The environmental significance of construction: the case of wooden buildings

Niko Heeren

ETH Zurich, Institute for Environmental Engineering, Ecological Systems Design Group

Email: heeren@ifu.baug.ethz.ch

ETH zürich

57th LCA Discussion Forum

Zurich, December 2, 2014

Objective & research question

Swiss National Research Programme NRP66 “Resource Wood”

PhD project: Assessing the ecological potential of wood construction in Switzerland

Are wooden buildings an adequate substitute for conventional (massive) buildings?

- Does thermal inertia of buildings have an important influence?
- Do wooden buildings have a favourable life cycle impact, when including embodied and operating energy?

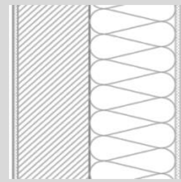
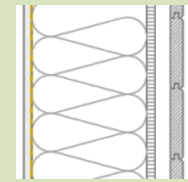
Method

- Scenario analysis based on two material variants of a **functionally equivalent** single family home
- Base variants: timber frame vs. massive brick construction
- Identical U-value, floor area, occupation, window size, etc.
- Functional unit: “1 single family home with 200 m^2 floor area and a service life of 90 years”
- System boundary
    - Construction material (production, transport, maintenance, end-of life (cut-off)) included
    - Space heat and cooling energy included
    - Construction work, furniture, technical and interior equipment excluded
- Results as total greenhouse gas emissions for the entire service life [t CO_2–eq]

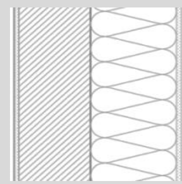
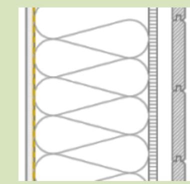
Model & assumptions

- Space heat and cooling demand simulated with energy plus v8.1 (CTF, 2 min resolution)
- LCI data: ecoinvent 2.2
- LCIA software: brightway2
- Material and building service life based on SIA 2031

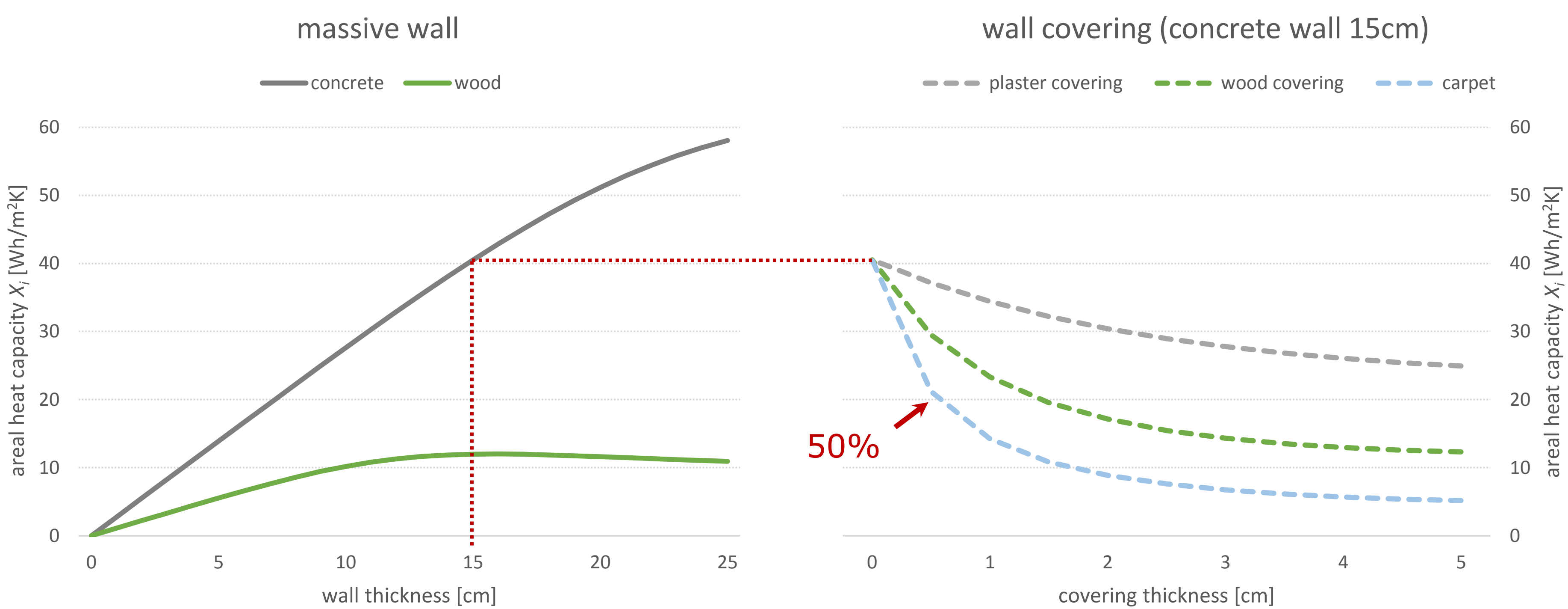
Model & assumptions (external wall)

Construction	Massive brick	Timber frame
Schema		
Exterior wall structure (interior to exterior)	- 1.0 cm interior plaster - 15.0 cm brick - 18.0 cm thermal insulation - 1.0 cm exterior plaster	- 1.5 cm gypsum fibreboard - 0.1 cm vapour barrier - 22.0 cm thermal insulation (56 cm) - 22.0 cm timber frame (6 cm) - 1.6 cm MDF board - 3.0 cm ventilated - 2.4 cm wood panel
U-value	0.149 W/m^{2}K	0.149 W/m^{2}K
Areal heat capacity X_i	14.0 Wh/m^{2}K	5.4 Wh/m^{2}K
Wall production GHG emissions	57.2 kg CO_2-eq./m^2	24.4 kg CO_2-eq./m^2

Model & assumptions (building)

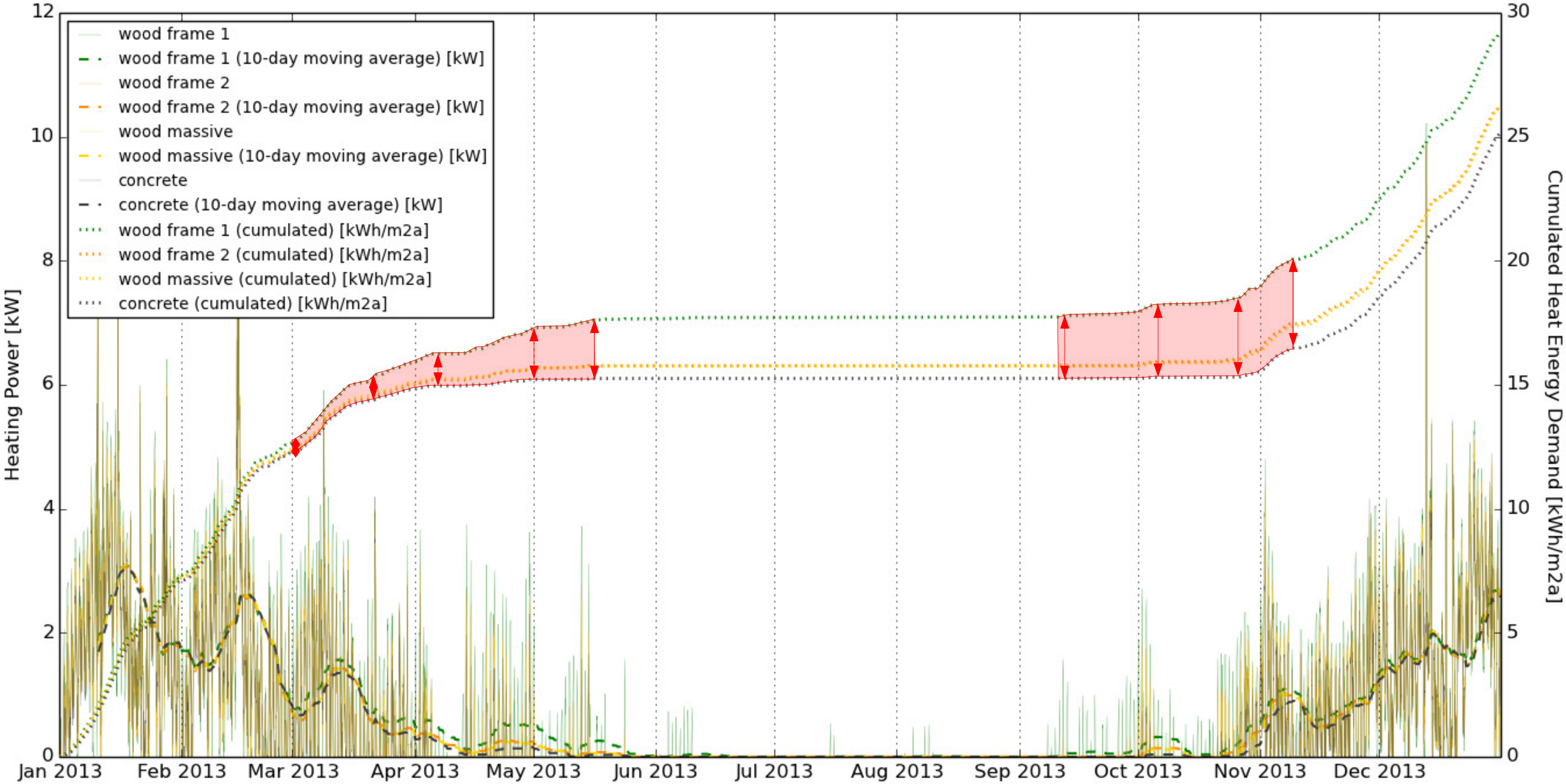
Construction	Massive brick	Timber frame
Schema		
Envelope U-value	0.27 W/m2K	0.27 W/m2K
Total heat capacity	12.3 kWh/K	4.0 kWh/K
Average space heat demand	53.3 kWh/m^2a	55.3 kWh/m^2a
Average space cooling demand	11.8 kWh/m^2a	14.4 kWh/m^2a
GHG emissions construction material	3.8 kg CO_2eq/m^2a	1.9 kg CO_2eq/m^2a

Understanding thermal inertia

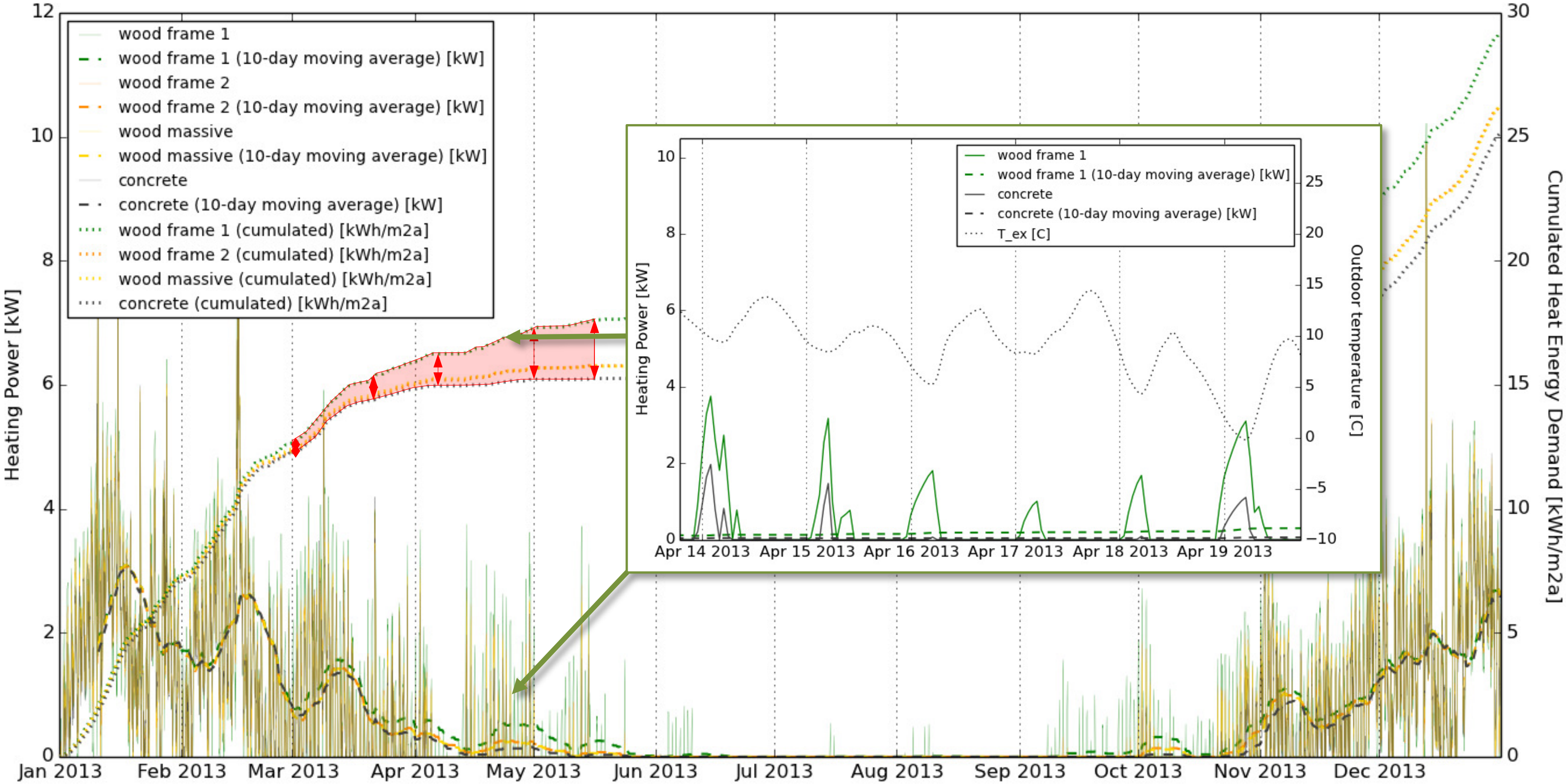


Areal heat capacity X_i calculated based on ISO 13786 (d=15cm, T=24h, $R_{si/se}$=0.0). Material properties: EN 12524

Simulation results – space heat demand



Simulation results – space heat demand



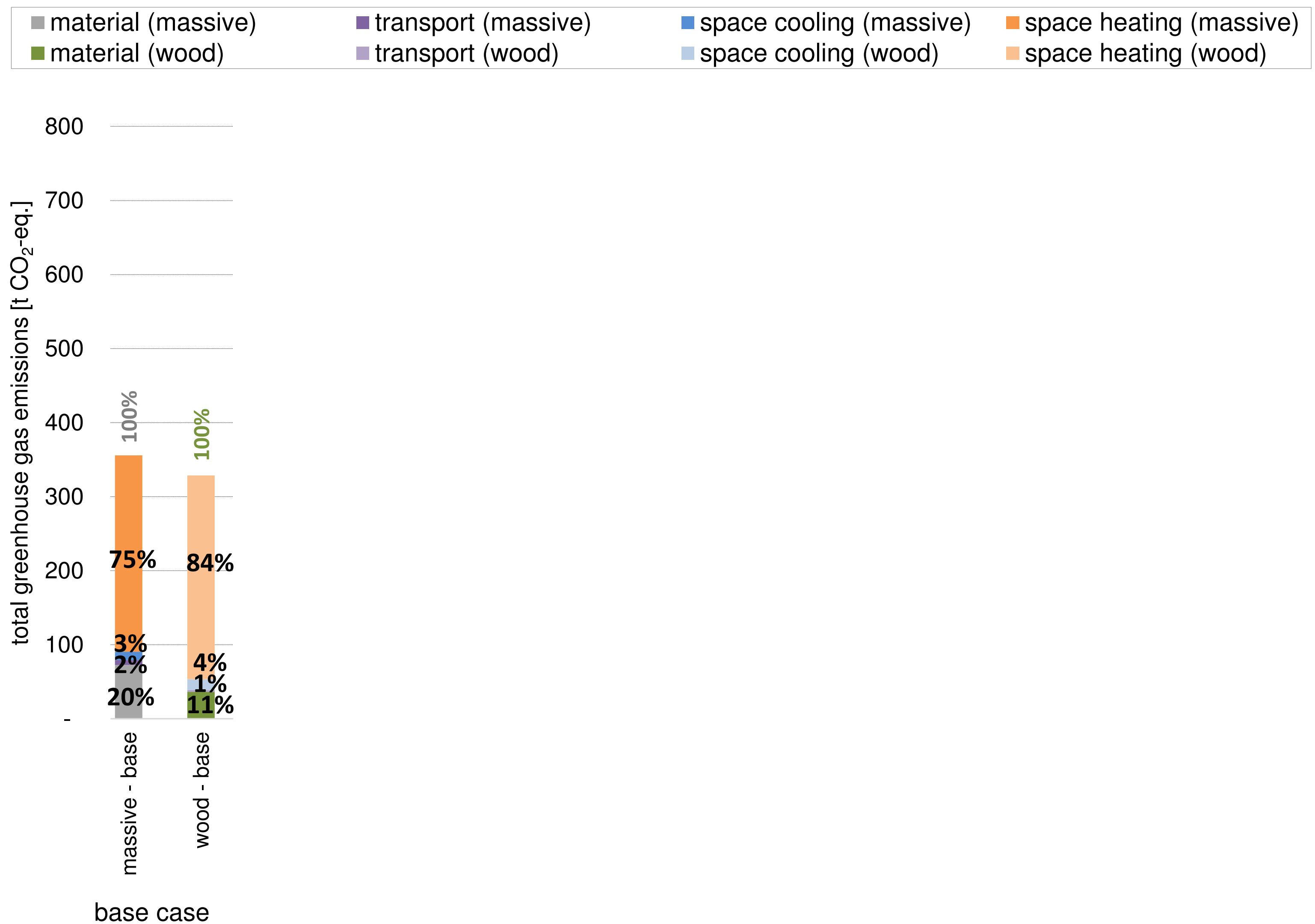
ETH zürich

ESD ecological systems design

Parameters

Parameter	Indicator [unit]	Lower value	Typical value	Upper value
Thermal inertia (baseline scenarios)	X_i [Wh/m²K]	4.0 (wood frame)	None	12.3 (massive brick)
Climate data – Degree Days	HDD20/12 CDD18 [Kd]	Lugano (2567 HDD, 281 CDD)	Zurich (3234 HDD, 148 CDD)	Davos (5864 HDD, 0 CDD)
Window ratio	% of façade area	10%	14 %	60%
Shading – window overhang	Length [m]	0.0	0.3	1.0
Ventilation rate	ACH [m³/m³h]	0.3	1.0	2.0
Internal load	[W/m2] (mean)	6.4	12.8	19.1
Heat generation	energy carrier	Oil heating, non-condens.	Gas heating, condensing	Ground source heat pump
Heating setpoint	T_h [°C]	17	20	23
Cooling setpoint	T_c [°C]	22	25	28
Thermal resistance	Insulation thickness [%]	50%	100%	200%
Window solar transmittance	g [-]	0.20	0.57	0.80
Service life	SL [a]	60 (SIA 2032)	90 (150% SIA 2032)	180 (250% SIA 2032)
Transport distance	[tkm]	10	50	300

Results base variants

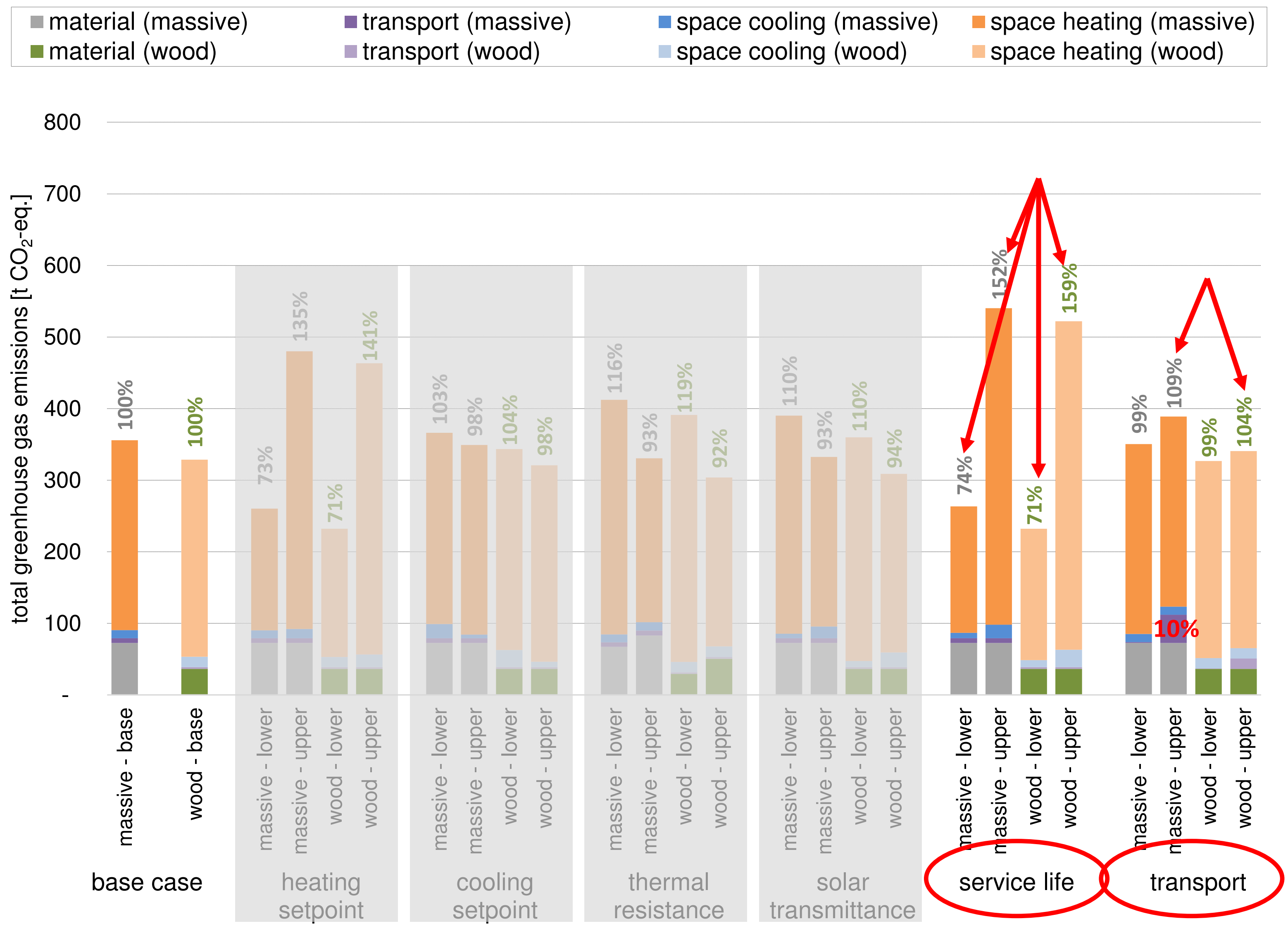


Results scenarios 1/2

ETH zürich

ESD ecological systems design

Results scenarios 2/2



Conclusions

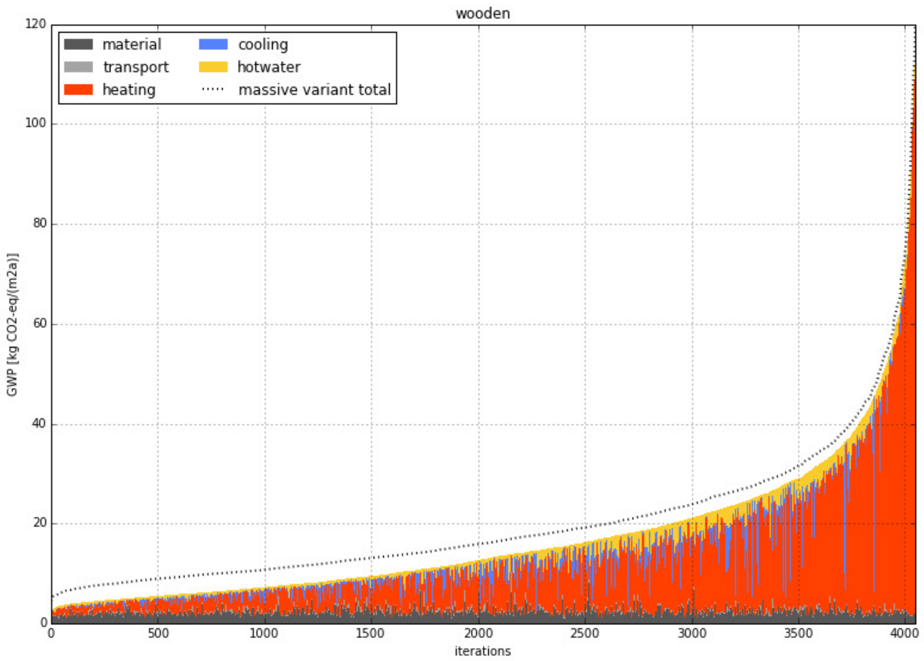
- Use phase normally most important: Parameters affecting space cooling and heating demand have highest impact
- Energy efficient buildings have almost equal impact from material and energy
- Massive constructions have better results due to reduced energy demand (heating and cooling)
- Service life determines "payback" material vs. energy impact

Design recommendations

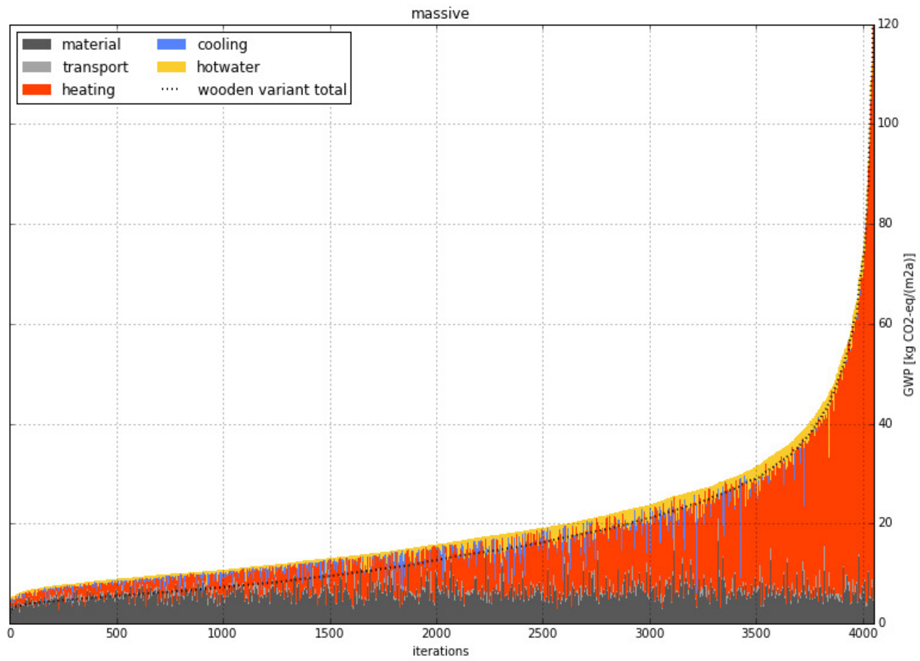
Criterion	Overall	
Life cycle impact recommendation	1. "Clean" energy production 2. Low energy demand 3. Low embodied energy	
Construction type	**Timber frame**	**Massive brick**
Energy demand	*Slight disadvantage (heating), susceptibility to overheating*	*Slight advantage*
recommendation	• Mitigate thermal mass (hybrid construction, PCM, etc.) • Focus on shading and cooling strategy • Avoid large window surfaces	
Embodied energy	*Advantage*	*Disadvantage*
recommendation	• Favourable for short service life (e.g. commercial) • Avoid large window surfaces	• Avoid short service life • Evaluate construction (structural elements, reinforcement, etc.) • Minimize transport (distance & mass)

Outlook: Monte Carlo simulation

wooden variant



massive variant



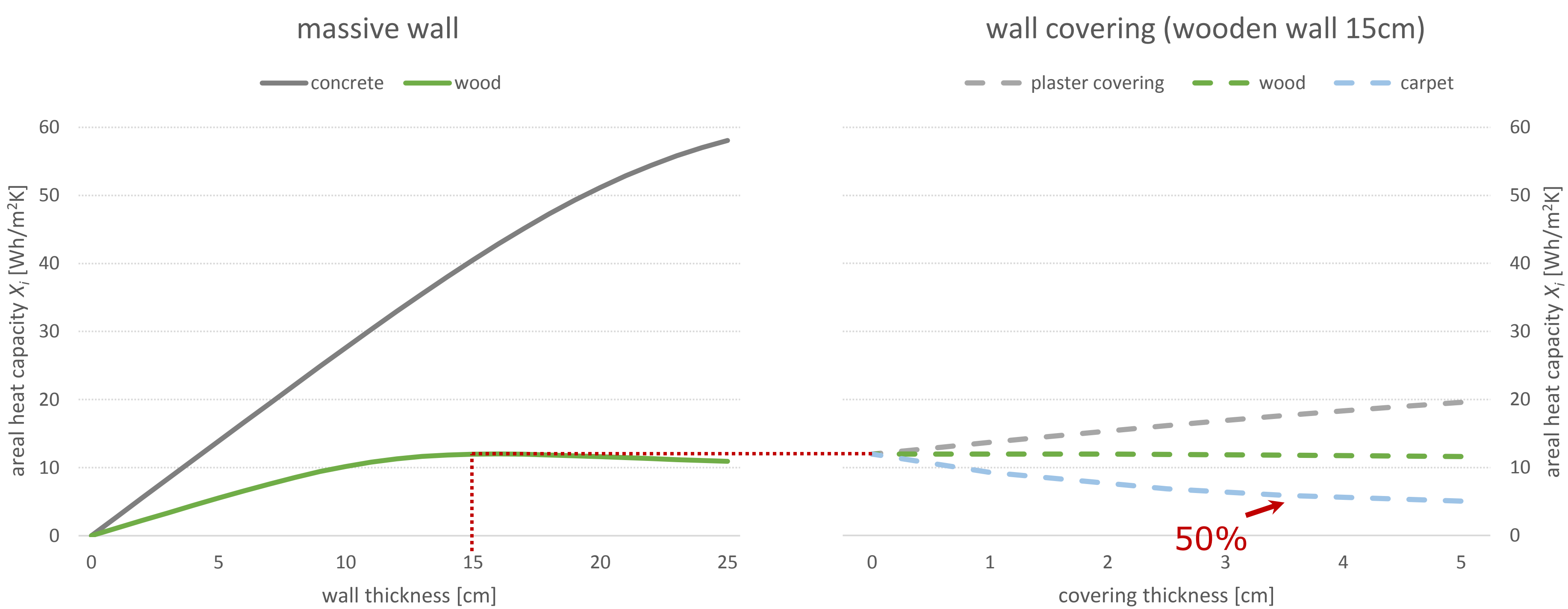
Acknowledgement

Swiss National Research Programme “Resource Wood” NRP 66 (grant number 406640_136612/1)

Thank you for your attention.

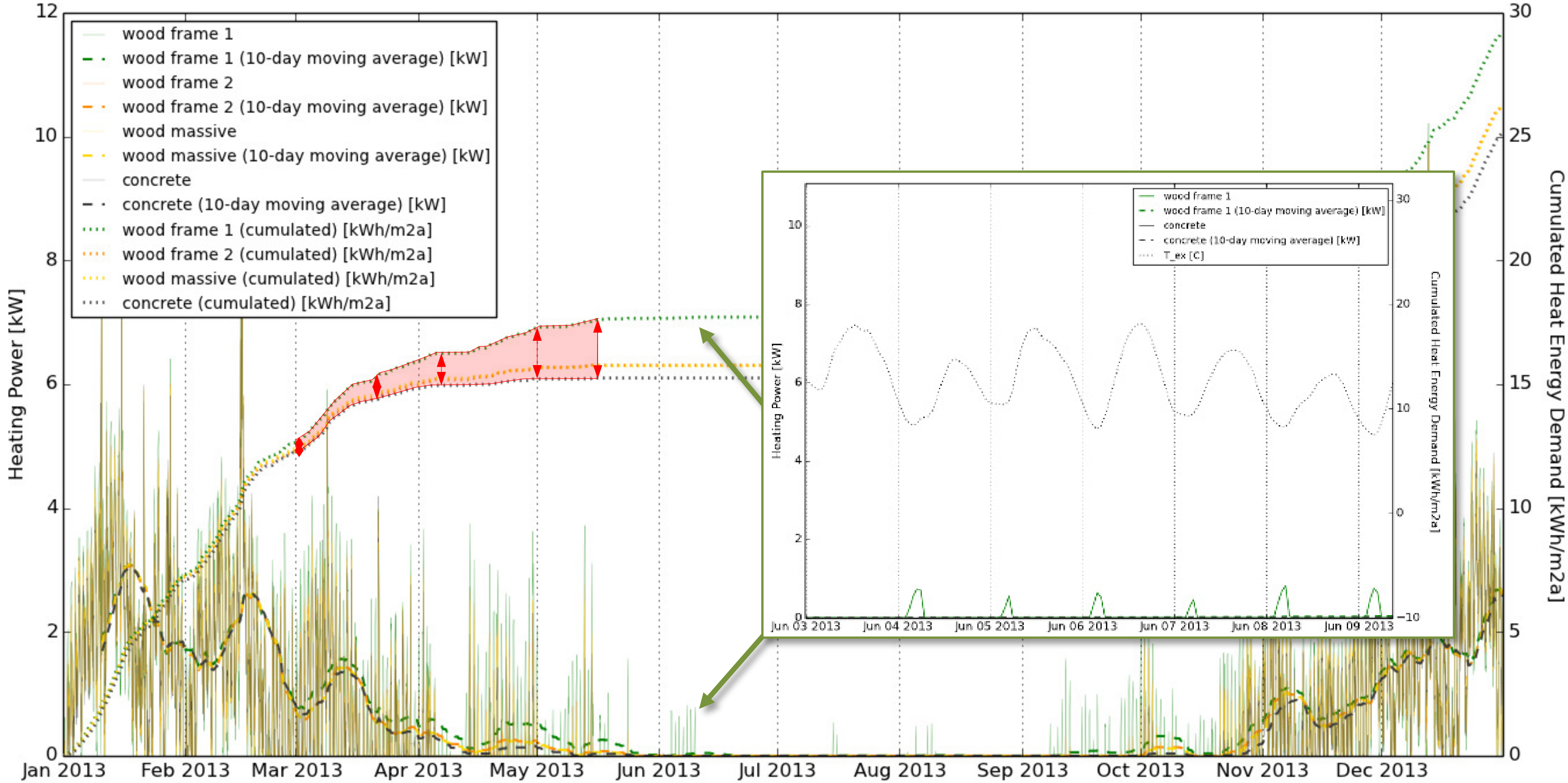
nheeren@ethz.ch

Understanding thermal inertia

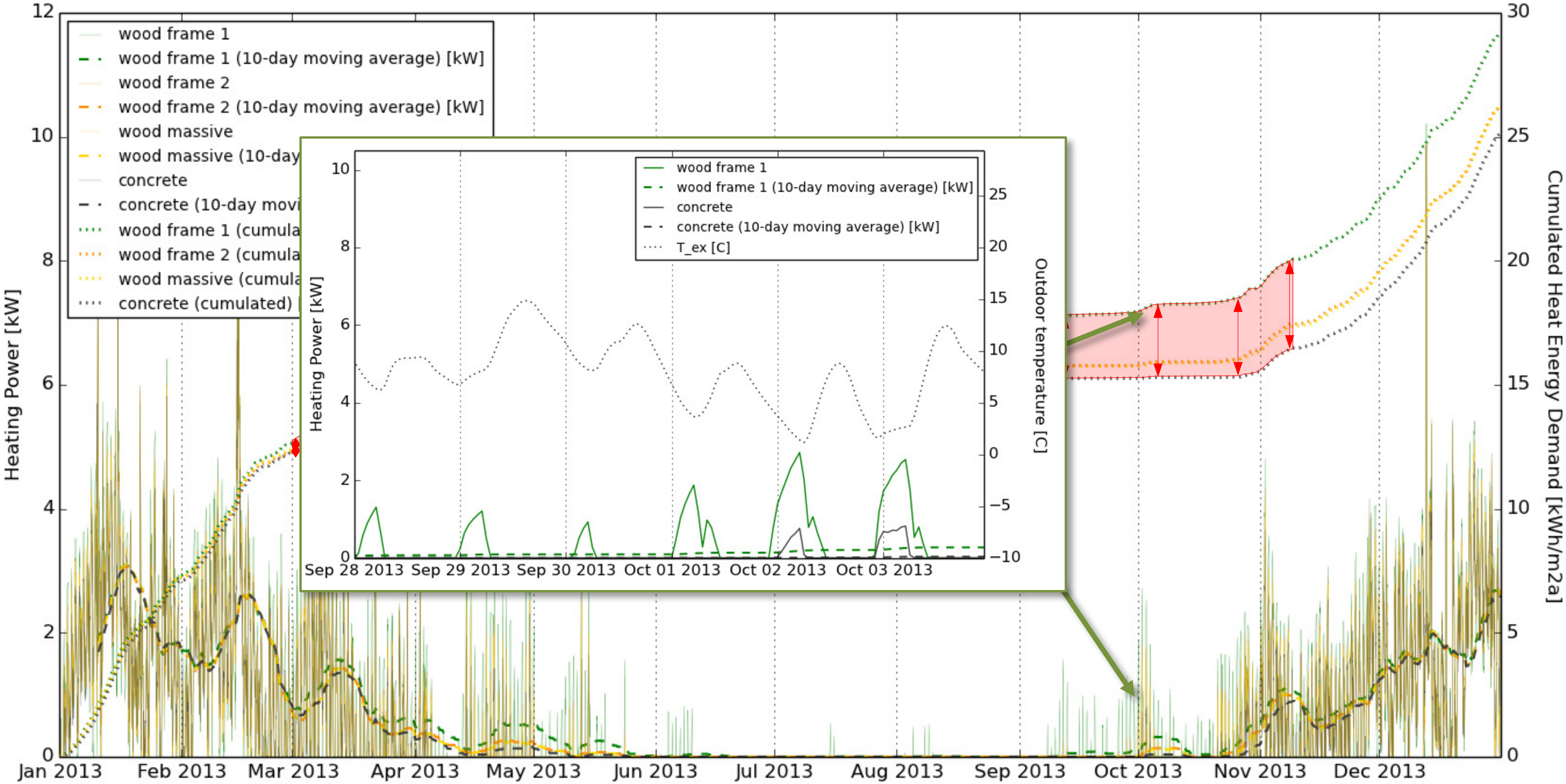


Areal heat capacity X_i calculated based on ISO 13786 (d=15cm, T=24h, $R_{si/se}$=0.0). Material properties: EN 12524

Simulation results – space heat demand



Simulation results – space heat demand

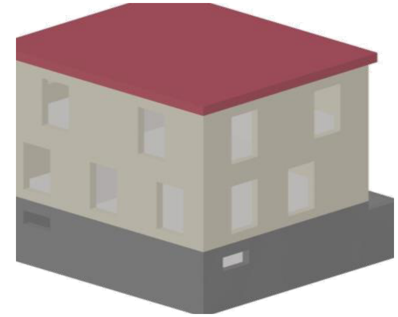


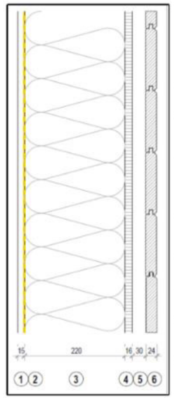
ETH zürich

ESD ecological systems design

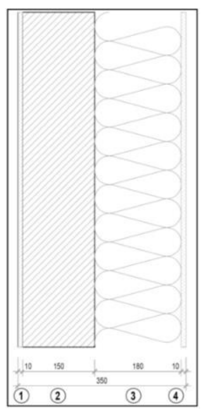
Building

- single-family home
- 2 floors
- 200 m^2 floor area
- window ratio 14%
- flat roof
- no basement



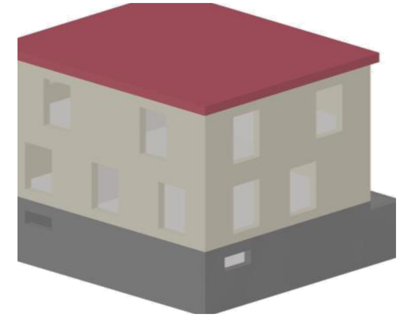


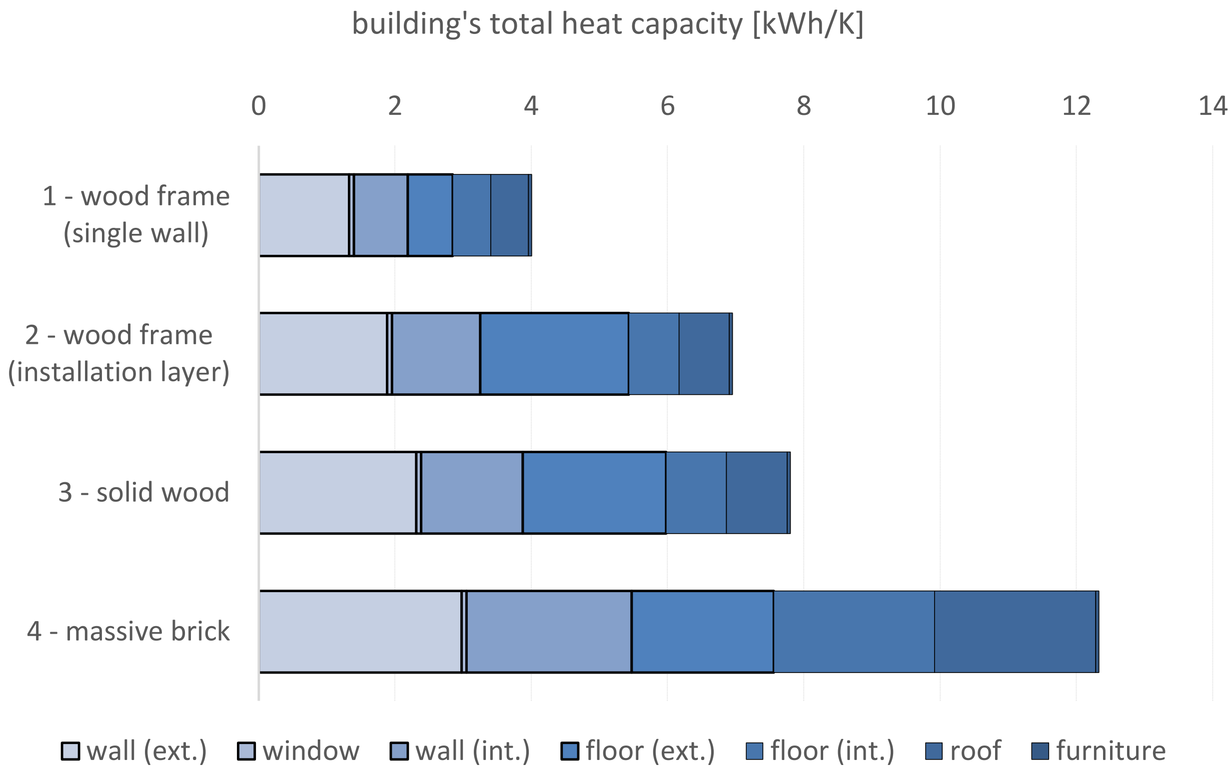
Nr.	Baustoff	Dicke d in mm	Breite b in mm (falls variiert)	Wärmeleit-fähigkeit (WLF) λ in W/(m*K)	Rohdichte ρ in kg/m³	spez. Wärmekapazität C_p in Wh/(kg·K)
1	Gipsfaserplatte	15		0.320	1150	0.278
2	Dampfbremse	-		-	-	-
3	Wärmedämmung	220	565	0.032/0.036/0.038	30/90/55	0.286/0.286/0.556
3a	Holzständer	220	60	0.130	500	0.444
4	MDF-Platte	16		0.100	400	0.472
5	Hinterlüftung	30		-	1	0.280
6	Fassade	24		-	-	-



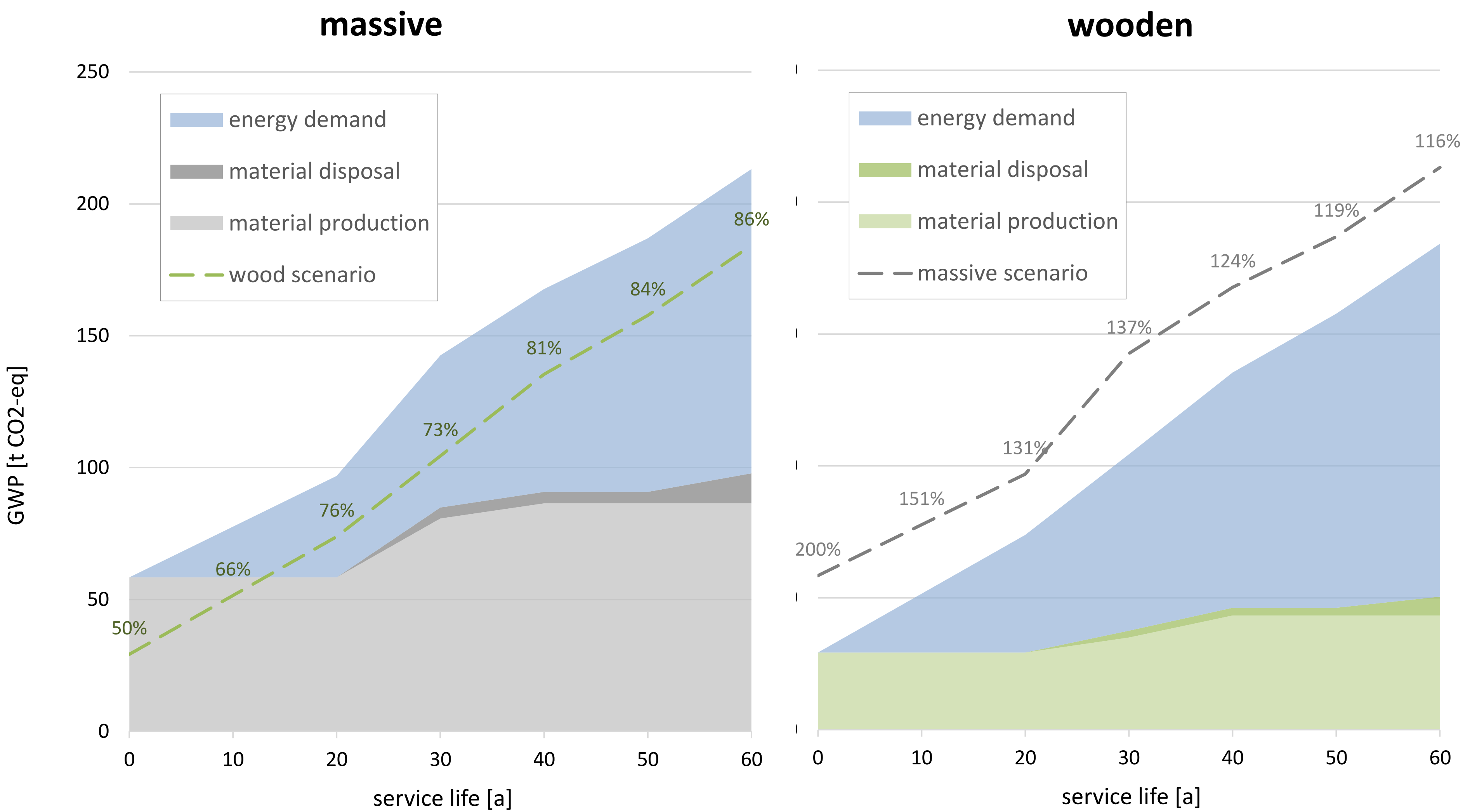
Nr.	Baustoff	Dicke d in mm	Breite b in mm (falls variiert)	Wärmeleit-fähigkeit (WLF) λ in W/(m*K)	Rohdichte ρ in kg/m³	spez. Wärmekapazität C_p in Wh/(kg·K)
1	Innenputz	10		0.700	1400	0.250
2	Backstein	150		0.350	1000	0.261
3	EPS Dämmung	180		0.038	20	0.390
4	Aussenputz	10		0.870	1600	0.278

Building thermal inertia

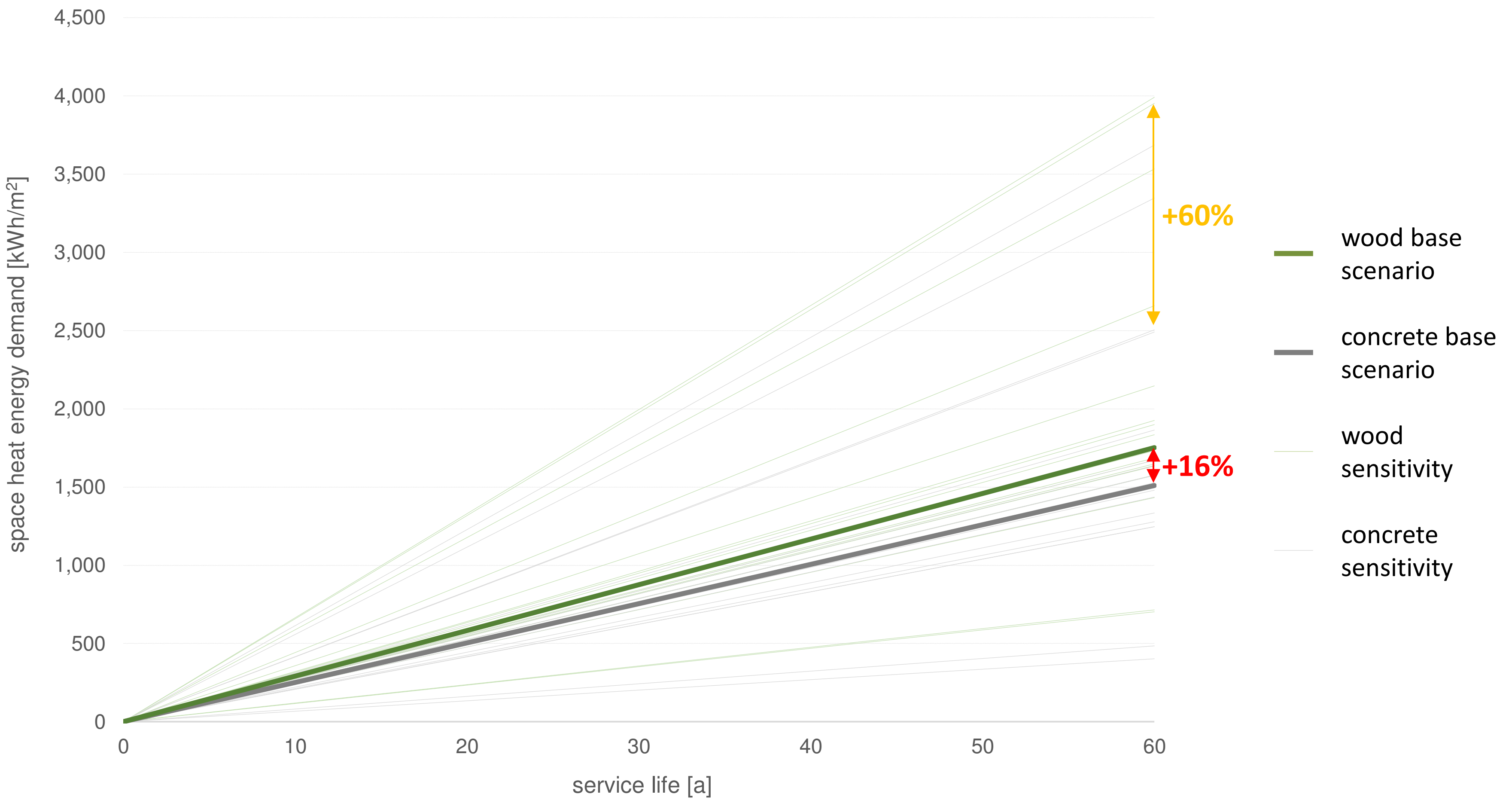




Life cycle comparison – GWP



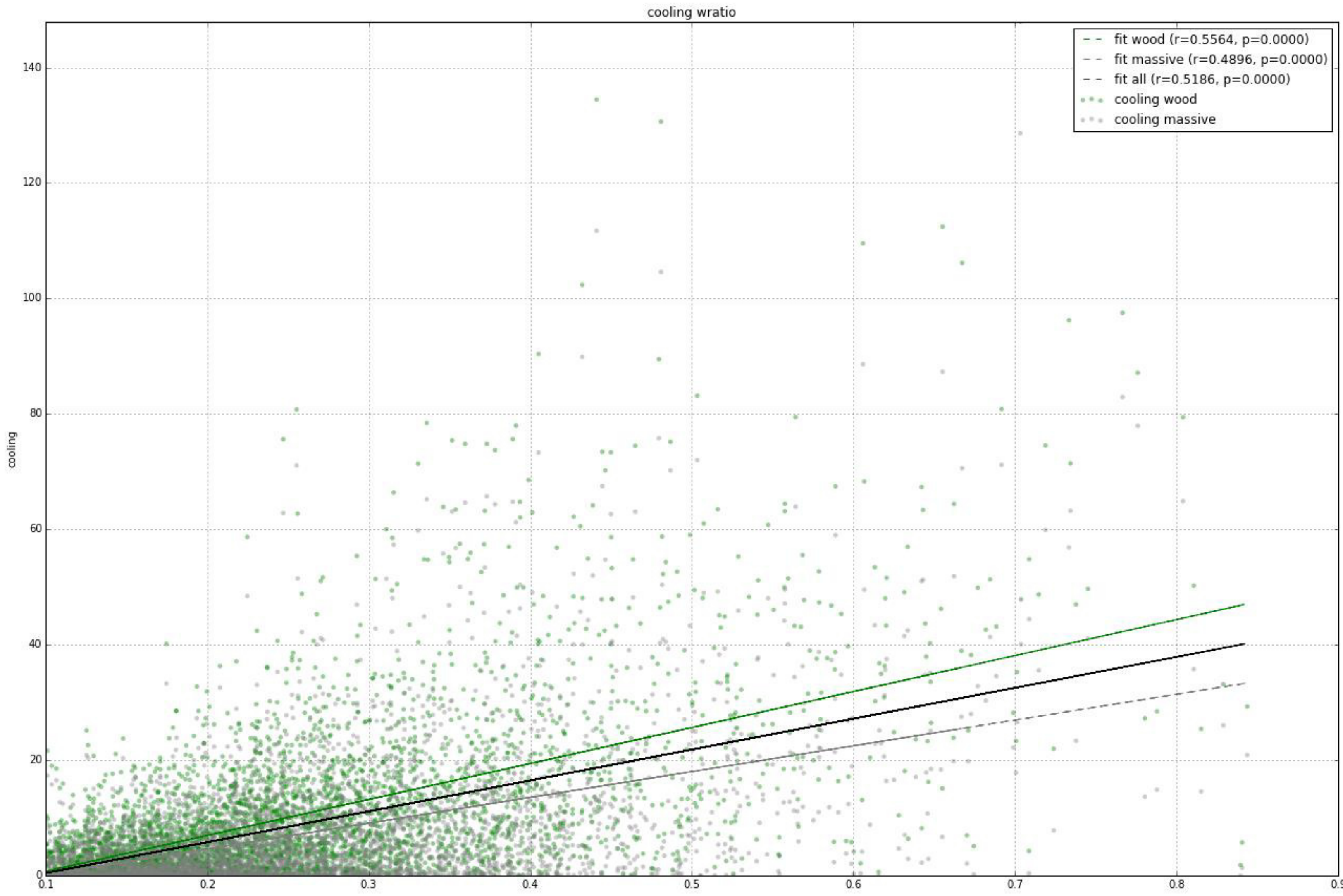
Scenario results thermal simulation



ETH zürich

ESD ecological systems design

Outlook: Monte Carlo simulation



Outlook: Monte Carlo simulation