pressure at Elevation 101121Pa				
Data Sour	ce IWEC Data				
WMO Stat	tion 014880				
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- ASHHeating	Besign co ll ditions are carefully generated fro	m a peri då of record ⁶]
- ASHHeating	Besign collitions are carefully generated fro	m a peri då of record ⁶	20.5	Night	D Y
- ASHHeating - (Peop	Besign co ll ditions are carefully generated fro	m a perid ⁸ of record ⁶	20.5 24.25	Night Security lights	
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Energy use for lighting

- Lighting types and lux levels
- Weekdays/weekend/nights hours of operations
- Control systems



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-							
- 101121Pa							
	AE Havigoroover un	Setpoint [C]					
²⁶ <i>Mekday</i> ¹⁸		20.5					
של של האביר האביר אין איר		end Jun	Jul Night Aug	Sep O	Oct	Nov	Dec
	3 VEC	VEC	VEC VEC	VEC VI	EC	YES	YES YES
es	Applia	nce 1	Appliance 2			TEO	TES
Type	LCD M	onitor	Laptop Computer				
Quantity	1/	J		10			
	8			8			
				0			
			0				
Density - design value [W/m2]							
Density - design value [W/m2] Electricity Use [W]	71.9	3 0		60.00			
	71.9			60.00			
	car&fully generat&d from a perid& of separative of tha Weekday, and to be s People ions with the Weekday CES Type	1.014880_IWEC DR +1.0 Hours} rel - 101121Pa Sekent Climate DWight Data 2009 hear INAE Having books "[h] cardfully generated from a peride of record 6 26 september of the Weekday and to be Weekend 6 26 september of the Weekday and to be Weekend 6 People ions 2009 Weekday 3 Weekend 6 Ces Applian Type LCD Ma Quantity 10 y hours of operation - weekend 0	1.014880_IWEC DR +1.0 Hours} rel - 101121Pa Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISImate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISIMate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISIMate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISIMate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISIMate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISIMate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISIMate Delight/CData 2009 hows IA E Haliab bours [[n]] Setem CISIMate Delight/CData 2009 hows IA E Haliab Deli	Image: Note of the weekday of the set of the se	I.014880_IWEC Image: Constraint of the second of the s	INDEC INVEC DR INVEC Pred INVEC - 101121Pa INVEC SetemUsing to Data 2009 house IAAE Hattabbooks"[b] Setpoint [C] Caraffully generated from a periods of record 6 20.5 SetemUsing to Data 2009 house IAAE Hattabbooks"[b] Setpoint [C] Caraffully generated from a periods of record 6 20.5 Setemulation of the Weekday, and to be weekend Jun Jun View People loss Weekday 3 Weekend View View CSS Appliance 1 Appliance 2 View View View View Quantity 10	AD14880_IWEC DR +1.0 Hours} rel - 101121Pa Srkeh/Difinate DMidgid/CData 2009/h0451/h/E H Hindthbank"(h) Setpoint [C] 20.5 24.25 Seter MDifinate DMidgid/CData 2009/h0451/h/E H Hindthbank"(h) Setpoint [C] 20.5 24.25 Seter MDifinate DMidgid/CData 2009/h0451/h/E H Hindthbank"(h) Setpoint [C] 20.5 24.25 Seter Mov YES YES CeS Appliance 1 Appliance 2 YES YES YES YES YES YES YES YES YES YES

Energy use for appliances

- Appliance types
- Weekdays/weekend hours of use



	Ventilation and Infiltration Losses			
-EnergyPlus We	+ Building Location	Urban areas - centre		
Statistics for NO	Window height above ground [m]	5		
Location OSLC	Width of zone/building [m]	8		
{N 59- 54'} {E		10		
Elevation 17		2.4		
Standard Pressu		420		
Data Source IN	+	Day: weekdays	Day: weekends	Night
Data Source IN	Building Type	Landscape office	No mechanical ventilation	No mechanical ventilation
	Mashanical, schodulo hours	8		
WMO Station 02	Mechanical - air flow rate - design value [m3/s]	, C		
-	Mechanical - air flow rate [m3/s]	0.192	0	0
Tempenternal	Mechanical HR efficiency [%]	85	85	85
- ASHRAtingesign	Mechanical - SFP [W/m3/s]	1000	1000	1000
People	Mechanical - Electricity Use [W]	45.71	0.00	0.00
- for Heating Patient	Mechanical - Total El Use [W]	45.71		
Cooling	Heat transfer coefficient [W/K]	8.23	0.00	0.00
Distan	Natural - schedule hours			8
	Natural - type of ventilation	No natural ventilation	No natural ventilation	Cross ventilation
Internal I	Natural - fraction of window area	0.5	0.5	0.1
Internal I	Natural - air flow rate [m3/s]	0	0	1.741849809
	Infiltration losses [1/h]	0.3	0.3	0.3
	Heat transfer coefficient [W/K]	42.00	42.00	738.74
	Total heat transfer coefficient [W/K]	830.9	7	

Natural and mechanical ventilation heat transfer

- HR efficiency
- Fans efficiency
- Natural ventilation single side/cross ventilation
- Weekdays/weekend/night hours of operation



			1				
Type 1:	Outdoor	Boundary	-				
	N	Orientation					
		Tilt Angle					
	53.0	m2					
Material Category	Product	GWP (kgCO2eq)	CED (MJ)	(W/mK)	Weight (kg)	Thickness (m)	(m2k/W)
Heat Transfer Resistance	Internal Rsi						0.13
b.Timber	Structural Timber of spruce and pine, exd. biogenic: Norwegian wood industry: NO	199.49	40168.22	0.13	1580.83		0
b.Steel	Welded and coated trusses and beams made of cold-formed structural tubes and sections: Rukki Constr	566.00	1356.00	17.00	200.00		0
c.InternalSurface	Knauf Danogips Solid Gypsum Board 12,5mm, indoor wall & ceiling, exd. biogenic: Knauf: DK	20.25	922.78	0.58		0.01	0.02
c.Insulation	Gava glass wool, 350mm: Glava: NO	316.91	5394.78	0.04		0.35	10.00
c.Membranes	Baca Vapour barrier, 0,15mm: Baca Plastindustri: NO	18.23	983.84	0.33		0.00	0.00
c.Membranes	Norgips Windliner-X/Utvendig-X type EH2 (GU-X): Norgips: NO	77.40	1535.10	0.58		0.01	0.02
c.Timber	Møre Royal Copper impregnated Pine Timber, Oadding, decking, exd. biogenic: Møre Tre, 21mm: NO	160.64	15321.20	0.13		0.02	0.16
Heat Transfer Resistance	External Rse				Quantity (m2)		0.04
Window and Door Openings:					10.00		U-value
c.TripleGlazedUnit	Pilkington Optitherm™4S(3)–18Ar-4–18Ar-S(3)4, U-value 0.5, g-value 50	723.91	16701.22		10.00		0.5
Choose Opening		0.00	0.00				0.0
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	EPDs of materials En	Environment				Energy	
	VII OIIIIICI	itui			Lincigy		
		imnact			<u> </u>	alculatio	n
		impact				iicuiutio	11

Part 2

Calculation of a building's **embodied energy** and **embodied** material **emissions**, for phases (A1-A3) according to EN 15804:

- Impact calculation for **different building parts** (external walls, internal walls, floors, roof) and for technical equipment
- Data sourced from EPDs from multiple sources (EPD-Norge, IBU-Germany, EPD-Sweden) and from Ecoinvent

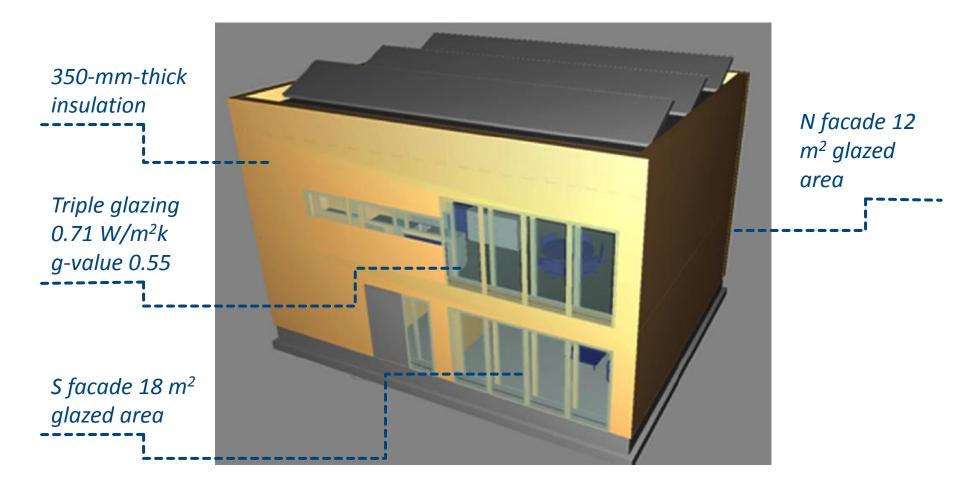


Type 1:		Outdoor			Boundary		
		Ν			Orientation 90 Tilt Angle		
					53,0 m2		
Material Cate	Building Lifeti	Draduct MA	60) years	GIMD (barnopaa)	CED (MIL (M/Jest) Maiabr (b)	Thiebase (m) (m7b/\A/l
<i>Heat Transfer</i> b.Timber	Building Perin			m m			
b,Steel	-) m2			
c,InternalSurfa	Heated Grour						
	Heated Buildi	-) m2			
c,Membranes	Heated Buildi	-) m3			
c,Timber	Floor to Ceilin	g Height	2.4	m	_		
Heat Transfer Window and D					,	20-	
c.TripleGlazed			Embodied Emissions	Embodied Energy	efficient		
Choose Openii			GWP (kgCO2eq)	CED (MJ)	(W/m2K)		
	1. Groundwor	k and Foundations	0	0.00	-		
	2. Outer Walls	5	7373	234471.38	0.10		
	3. Inner Walls		1759	62866.21	-		
	4. Floor Struct	ture	4826	237945.84	0.85		
	5. Outer Roof		2479	118961.33	0.09	Operational Energy	Operational Energy
	6. Stairs and E	Balconies	0	0.00	-	Use	Emissions
	7. Technical E	quipment	12144	91821.61	-	(kWh)	(kgCO2eq)
	Whole Buildin	ng (A1 - A3)	16437	654245		2 011 620	583 370
	Appliances						
	FU: /m2		102.73	4089.03		12572.63	3646.06
	FU: /yr		273.96	10904.08		33527.00	9722.83
	FU: /m2/yr		1.71	68.15		209.54	60.77

Results of single variable analysis

- Two impact categories for material use: CED and GWP
- Operational energy use/emissions





- Tool tested on a case study: net zero emission building concept. From Houlihan Wiberg, A., et al. (2014). "A net zero emission concept analysis of a single-family house." <u>Energy and Buildings</u> 74: 101-110.
- Located in Oslo, Norway.



Parameter	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Insulation	50mm	100mm	150mm	200mm	250mm	300mm	350mm*
Window type	3-ply*	2-ply	3-ply	2-ply			
	0.71 W/m ² k	2.6 W/m ² k	$0.50 \text{ W/m}^2 \text{k}$	$1.30 \text{ W/m}^2 \text{k} \text{ g-}$	-	-	-
	g-value 0.55	g-value 0.78	g-value 0.50	value 0.62			
North window area	10 m ²	12 m ² *	15 m ²	20 m ²	25 m ²	30 m^2	35 m ²
South window area	10 m ²	15 m ²	18 m^{2*}	20 m ²	25 m ²	30 m^2	35 m ²

- Variation of parameters of case study: window type, wall insulation thickness, and glazing areas in N and S facades.
- To test the **mutual influence** of the different **parameters**
- Find **optimal results** within a given set of variations



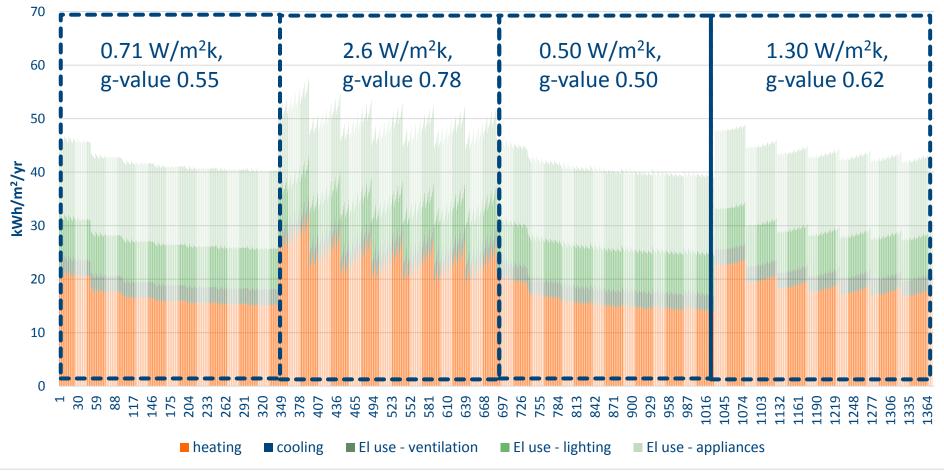
Parameter	Option 1	Option 2	Option 3	Option 4	Option 5		ion 6	Option 7	
Insulation	50mm	100mm	150mm	200mm	250mm	300	mm	350mm*	
Window type	3-ply*	2-ply	3-ply	2-ply					
2 way opening inwards	window, Triple glaze	ed, with Al							
dad, 105mm frame, exc	d. biogenic: Lian Trev	varefabrikk: St	tone wool high bulk de	nsity (121–250kg/m	13), 50mm:				
NO			OCKWOOL Mineralwoll			10	() 10	0
Pilkington Optifloat™O	lear 4–16Ar–4, U-valu	-	tone wool high bulk de		n3), 100mm:				
value 78			OCKWOOL Mineralwol			12		15	
Pilkington Optitherm [™]	<mark>4S(3)-18Ar-4-18Ar-S</mark>	(3)4, U-value St	tone wool high bulk de	nsity (121–250kg/m	n3), 150mm:				
0.5, g -v alue 50			OCKWOOL Mineralwol			15		18	
Pilkington Optitherm [™]	4–12Ar <i>–</i> S(3)4, U-valu	-	one wool high bulk de		n3), 200mm:				
value 62			OCKWOOL Mineralwol			20		20	
			tone wool high bulk de		13), 250mm:				
			OCKWOOL Mineralwol			25		25	
			tone wool high bulk de		13), 300mm:				
			OCKWOOL Mineralwol			30		30	
			tone wool high bulk de		13), 350mm:				
		R	OCKWOOL Mineralwol	IGmbH&Co:DE		35		35	
						Glazing	Glazing	Glazing	Glazing
Window type		In	sulation thickness			area N	area E	area S	area W

Part 3

- Parameters are fed in the console for the **analysis of multiple variables**.
- Initial values are replaced and simulations based on all permutations.
- **1372 iterations**. Outputs for operational energy use, CO_{2-eq} emissions, CED.



Operational energy use

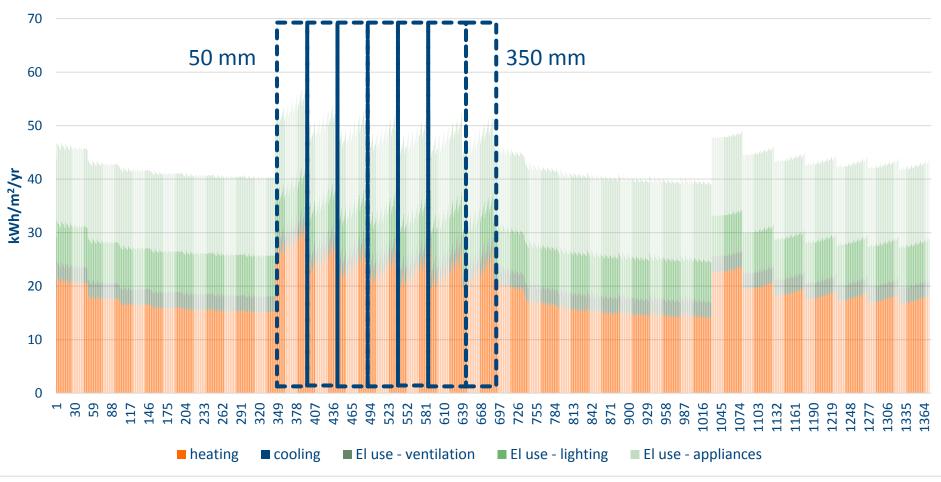


Result of multiple variables analysis

• Variation of 4 window types.



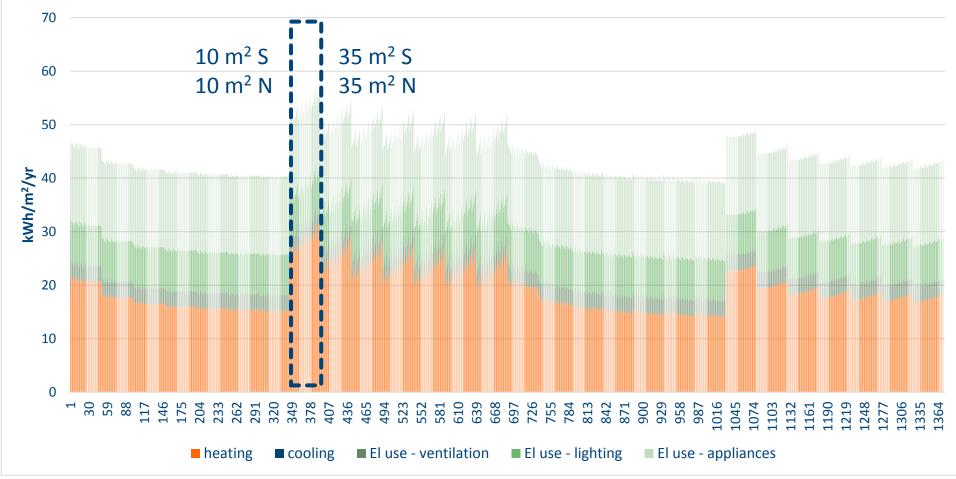
Operational energy use



• Variation of 7 insulation thicknesses.



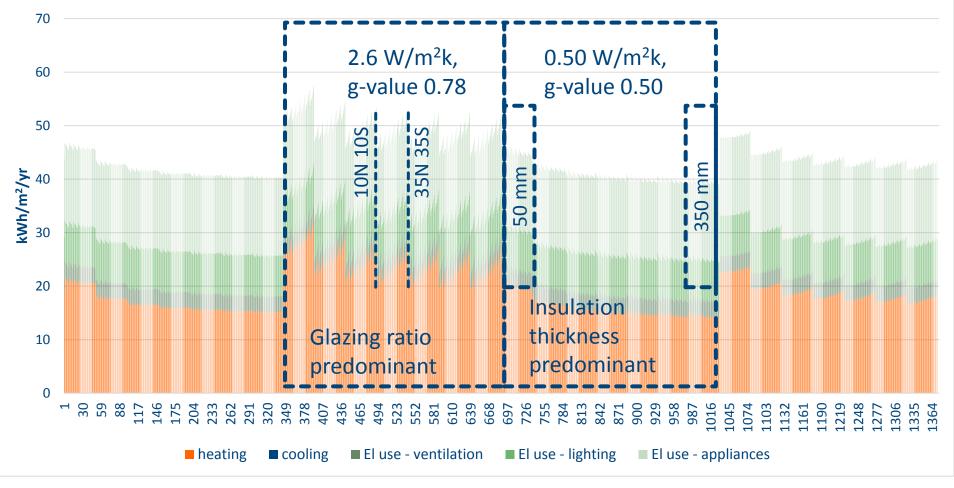
Operational energy use



Variation of 7 glazed areas in N facade and 7 glazed areas in S facade (49 different simulations).



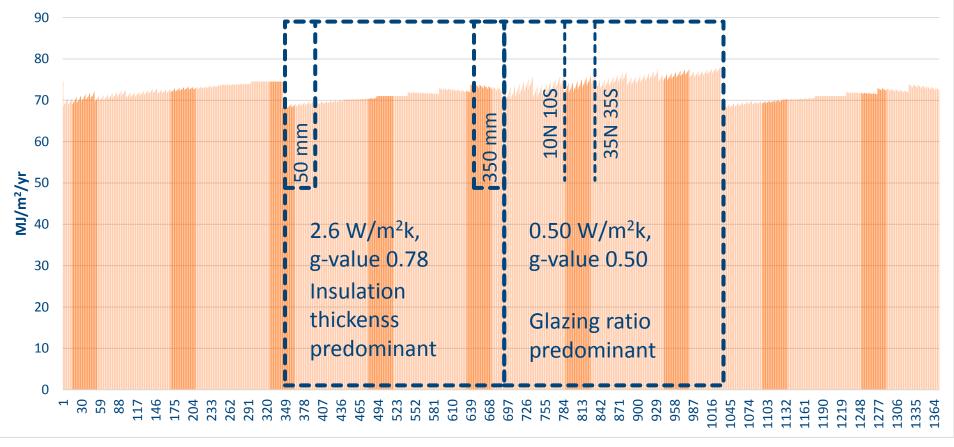
Operational energy use



 Comparison of results for different combinations of paramenters: operational energy use

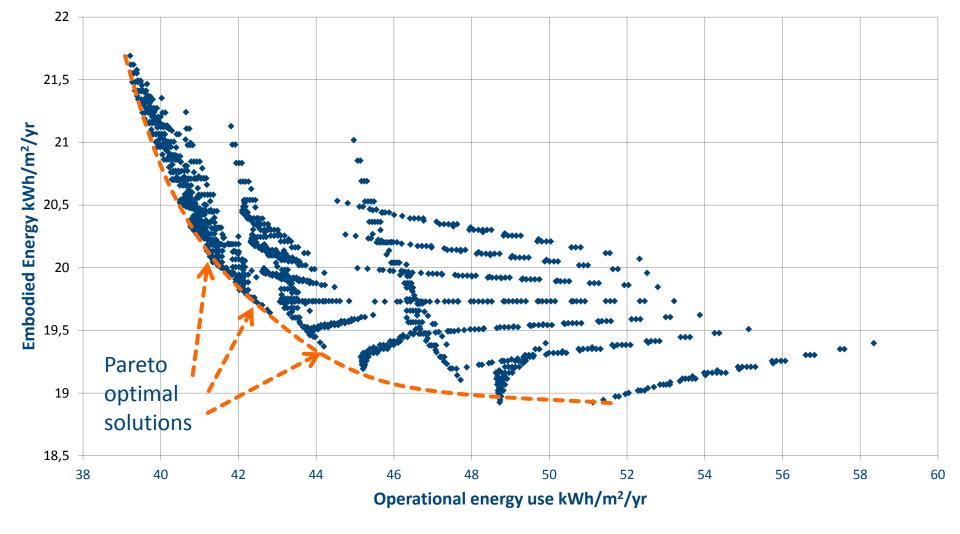


Building embodied energy



Comparison of results for different combinations of paramenters: embodied energy.

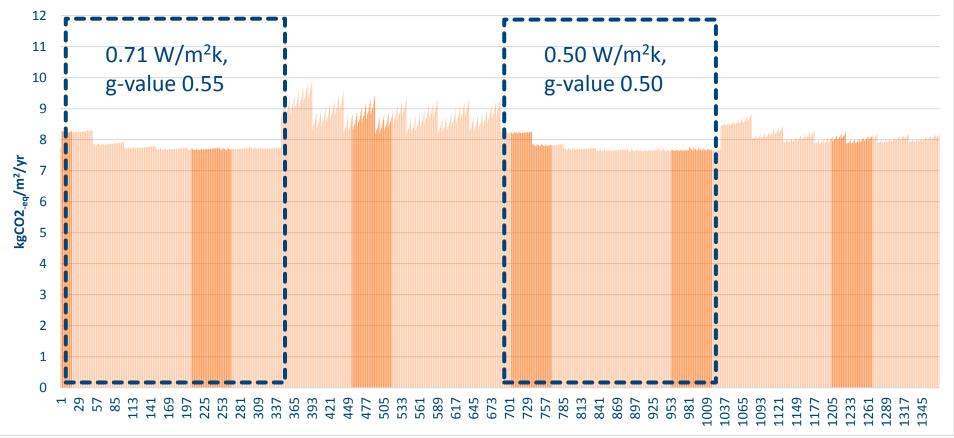




• Comparison of results for different combinations of paramenters: embodied energy vs operational energy use.



Building lifecycle emissions



- Comparison of results for different combinations of paramenters: lifecycle emissions.
- Glazing ratio and insulation thickness (more than 100 mm) are unifluential with high insulating window types.



Current limitations:

- Energy production and Embodied energy/emissions from on-site PV systems not included yet
- Embodied energy/emissions of appliances, luminaires, and energy systems not included yet
- Simplified models of **energy systems** (currently theoretical COP only)
- Limited number of variables (wall insulation, glazing area, window type, shading strategy)
- Maintenance and material replacement phase is not included yet
- Material **transportations** is not included yet
- End-of-life phase is not included yet

Conclusions:

Useful potential for evaluating different options in zero energy/emissions balance.

User target: professionals, students/educators



