ETH zürich

Identification of robust renovation strategies under uncertainties

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FNSNF Swiss National Science Foundation

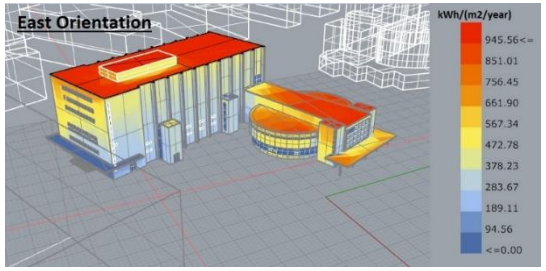
Background

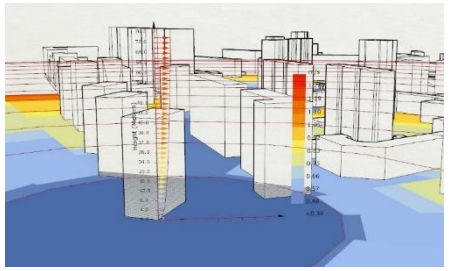
Alina Galimshina

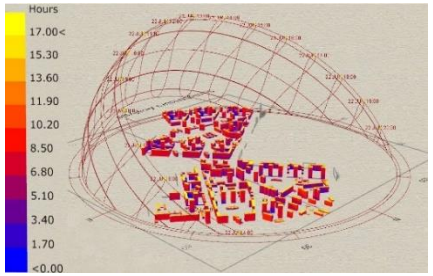
PhD student, Chair for sustainable construction,
Institute of construction and infrastructure management,
D-BAUG

Education

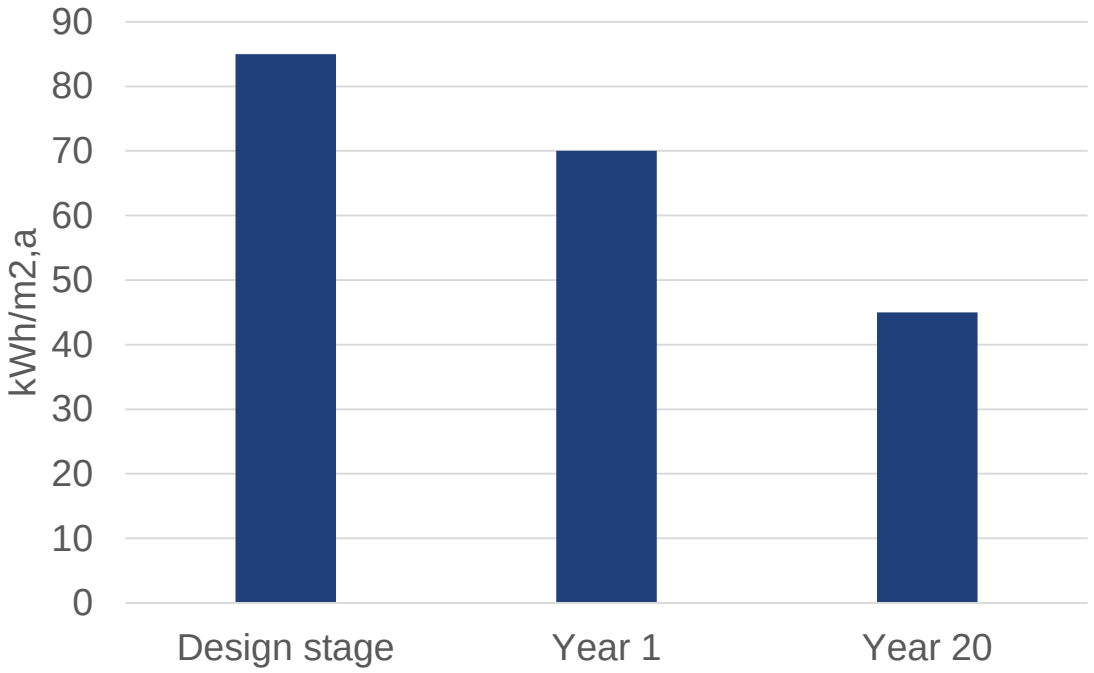
2010-2015 Bachelor in Civil Engineering, Magnitogorsk, Russia
2015-2017 Master in Energy-efficient and environmental building design, Lund, Sweden

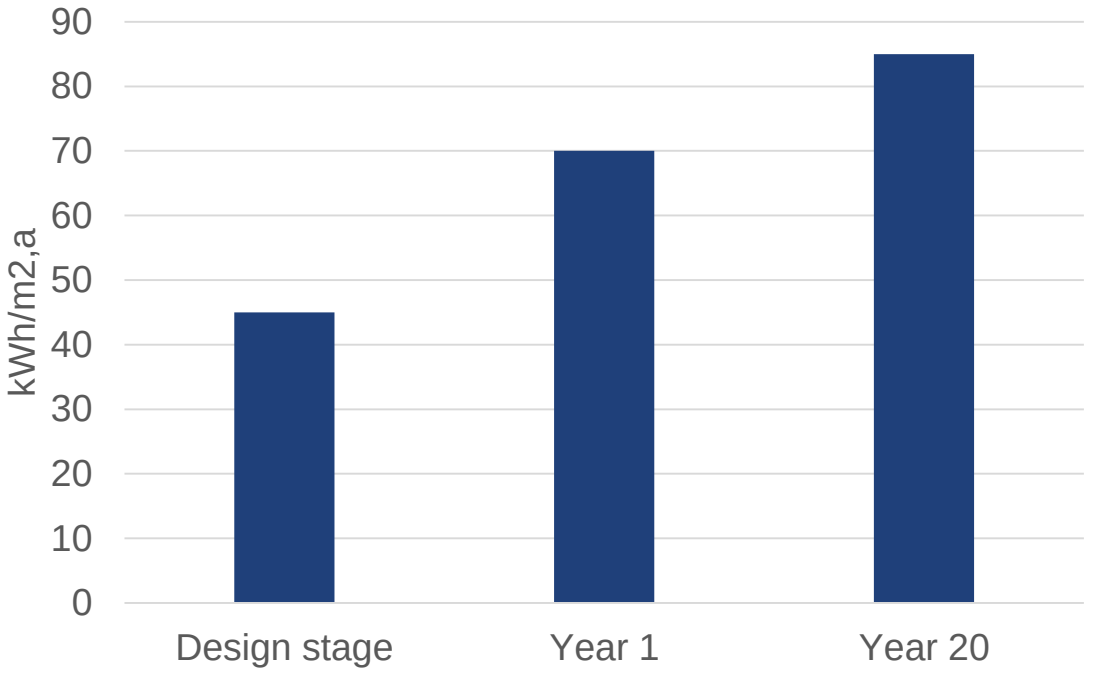






Performance gap

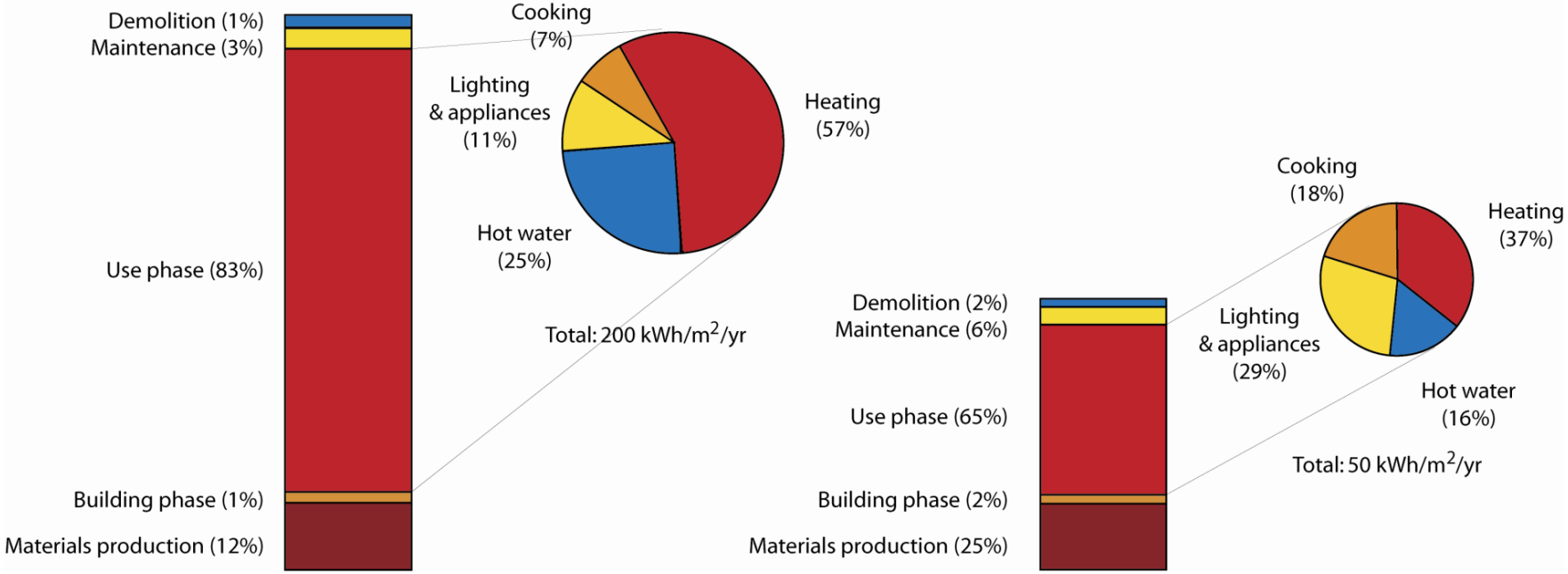




«Performance gap» – initial design does not match with real system

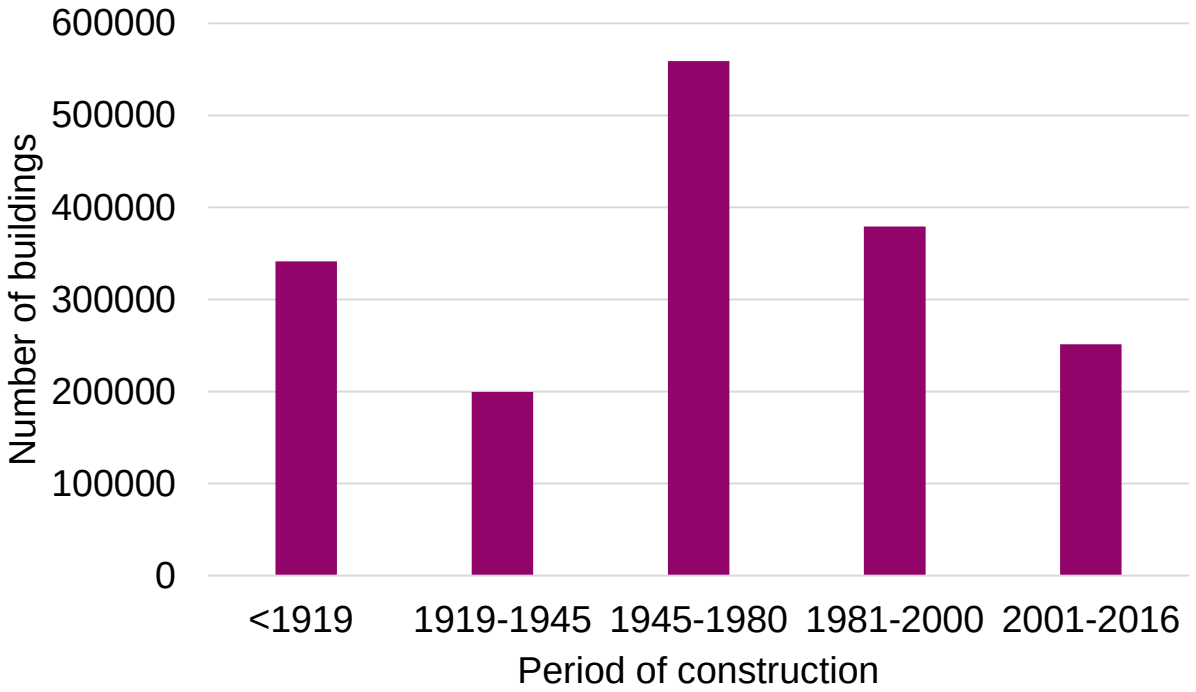
Problem motivation

Buildings are responsible for a large amount of energy and GHG emissions in the world.
80% of the total energy consumption is coming from the operational part



[Sartori and Hestnes, *Energy & Buildings*, 2007]

Problem motivation

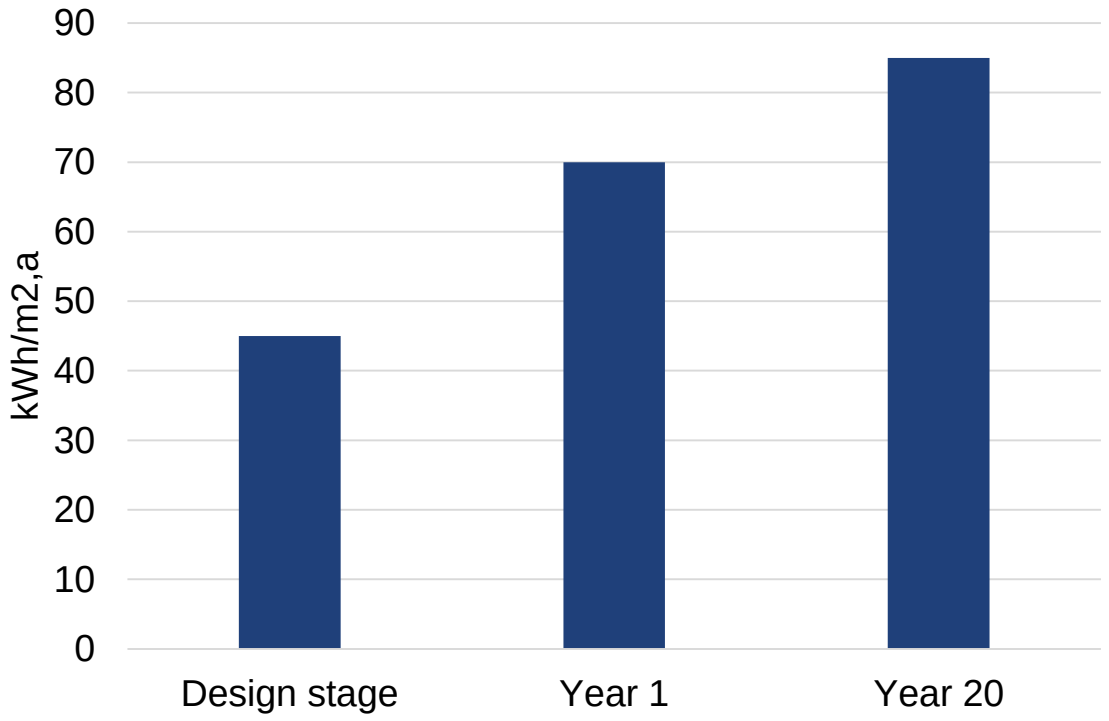


Renovation rate in Switzerland (annual % of building stock renovated) -

0.8-1.8%

Problem motivation

Improving energy efficiency in buildings therefore has a key role in achieving the ambitious goal of carbon-neutrality by 2050



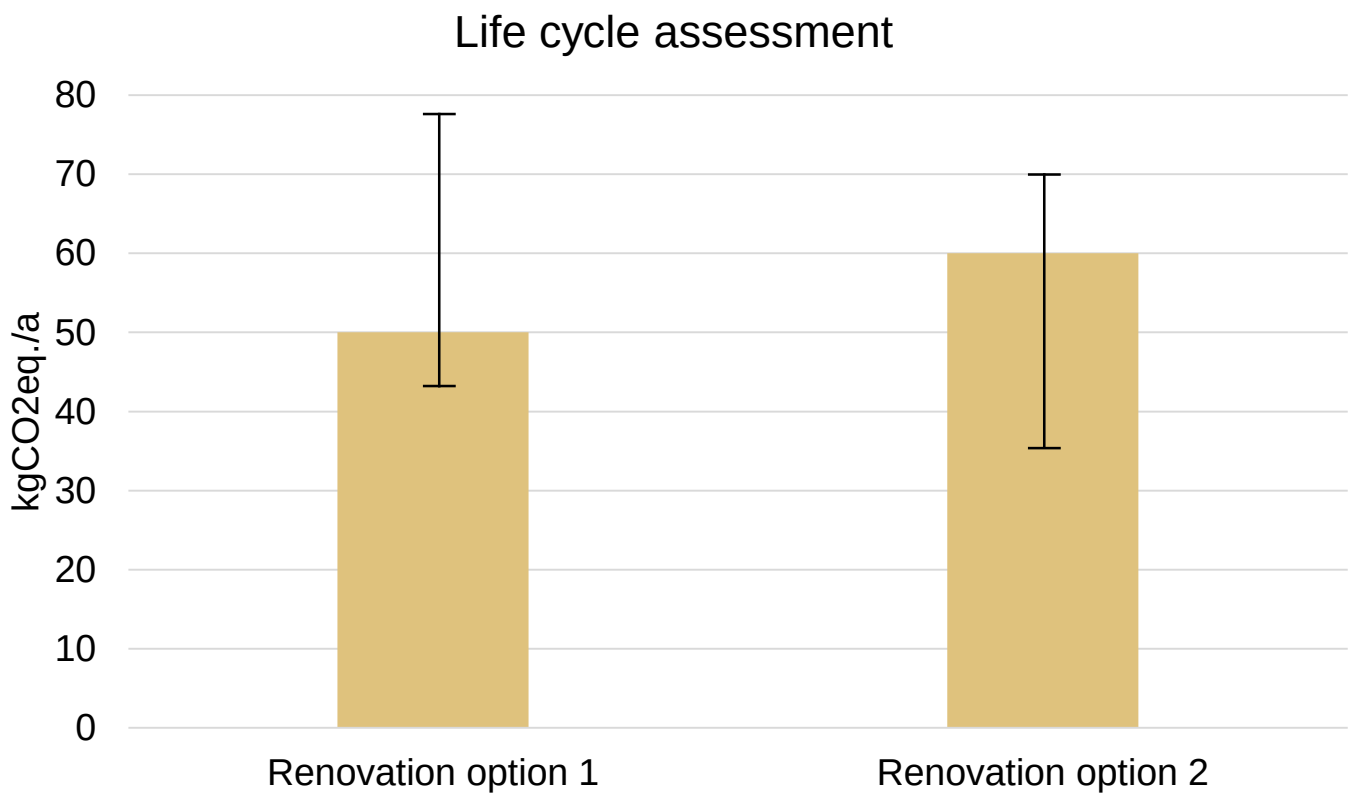
Where does it come from?

The reasons are:

- Uncertainties associated with the system (imperfections, material properties, geometry)

- The loading (boundary conditions) – idealized designed conditions so that they can only roughly represent the complexity (climate, indoor conditions, material service life, nature of the energy carrier)

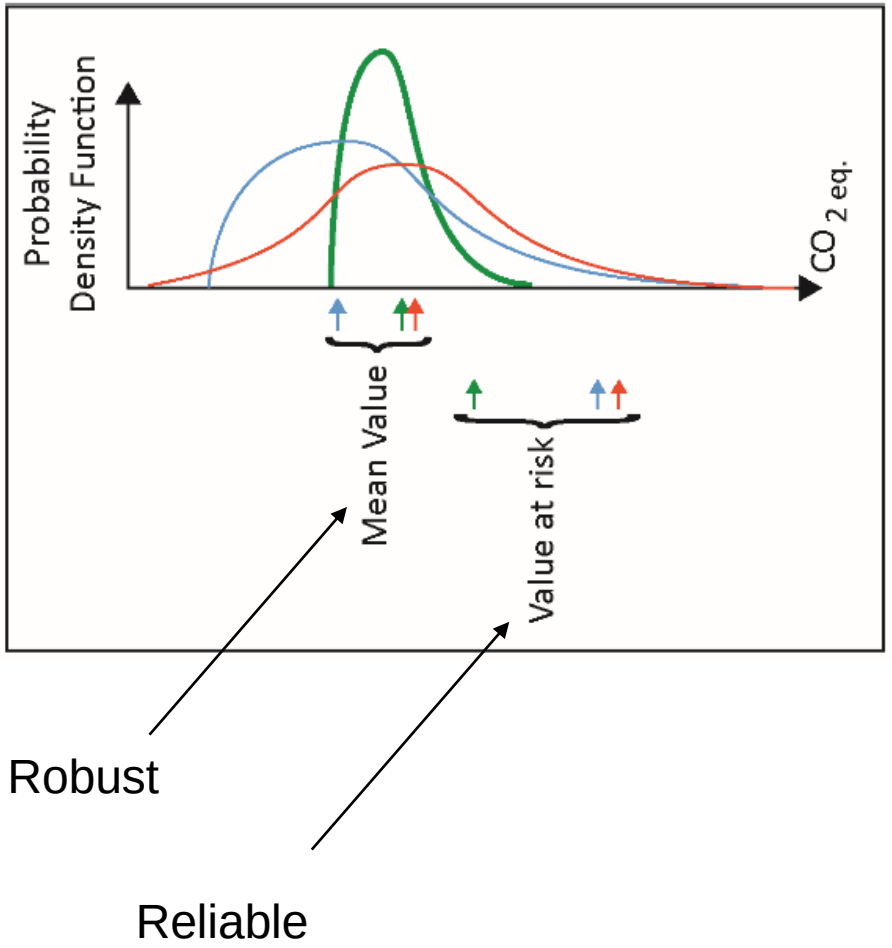
Renovation options



Goal

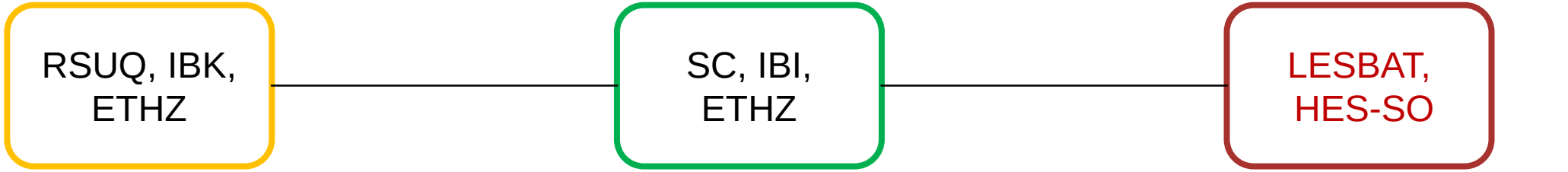
Identify a robust renovation scenario in terms of:

- Life cycle assessment
- Life cycle cost



PhD topic – Robust and reliable sustainability assessment for building renovation strategies

Collaboration



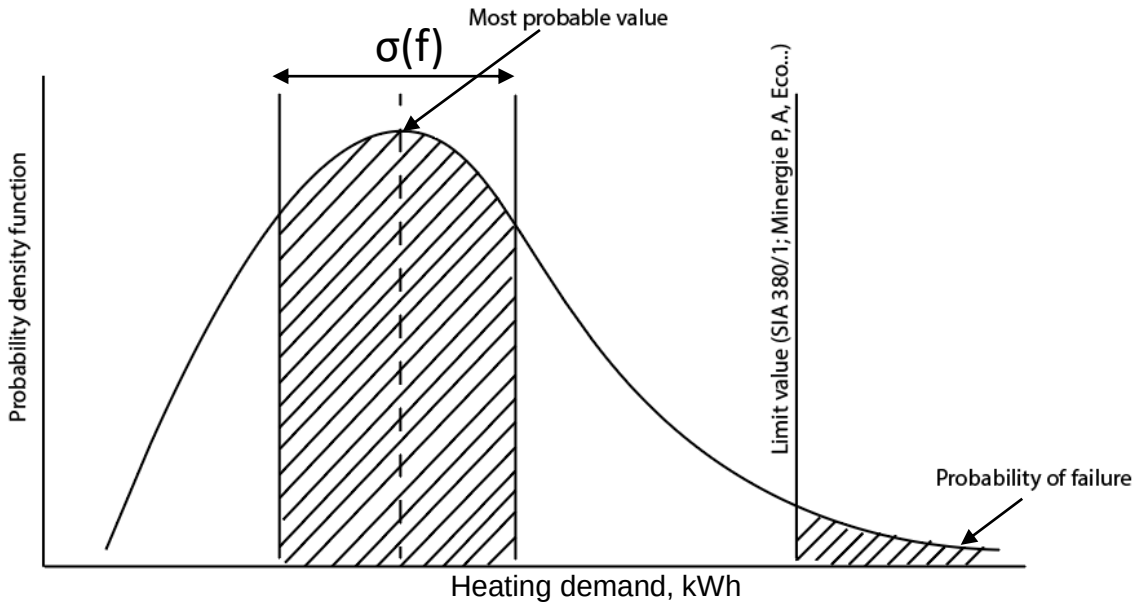
Uncertainty quantification
Sensitivity analysis
Optimization under uncertainties

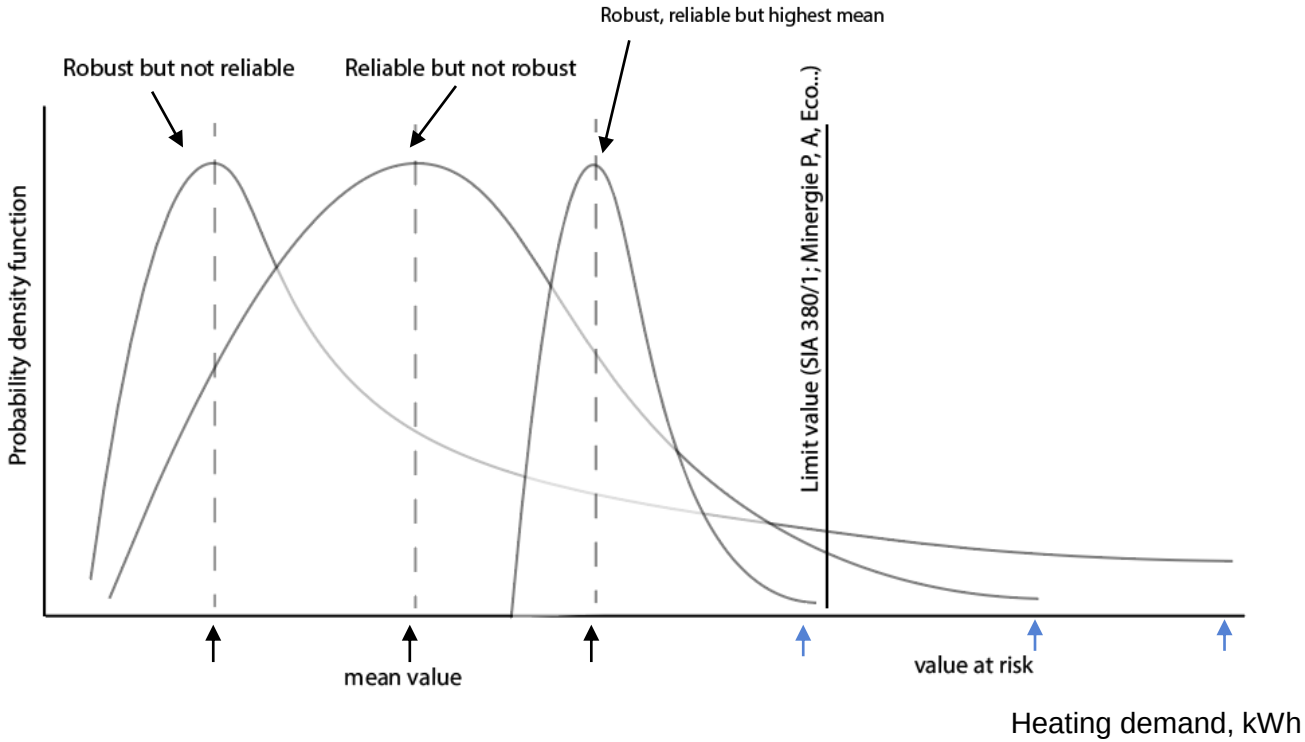
Life cycle assessment
Life cycle cost
Energy simulation

Building renovation scenarios
Building stock modelling

Reliability and robustness?

If a system is reliable, is it also robust?
Does a robust system have to be reliable?





How do we achieve this?

Step 1
Model definition

Heating demand

LCA
Production
Operation
(heating)
Replacement
Demolition

LCC
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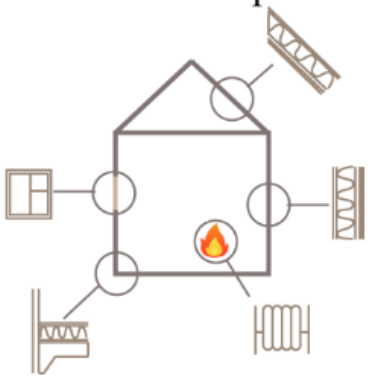
Repair
Demolition

Step 2
Renovation measures description

Renovation options



Step 3
Uncertain parameters description

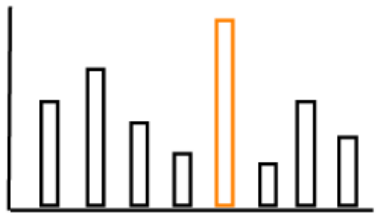
Parameters

Design
Possible design decisions

Exogenous
Economic and social uncertainty

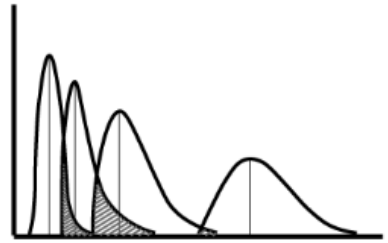
Step 4
Sensitivity analysis

Identification of the most influential renovation measures

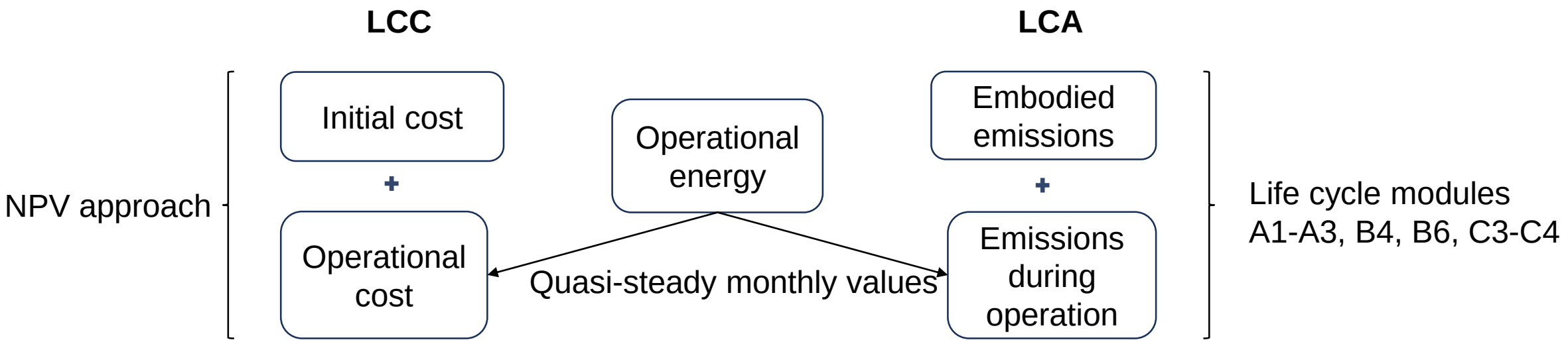


Step 5
Uncertainty propagation

Robustness of the renovation measures

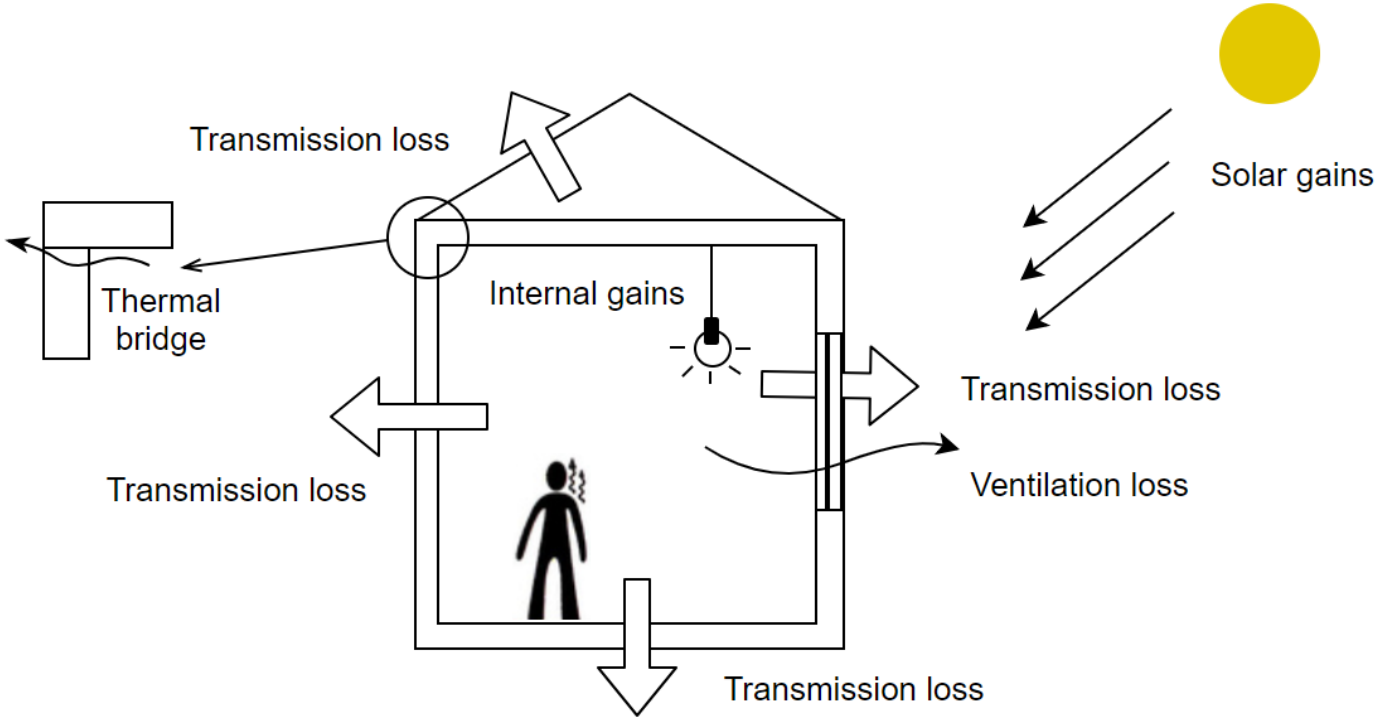


Model description



Model description

Heating demand calculations
SIA 380/1



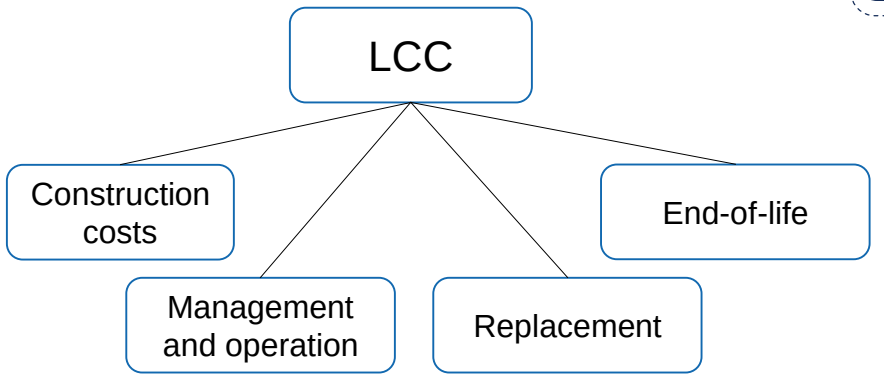
$$Q_h = \Sigma[Q_T + Q_V - \eta_g (Q_i + Q_S)]$$

Q_h - *heating demand*
Q_T - *transmission heat loss*
Q_V - *ventilation heat loss*
η_g - *utilization factor for heat gains*
Q_i - *internal heat gains*
Q_S - *solar heat gains*

Model description

Life cycle cost

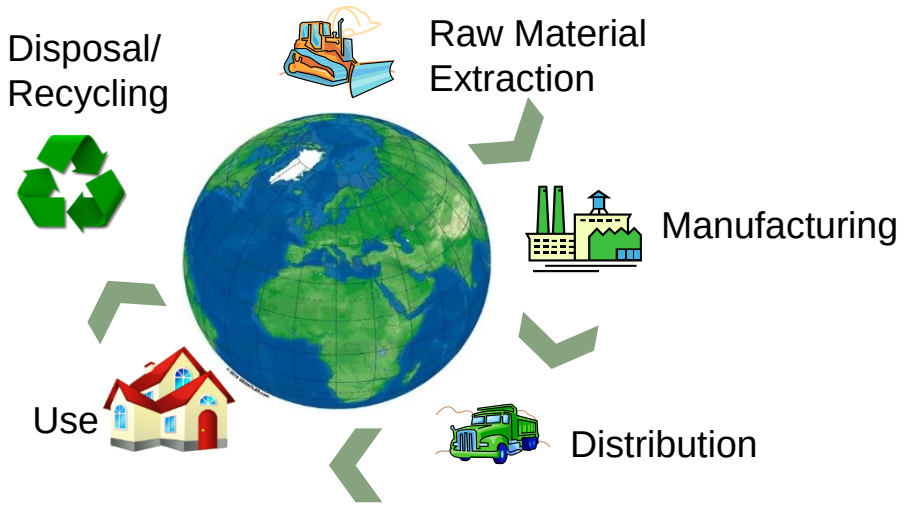
A methodology for systematic economic evaluation of life-cycle costs over a period of analysis



Building life cycle ~ 60 years

Life cycle assessment

Method to calculate the environmental impact of products or services



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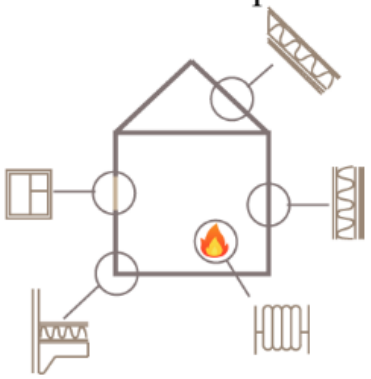

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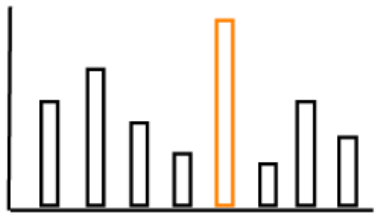

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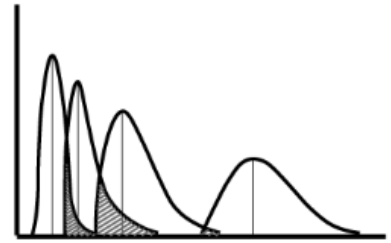
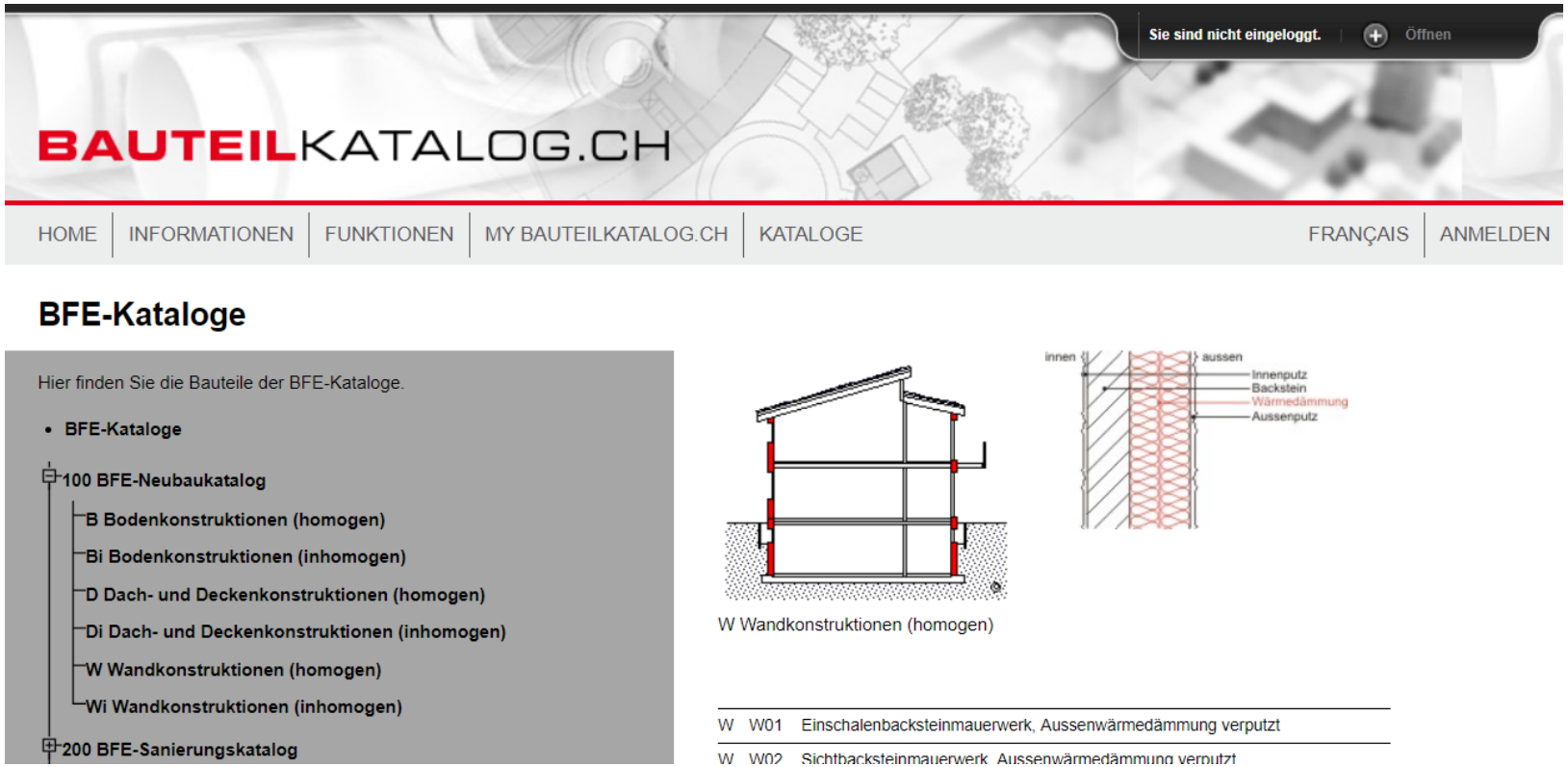
Uncertainty propagation

Robustness of the renovation measures



Building renovation data

Bauteilkatalog - Datasets for elements/components per m²

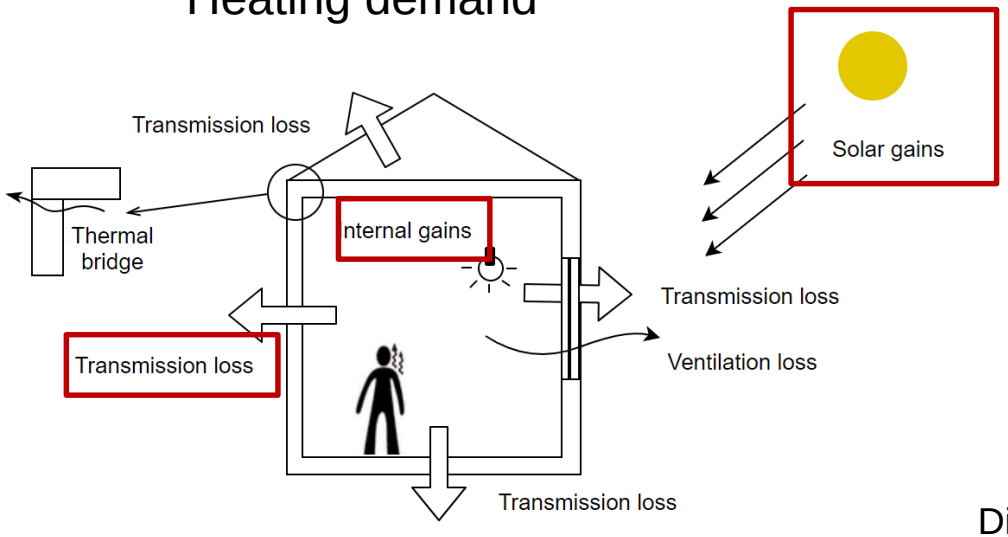


Uncertain parameters

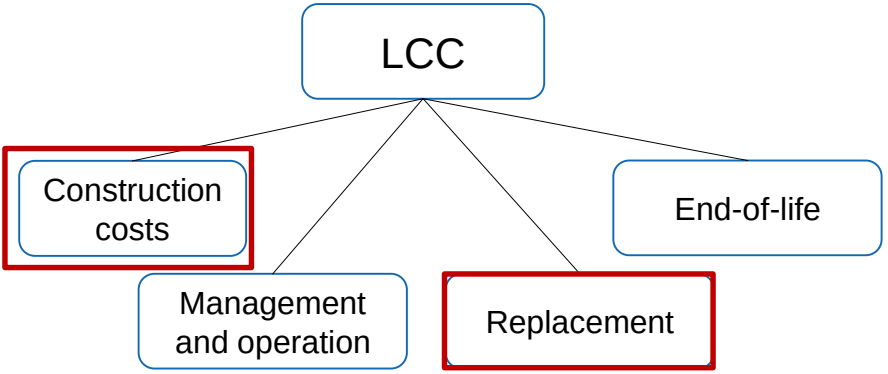
- Design – those that can be affected by a designer
- Exogenous – boundary conditions, occupancy behaviour, system performance

Uncertain parameter?

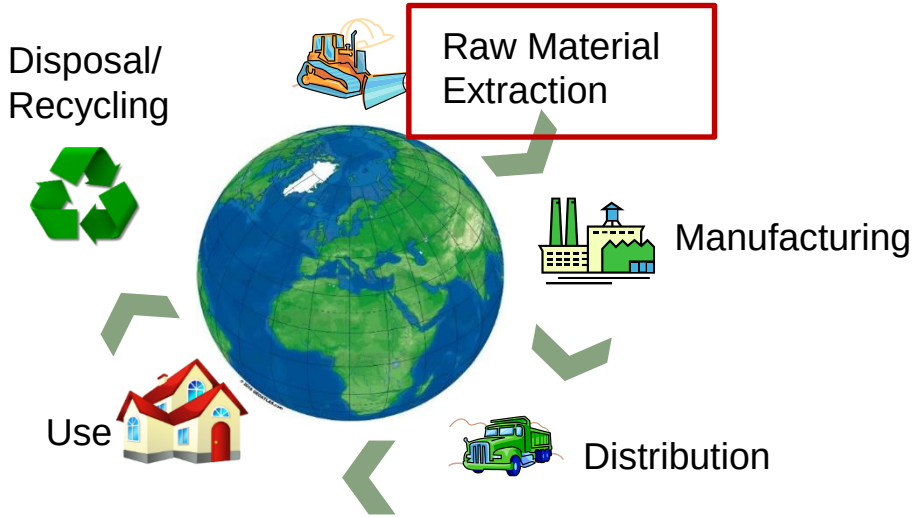
Heating demand



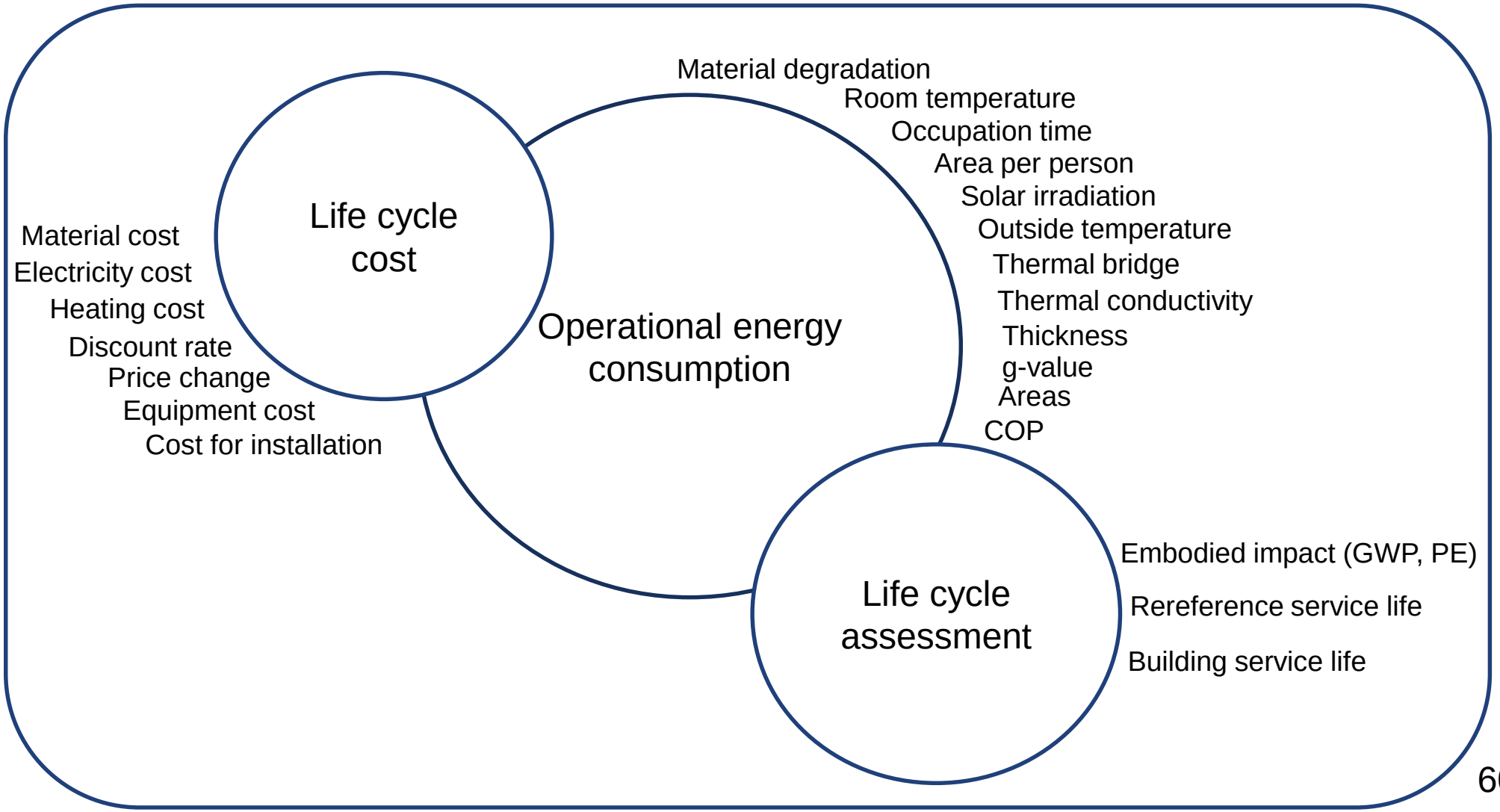
Life cycle cost



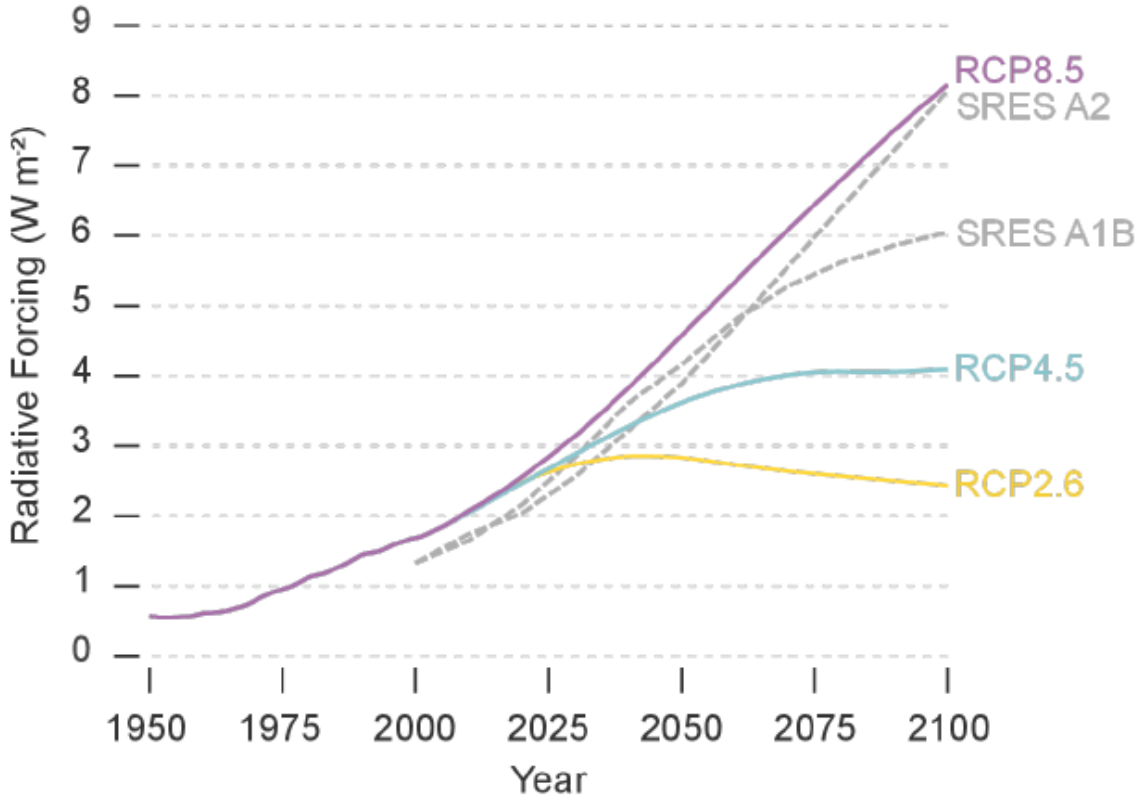
Life cycle assessment



Uncertainties in LCC and LCA

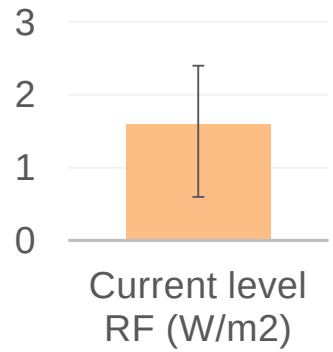


Climate change in Switzerland



RCP – representative concentration pathways

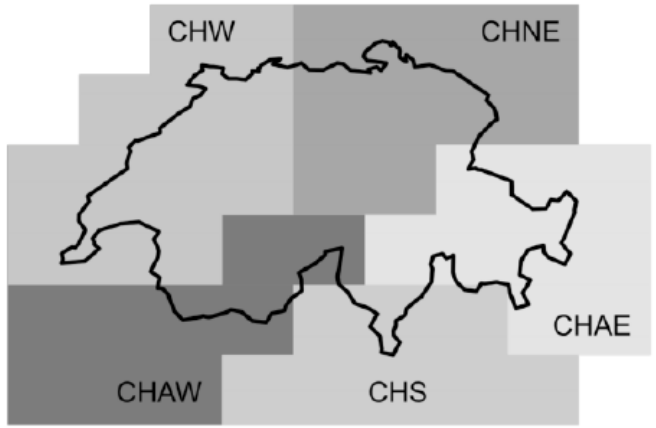
Radiative forcing – difference between the insolation absorbed by the Earth and energy radiated back



National Centre for Climate Services, *CH2018 – Climate Scenarios for Switzerland*. Zurich, 2018.

Climate change modeling in probabilistic context

Data: NCCS
Resolution – 11 km
Data from 1981 to 2099 daily
10 models
85 stations



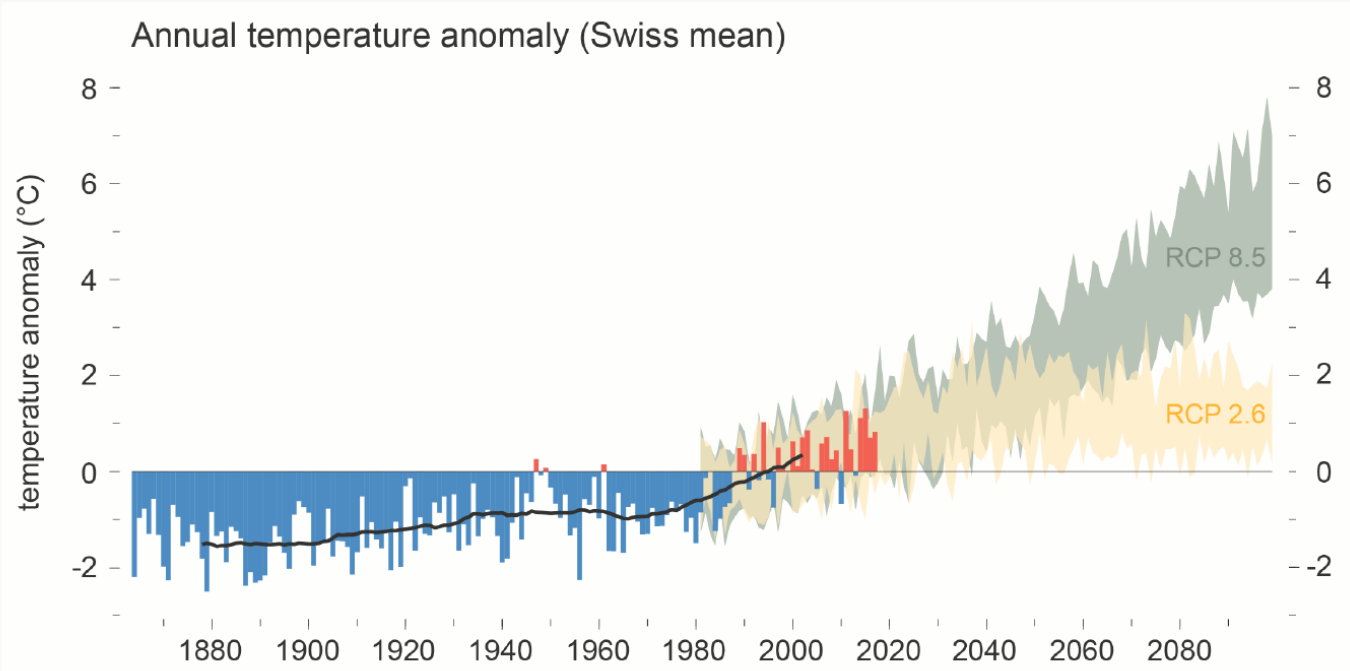
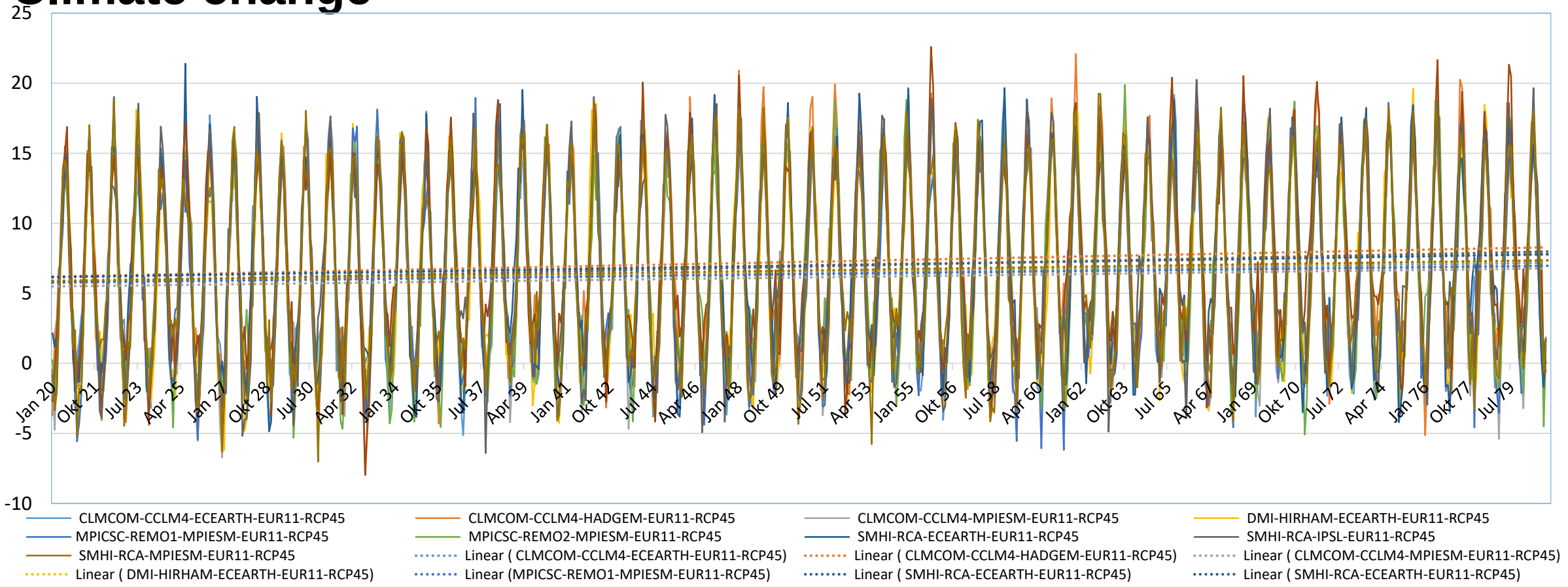


Figure 11.1. Evolution of Swiss annual mean temperature from 1864 to 2099, shown as deviation (°C) from the baseline 1981 - 2010. The bars show the observations from 1864 to 2017 (negative anomalies in blue, positive anomalies in red). The green (orange) shading shows the projected (5th to 95th percentile) range using the RCP8.5 (RCP2.6) scenario.

Climate change

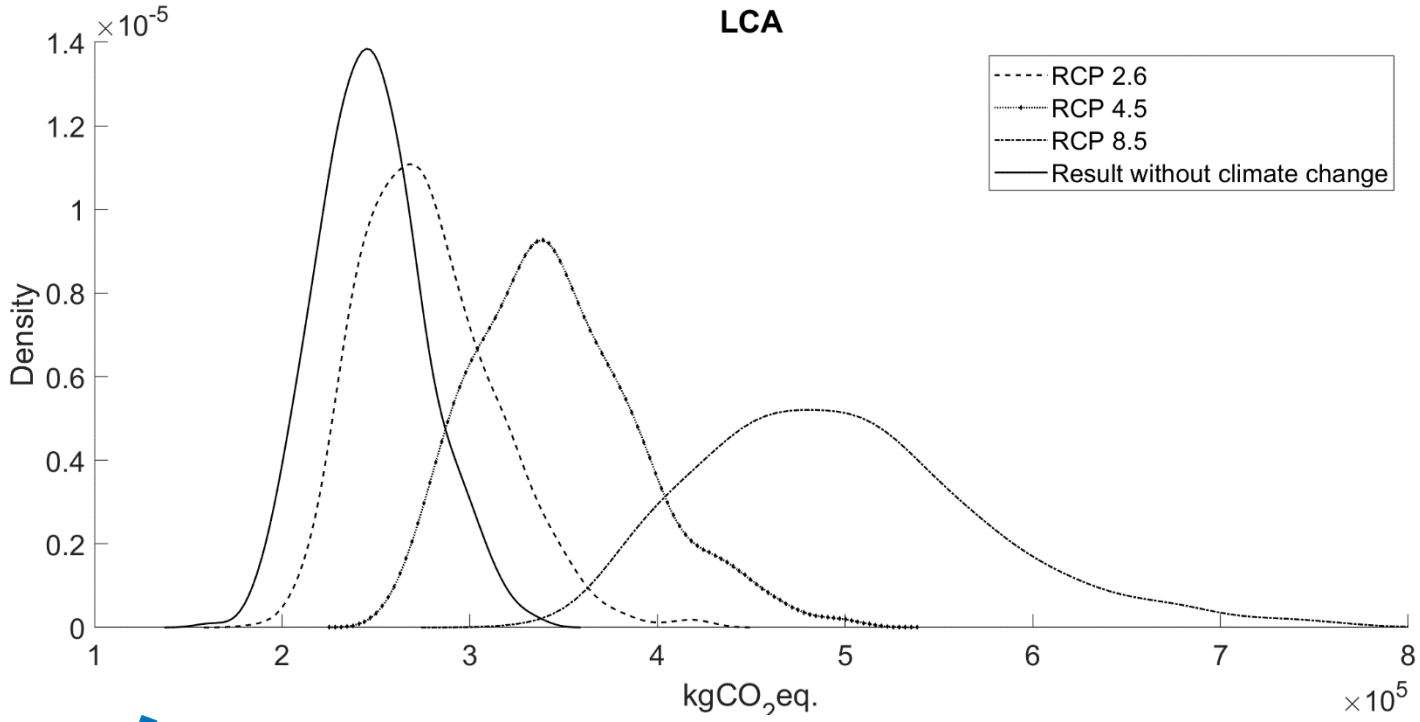


720 correlated variables

Aproach

Goal – to compress the dataset into a smaller number of random variables (for 3 scenarios and 5 regions).

Principal component analysis (PCA) – helps to reduce the dimensionality of the initial sets of points by creating a smaller set of variables with minimum information loss.



How do we achieve this?

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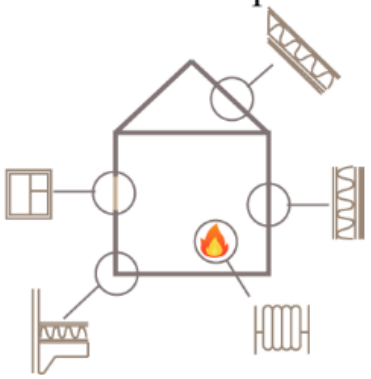
Renovation measures description

Renovation options



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Parameters

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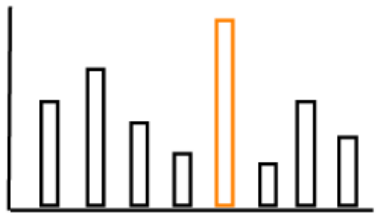
Economic and social uncertainty

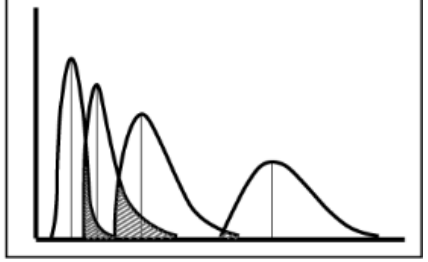
Step 4
Sensitivity analysis

Identification of the most influential renovation measures



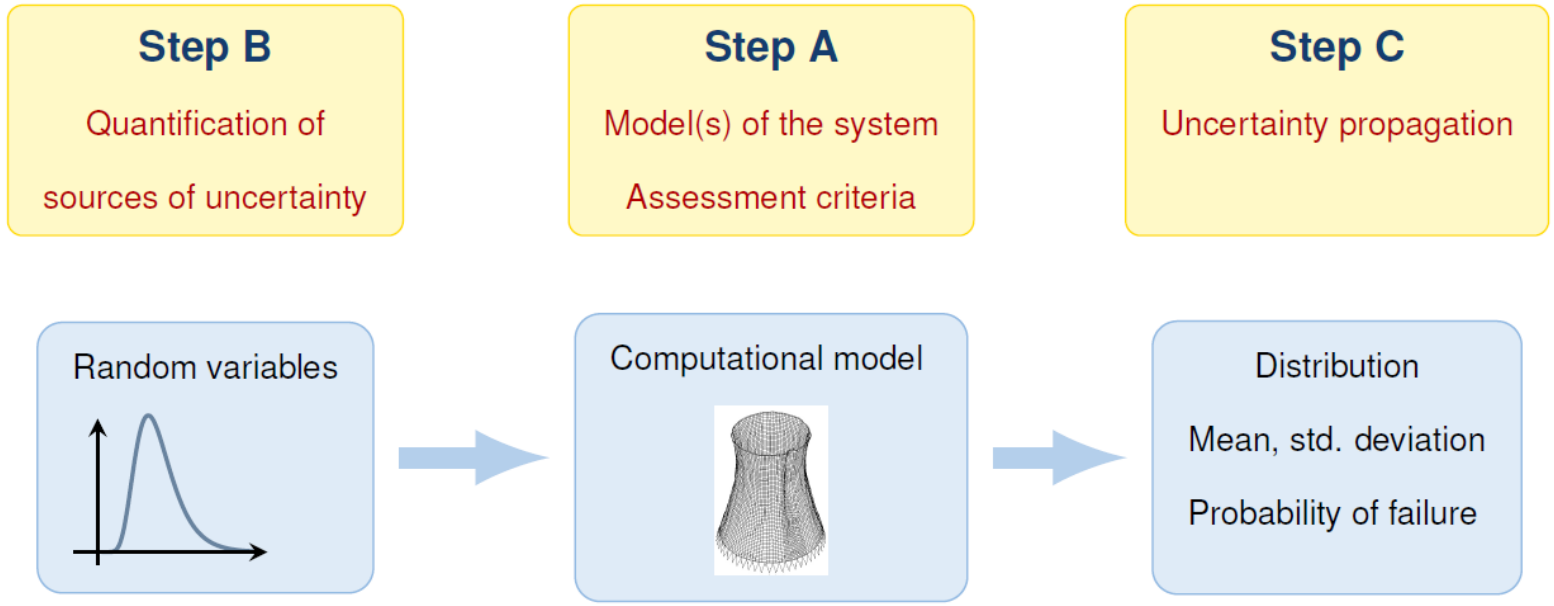
Step 5
Uncertainty propagation

Robustness of the renovation measures



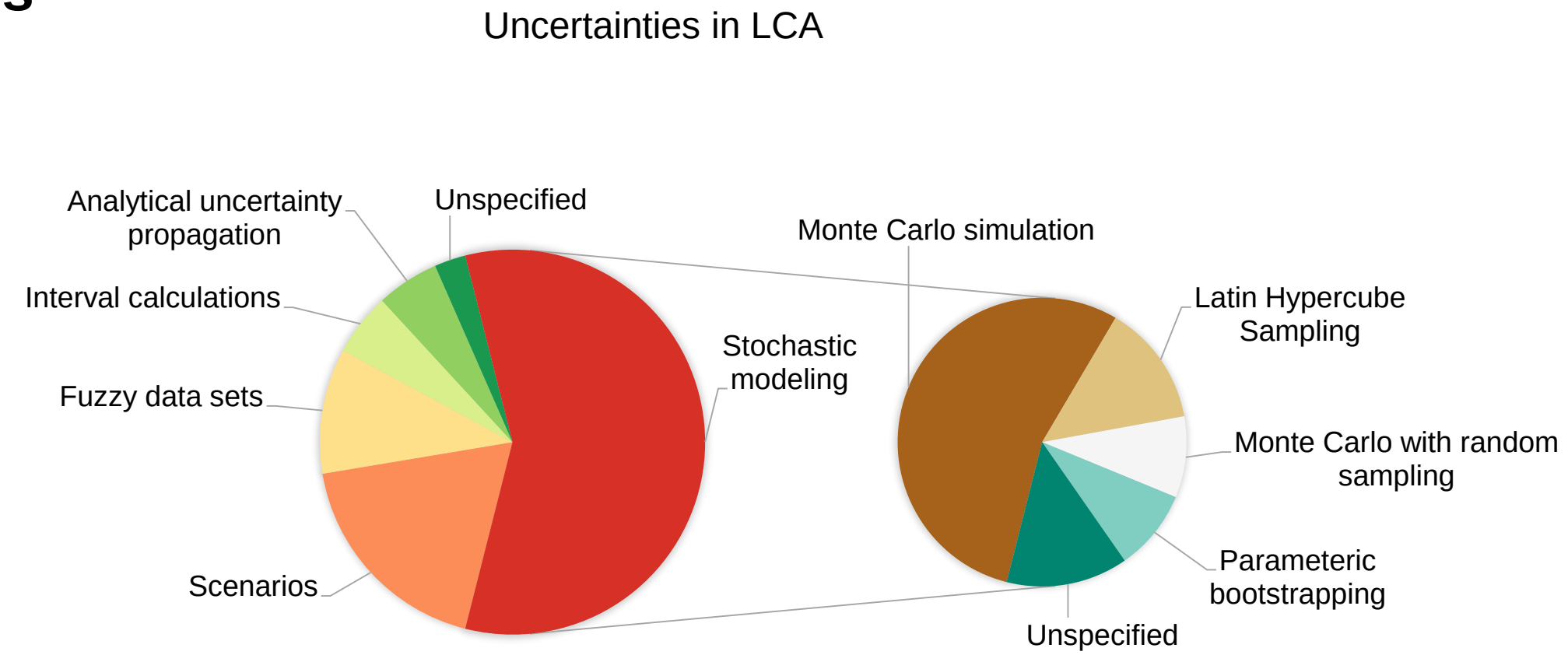
Uncertainty quantification

Aims at taking into account all sources of uncertainties and quantifying their impact on the model response.



Sudret, B. Uncertainty propagation and sensitivity analysis in mechanical models, Habilitation à diriger des recherches, 2007.

Methods



Adapted from: S.M. Lloyd, R. Ries, Characterizing, propagating, and Analyzing Uncertainty in Life-Cycle Assessment. A Survey of Quantitative Approaches, 2007

Monte Carlo simulation

Advantages:

- Easy
- Always converges
- Complete representation of the model output in a histogram

Disadvantages:

- Slow convergence ($1/\sqrt{N}$)
- Might be difficult if the model is expensive

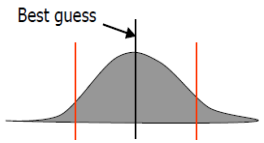
Polynomial chaos expansion

Quantification of sources of uncertainty

Models of the system

Uncertainty propagation

Random variables

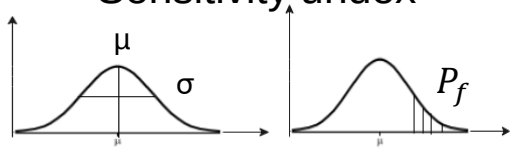


Computational model

Cost

Environmental impacts

Moments, Response PDF
Sensitivity index



PCE model or surrogate $\mathcal{M}^{PC}$

MC-based sensitivity index = n (M+1),
n – size of the simulation, M – number of parameters

Sobol indices can be achieved as a postprocessing of PCE coefficients analytically at no computational cost

B. Sudret, *Uncertainty propagation and sensitivity analysis in mechanical models – contributions to structural reliability and stochastic spectral methods (2007)*

PCE features

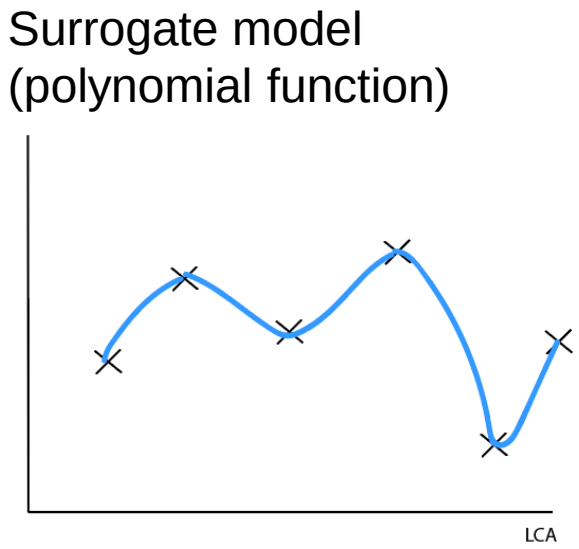
Polynomial chaos expansion – *non intrusive spectral method that allow the analyst to compute the PC coefficients from a series of calls to the deterministic model*.

Advantages:

- Requires several model runs to build a surrogate
- Takes a model as a black box
- Postprocessing allows getting the mean, variance,

Disadvantages:

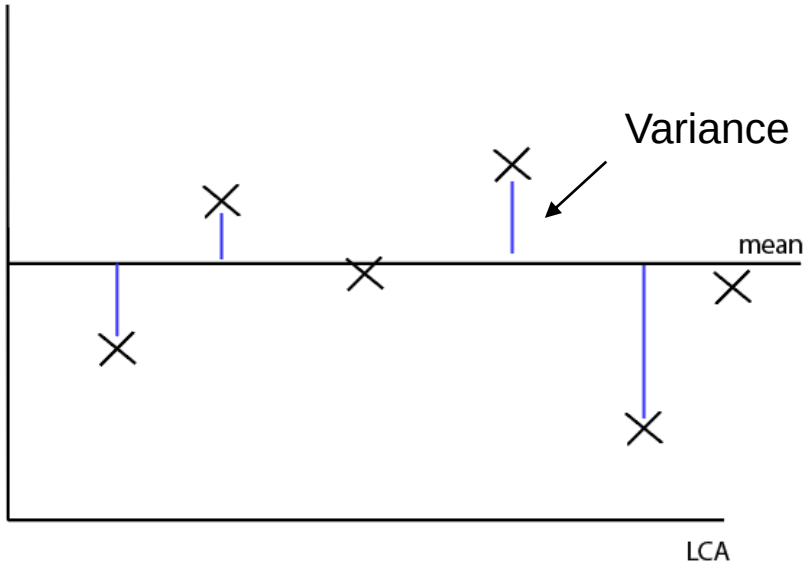
- The surrogate needs to be built



Global sensitivity analysis

Allows to understand the most influential parameters for the model output

Can be computed with Monte Carlo simulation, however, the size = n (M+1), n – size of the simulation, M – number of parameters



$$\sigma^2 = \frac{\sum(x-\mu)^2}{N}$$

σ^2 is variance.
x is the value of an individual data point.
μ is the mean of data points.
N is the total # of data points.

The higher the variance – the bigger the contribution of the input

Can be computed as a post processing of PCE at no computational cost

Variance (σ^2) is a measurement of the spread between numbers in a data set.

B. Sudret, Global sensitivity analysis using polynomial chaos expansions, Reliab. Eng. Syst. Saf. 93 (2008) 964–979. https://doi.org/10.1016/j.ress.2007.04.002.

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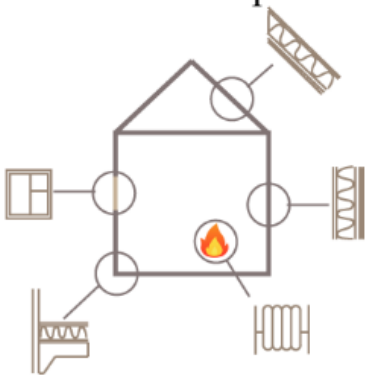

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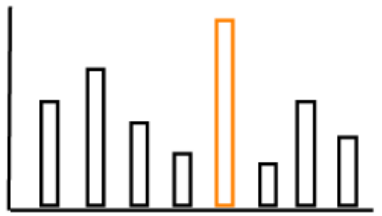

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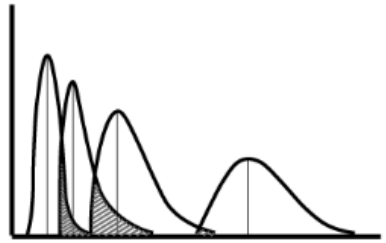
Uncertainty propagation

Robustness of the renovation measures



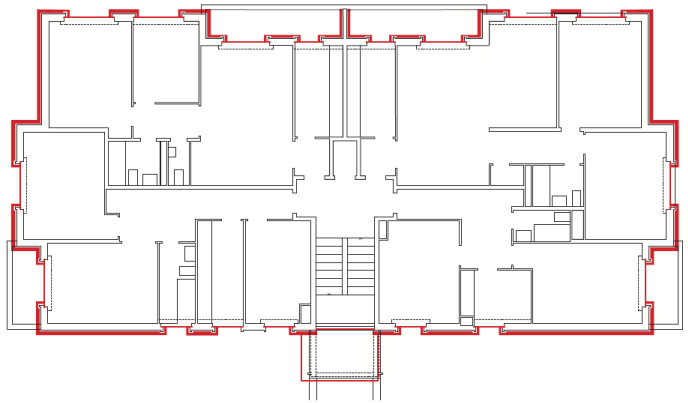
Case study

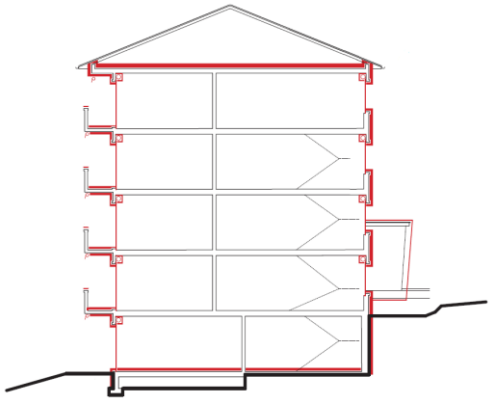
Lausanne, Switzerland

ERA – 1475 m^2

Year of construction - 1972

- 4 storeys + ½ basement: 18 flats
- ½ basement partially underground: technical rooms
- Attic: unheated
- Ext. Walls: hollow bricks
- Floors: concrete & hollow core clay slabs

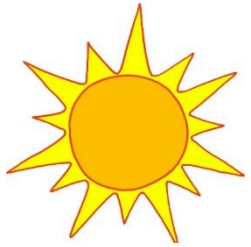


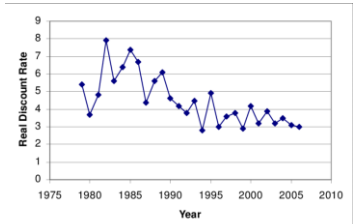


Renovation constraints:

- No special complexity in facades
- No need to keep the architectural aspects of facade

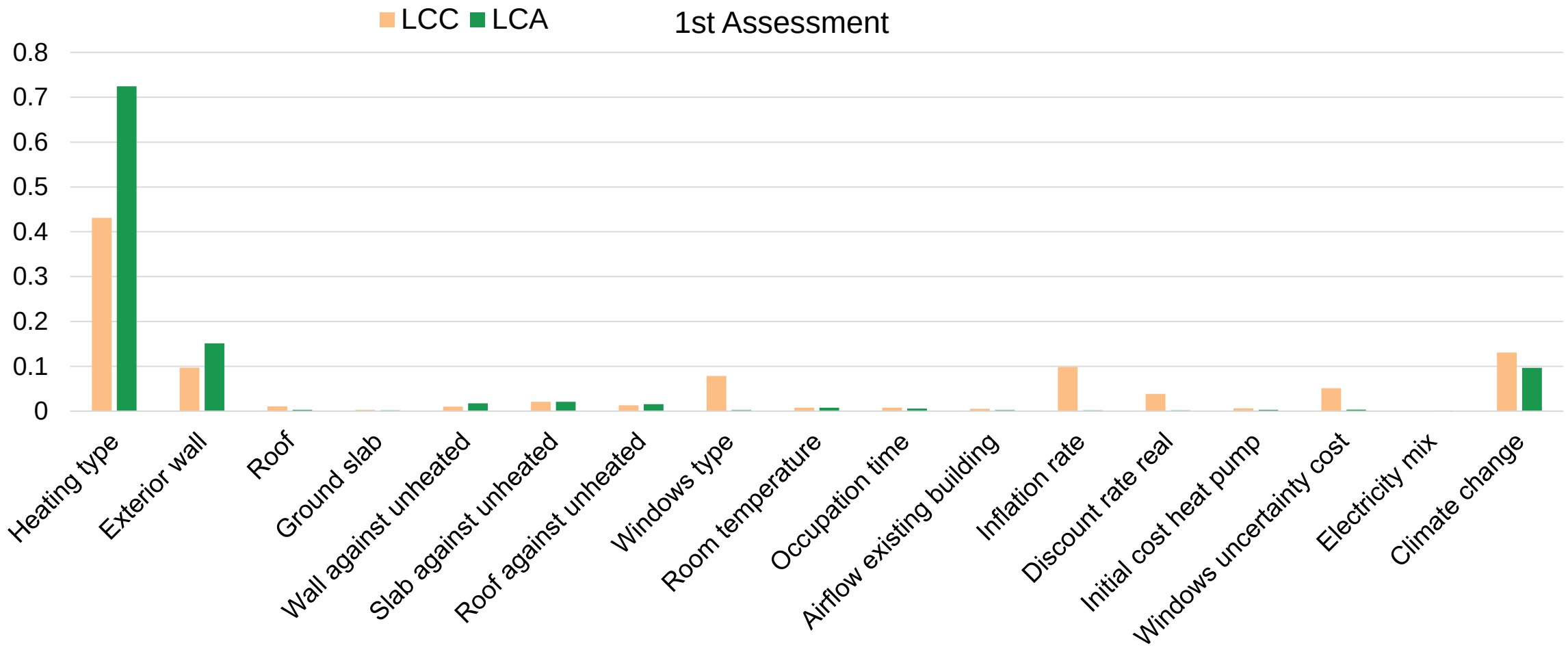
Renovation options and uncertain parameters

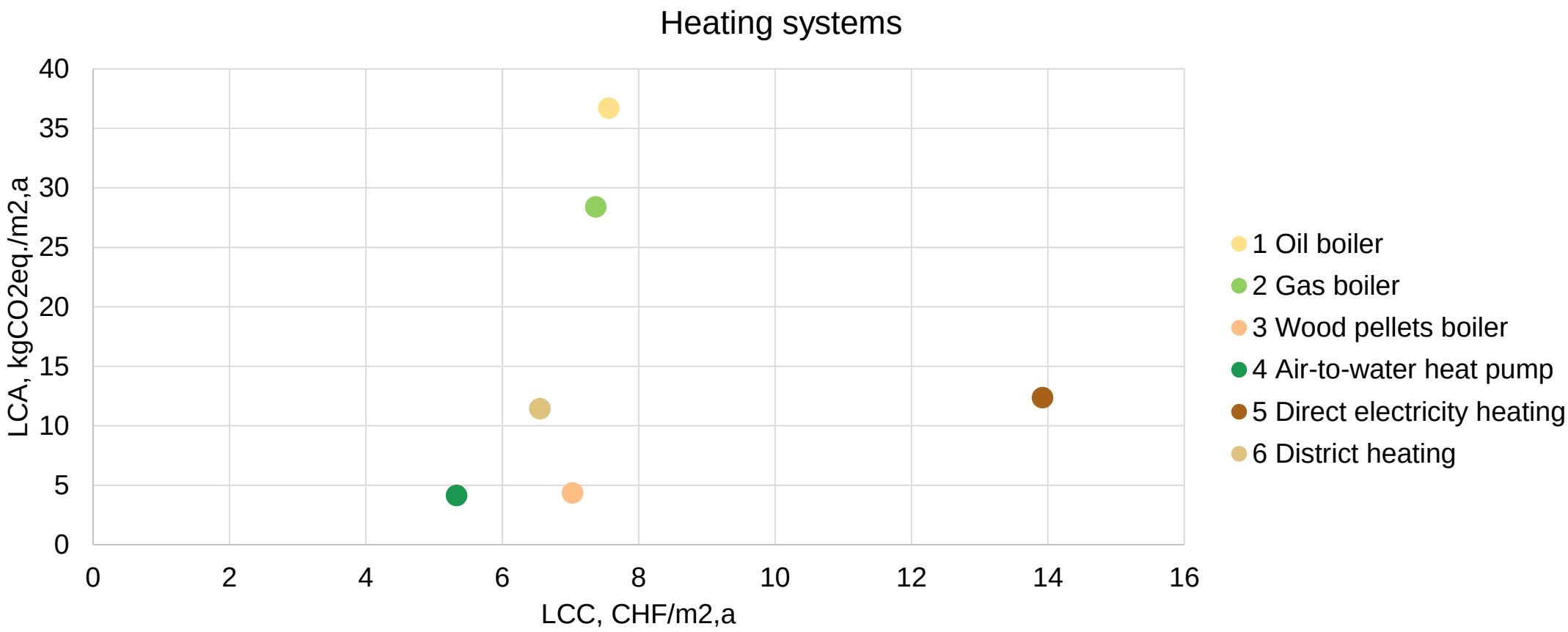




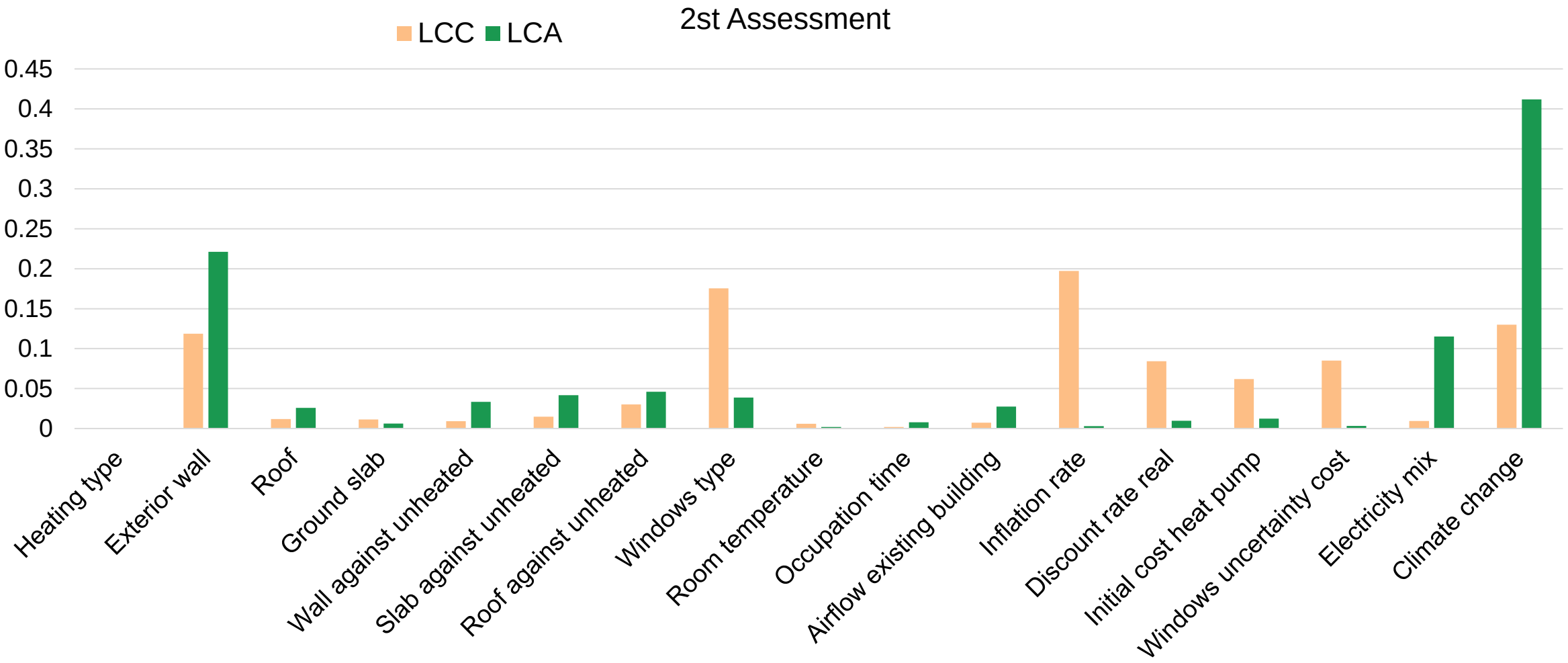
75 parameters

Sensitivity analysis

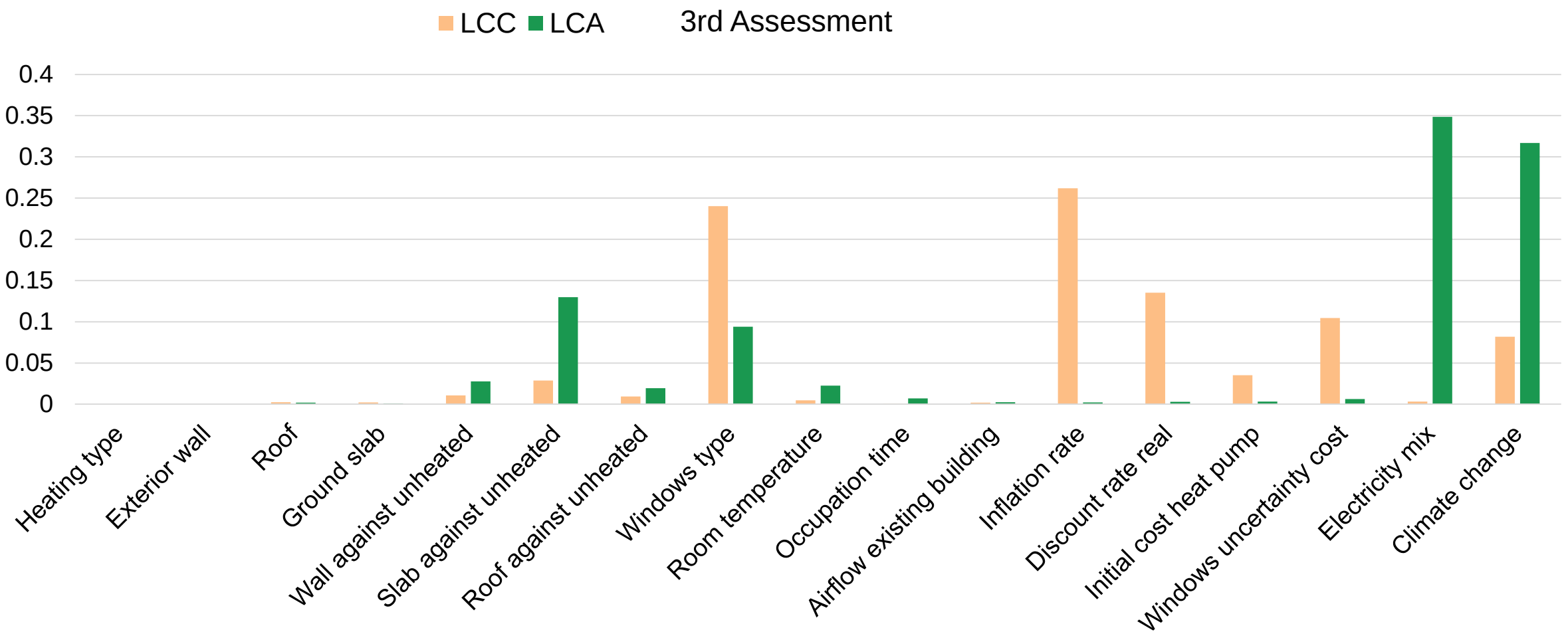



Heating systems
LCA, kgCO2eq./m2,a
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
16
LCC, CHF/m2,a
1 Oil boiler
2 Gas boiler
3 Wood pellets boiler
4 Air-to-water heat pump
5 Direct electricity heating
6 District heating

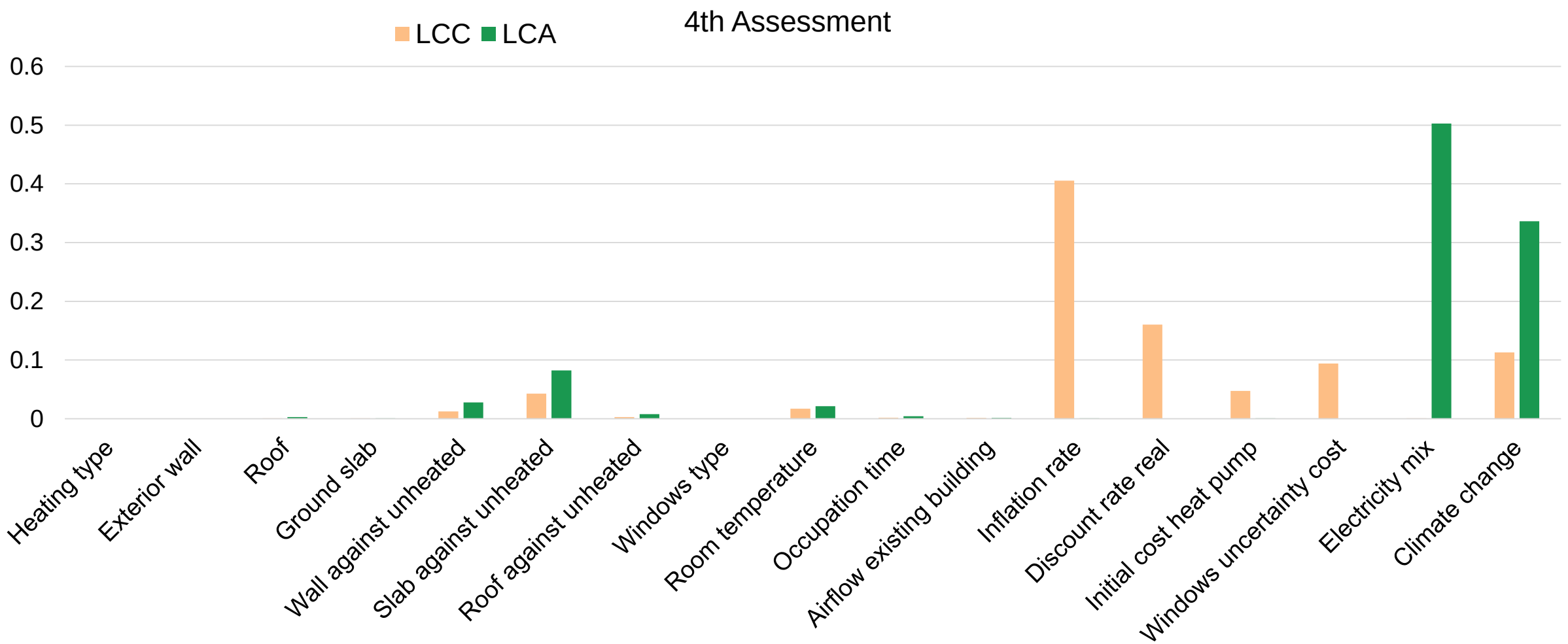
Sensitivity analysis



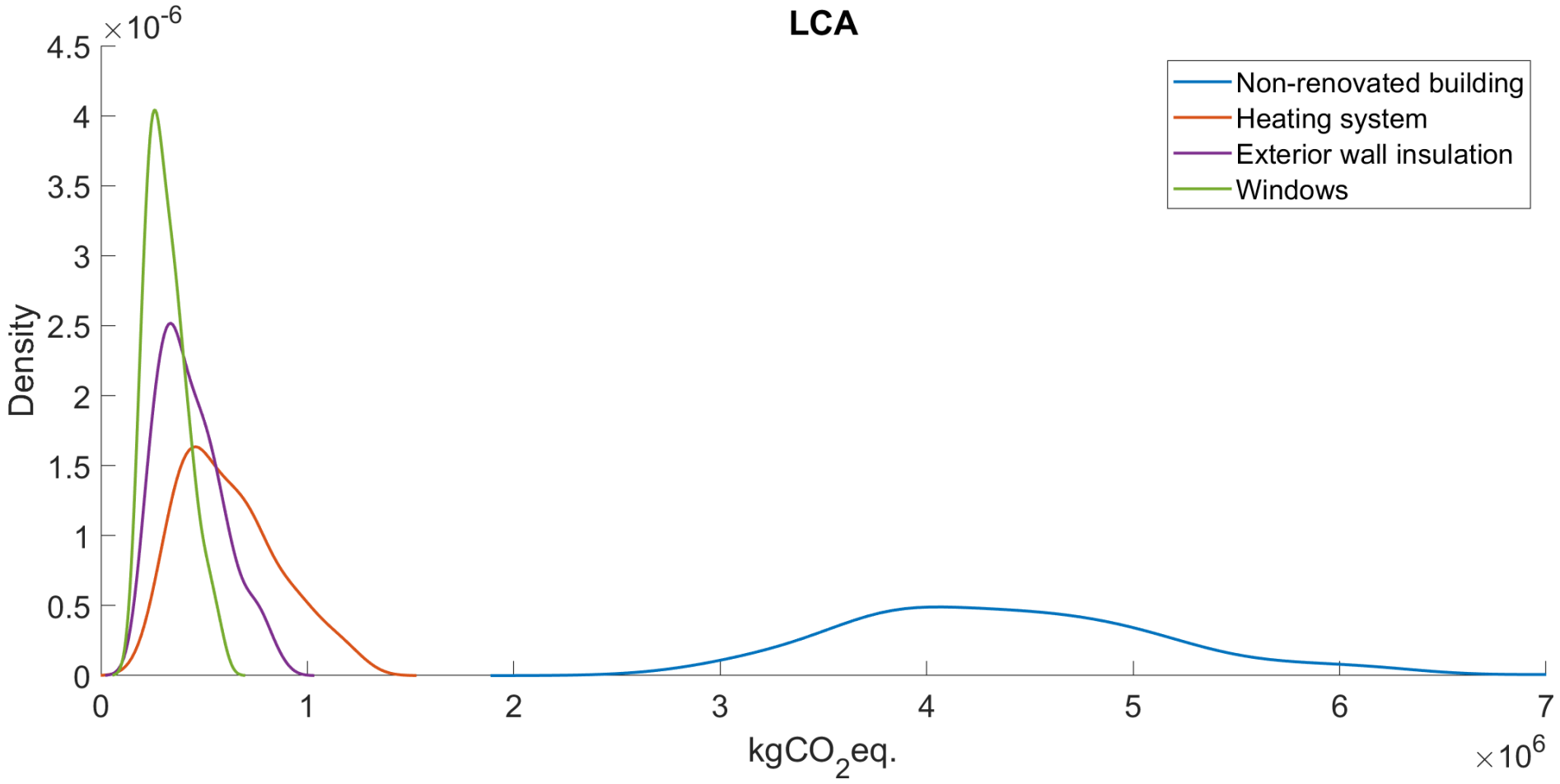
Sensitivity analysis



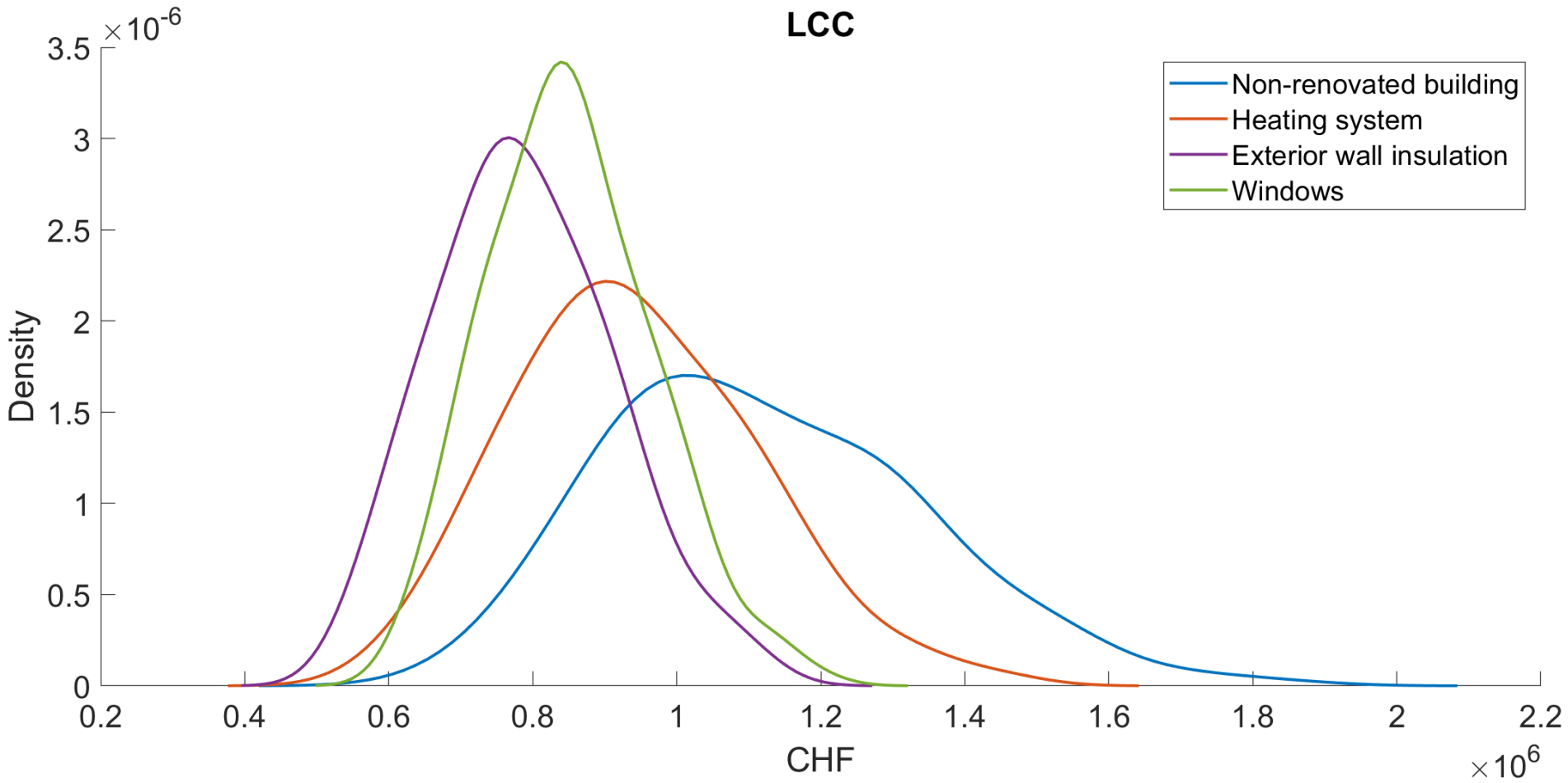
Sensitivity analysis



UQ results


LCA
Non-renovated building
Heating system
Exterior wall insulation
Windows
Density
×10^-6
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
kgCO2eq.
×10^6

UQ results


LCC
Non-renovated building
Heating system
Exterior wall insulation
Windows
Density
×10^-6
3.5
3
2.5
2
1.5
1
0.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
CHF
×10^6

Conclusion

Advantages

- The current method allows to prioritize the renovation scenario during the early design stages
- Current method also allows to evaluate the renovation scenario in terms of robustness and reliability.

Disadvantages

- This method does not optimize the renovation scenario but maximize the robustness of the result

Challenges

- Uncertainty data

Used tools and papers

- https://www.uqlab.com/ The framework for uncertainty quantification
- https://github.com/AlinaGalimshina/LCC-LCA-simulation LCC and LCA analysis

- S. Marelli and B. Sudret, “UQlab user manual - Polynomial chaos expansions. Technical report, Chair of Risk, Safety & Uncertainty Quantication, ETH Zurich. Report # UQLab-V1.2-104.,” 2019.
- B. Sudret, Global sensitivity analysis using polynomial chaos expansions, Reliab. Eng. Syst. Saf. 93 (2008) 964–979. https://doi.org/10.1016/j.ress.2007.04.002.
- S.M. Lloyd, R. Ries, Characterizing, propagating, and Analyzing Uncertainty in Life-Cycle Assessment. A Survey of Quantitative Approaches, J. Ind. Ecol. 11 (2007). https://doi.org//10.1162/jiec.2007.1136.
- A. Galimshina *et al.*, “Probabilistic LCA and LCC to identify robust and reliable renovation strategies,” *Sustain. Built Environ. Reg. Conf. Graz*, 2019.

Thank you!

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