“Towards Zero Carbon: A Comprehensive Evaluation of Conventional Renovation Strategies for Terraced Houses, Using Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) to Enhance Decision-Making Support – accompanied by the design of a tool.”

SUPPORT FOR SHORT TERM AND LONG TERM DECISION-MAKING IN RENOVATION

TOWARDS A ZERO CARBON EXISTING BUILDING STOCK

MADEVI SEWNATH - MASTER THESIS

P5 | 16-01-2023

TUDelft

Ever wondered

How will energy transition develop?

We can al agree

The future is unpredictable

But the question remains

But the question remains

What is the best choice for me?

As time passes

Renovation catches up on us

to meet 2050s climate target

The thesis aims

to provide insight in the holistic performance of a renovation

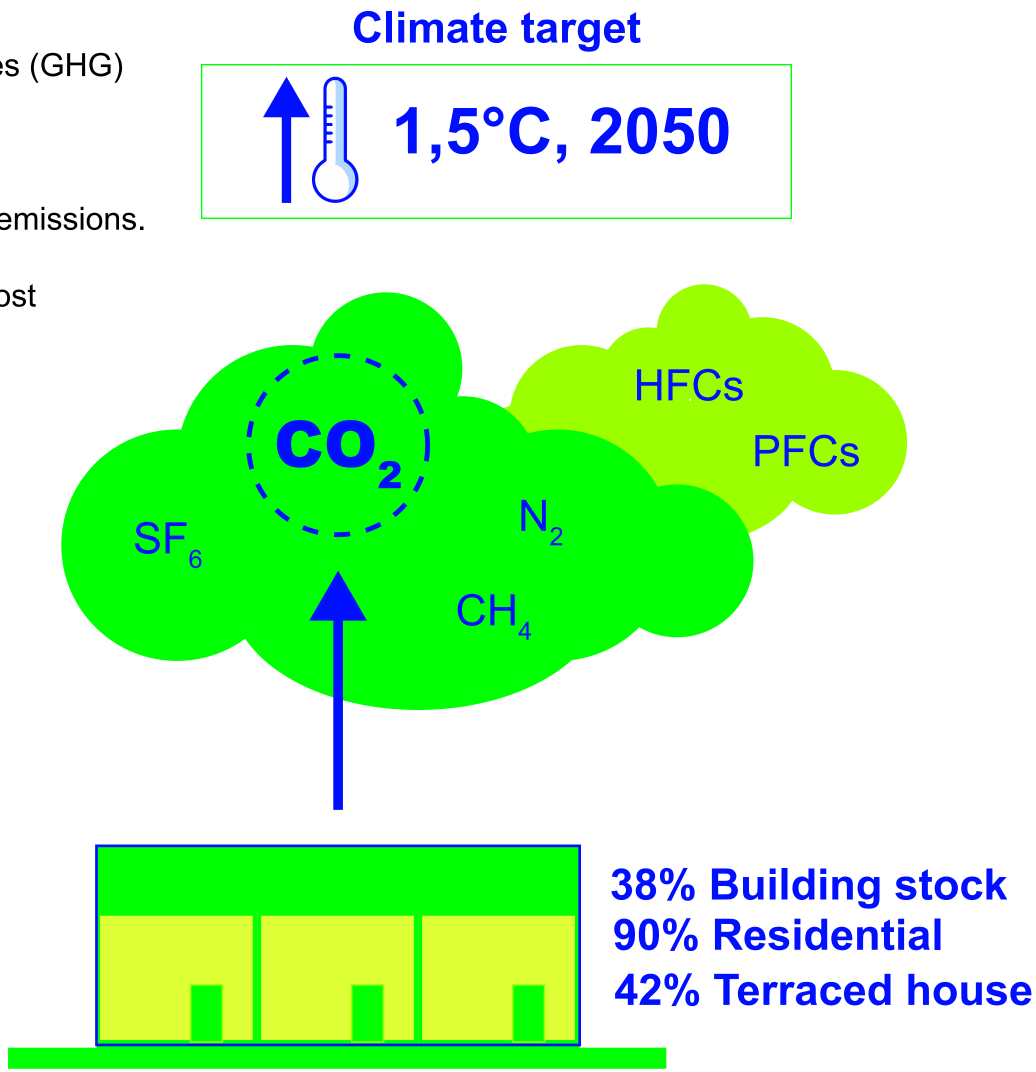
and

to support decision-makers in renovation

Research background

The global climate challenge

- Max. temperature increase 1,5 °C
- Reduce emissions green house gasses (GHG)
- CO_2 highest impact.
- Buildings responsible for 38% of CO_2 emissions.
- Residential buildings contribute the most



Strategy on a national scale

- Reducing operational carbon
- By renovating residential buildings

Global climate target

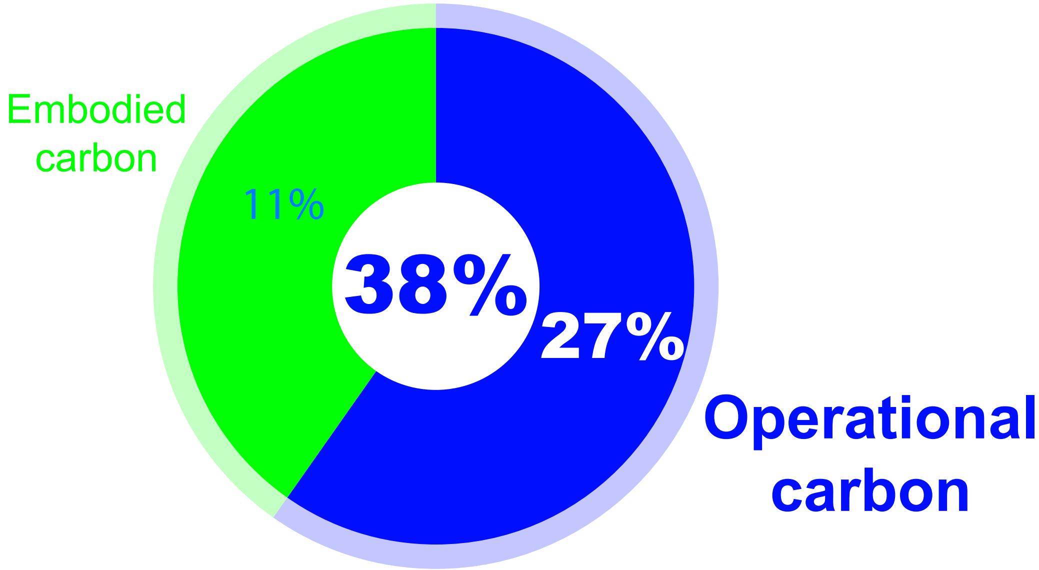
Temperature increase max. 1,5°C

National climate target

CO2 reduction targets [1]:
2030 49%
2050 95%

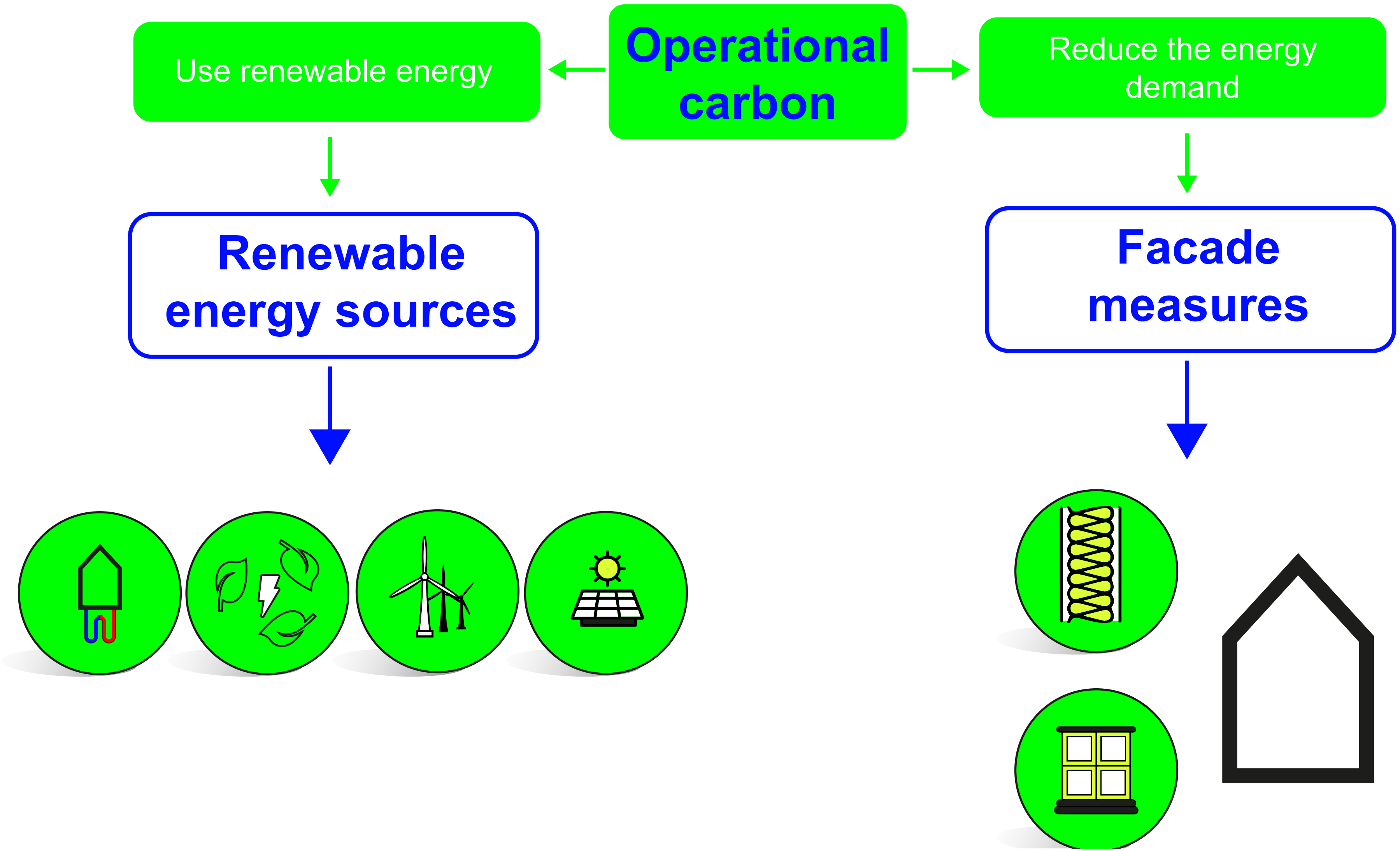
National strategy

Energy transition
Renovation gas free houses [2]:
2030 1.5 million houses
2050 5.5 million houses



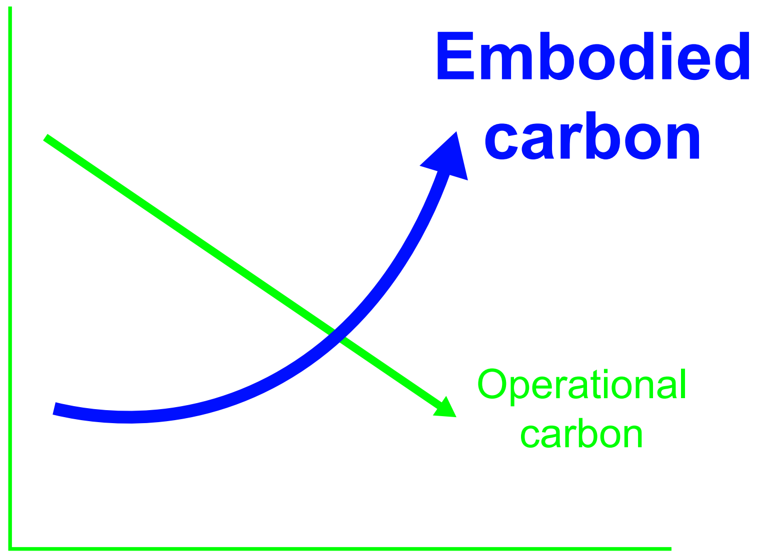
Strategy on a building scale

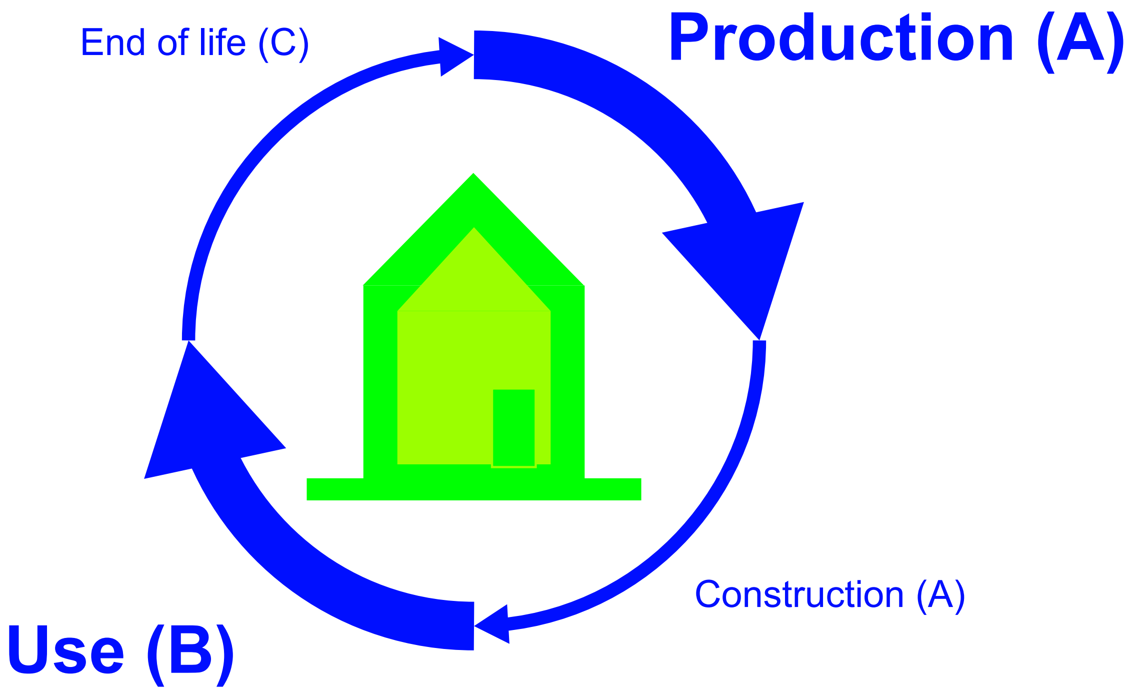
- Reducing operational carbon
- By renovating residential buildings



Importance to reduce the Embodied carbon

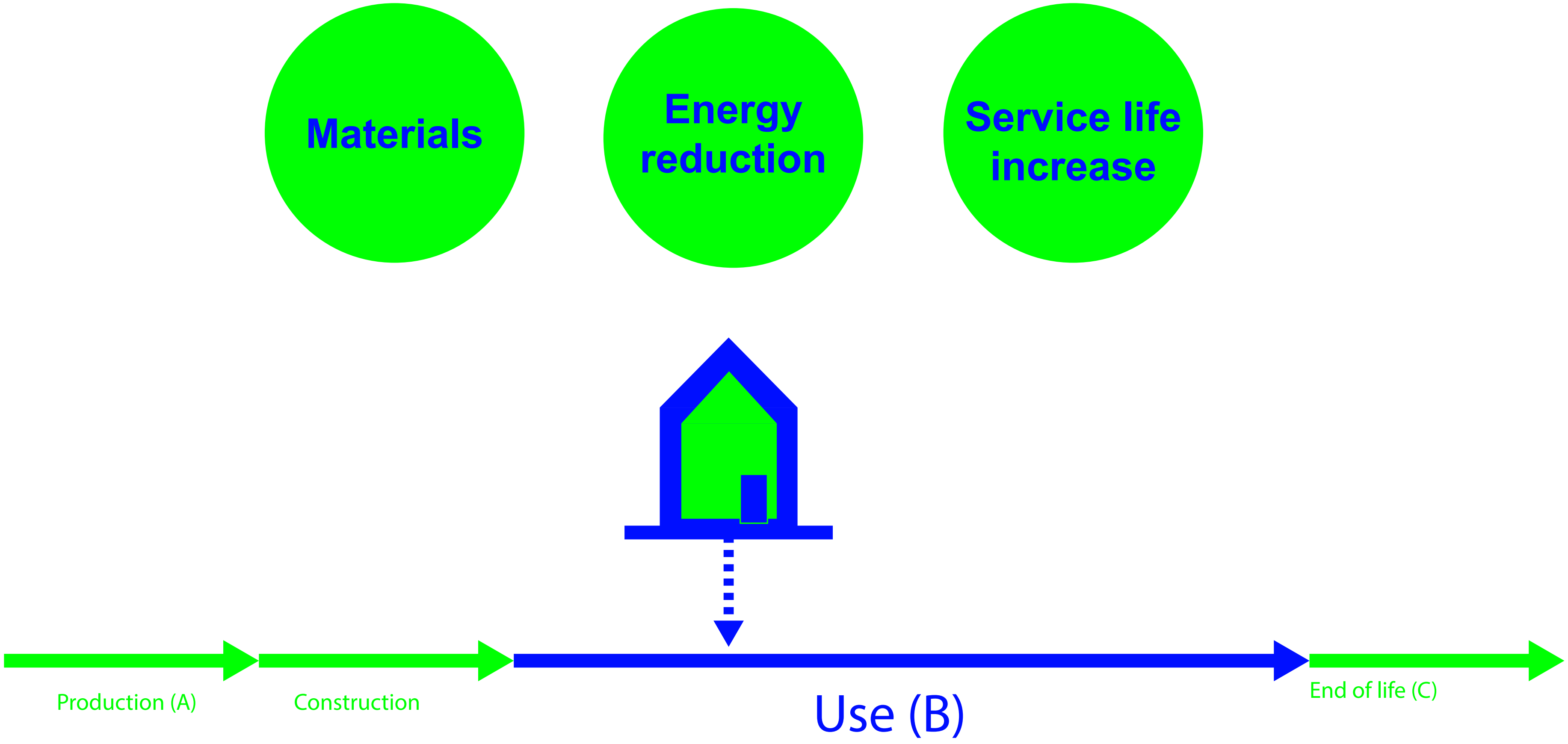
- Strategies should consider embodied and operational emissions
- Procedure for assessing embodied carbon is incomplete
- Current strategies are not selected on complete spectrum of carbon emissions
- Risk, overall lower carbon reduction than expected





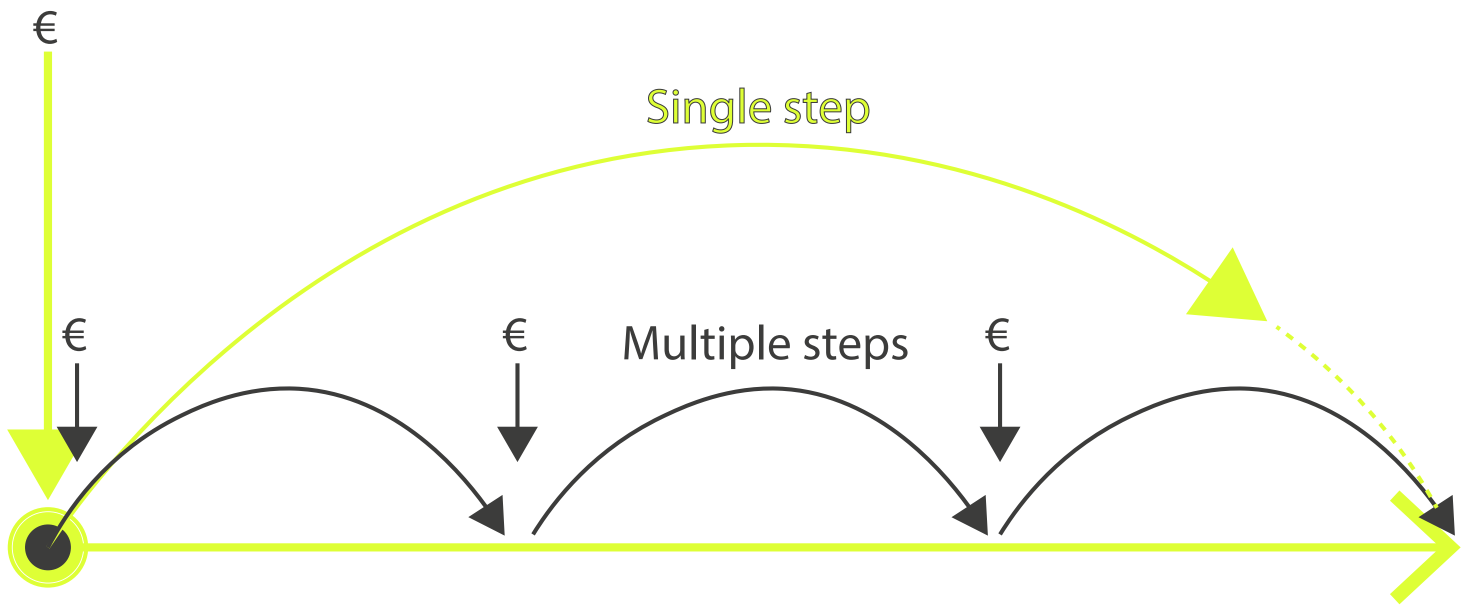
The need for a life cycle approach

- Renovation influences the service life of a building:
  - Increase service life
  - The use of materials
  - And achieved energy reduction
- Service life planning determines overall carbon reduction



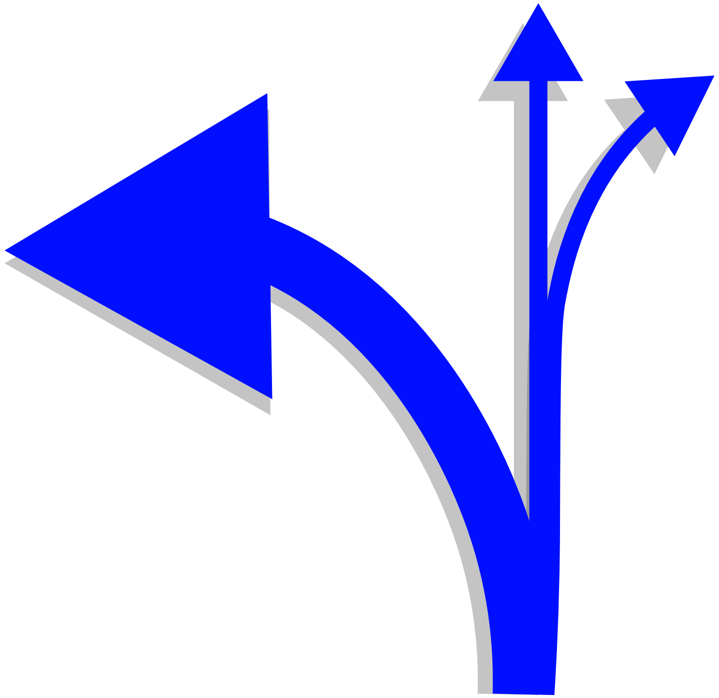
Life cycle planning

- Additionally carbon emissions are influenced by execution of renovation
- Due to limited budget renovation is often performed in steps,
- This influences emissions on the long term
- Compared to when renovation is performed in one go



Support in decision making

- Design decisions based on multiple criteria
- Designs are specific for each building
- Performance assessment is time consu-ming
- The decision-making process could benefit from a long-term perspective
- Support for managing large portfolios is lacking



Problem statement

As the operational carbon decreases the share of embodied carbon increases. However the procedure for assessing the embodied carbon is incomplete. Therefore current renovation strategies are not assessed on total carbon emissions.

Assessing total carbon emissions

Secondly, renovation influences the service life of a building and future emissions. Therefore, service life planning is crucial to estimate emissions on the long-term.

Life cycle planning, long term emissions

Thirdly, the assessment of designs for renovation on multiple criteria is time consuming.

Assessment time

At last, deep renovations are often not performed in a single go due to a lack of budget. Assessment of steps on the long term performance of a building are often not considered.

Assessment of steps, and long term performance

How can decision-making for renovation strategies take into account carbon emissions over the life cycle of a building, in the Netherlands?

Sub questions

1. How can renovation strategies be created and which renovation measures should be included in the strategies regarding carbon emissions?

2. How do the renovation strategies influence the operational performance of a building?

3. How do the renovation strategies influence the buildings embodied performance?

4. How do the renovation strategies influence the buildings life cycle performance?

5. What renovation scenarios for a terraced house can be defined considering a buildings life cycle in the Netherlands?

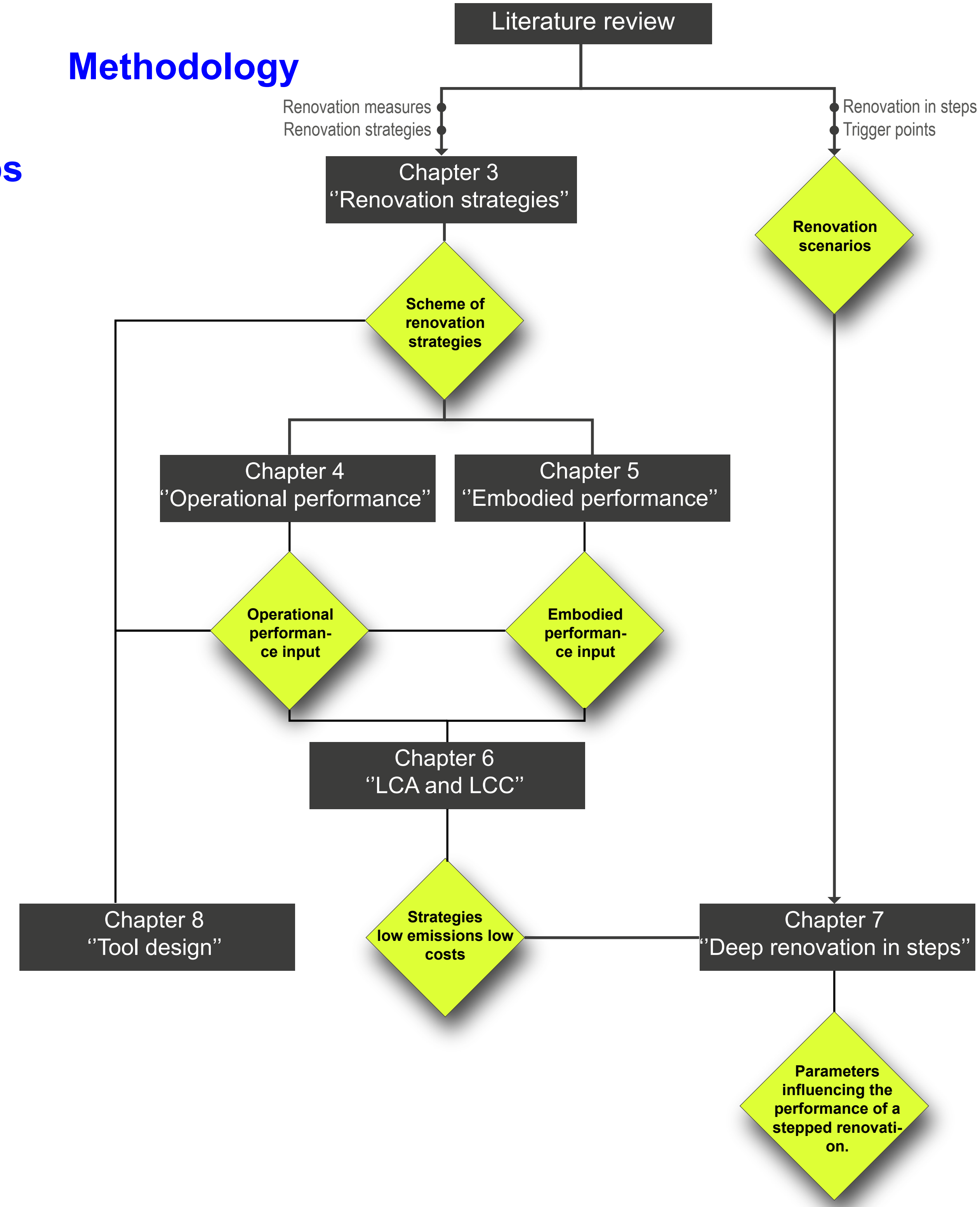
6. How can decision making be supported with the results, through a design?

Renovation scenario	Renovation strategy	Renovation measures
Execution of renovation	Aim of renovation approach	Possible measures

Methodology

Main approach consist of 4 steps

1. Renovation strategies
2. Performance assessment
3. Performance assessment, steps
4. Design of a tool



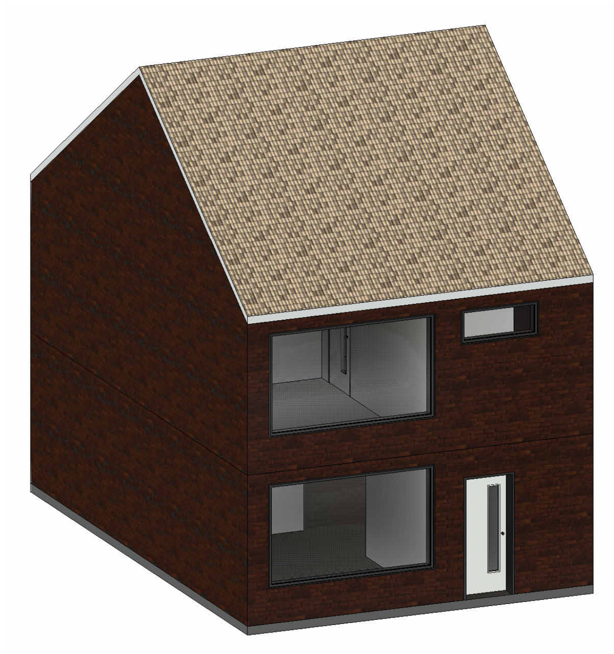
Defining renovation strategies, with conventional measures.

Boundary "a typical terraced house"

In the Netherlands, the building stock consist of:
7 million residential buildings

Dominant housing typology:
Terraced houses (42%)

Building year:
1965-1985, also referred to as 60s terraced house

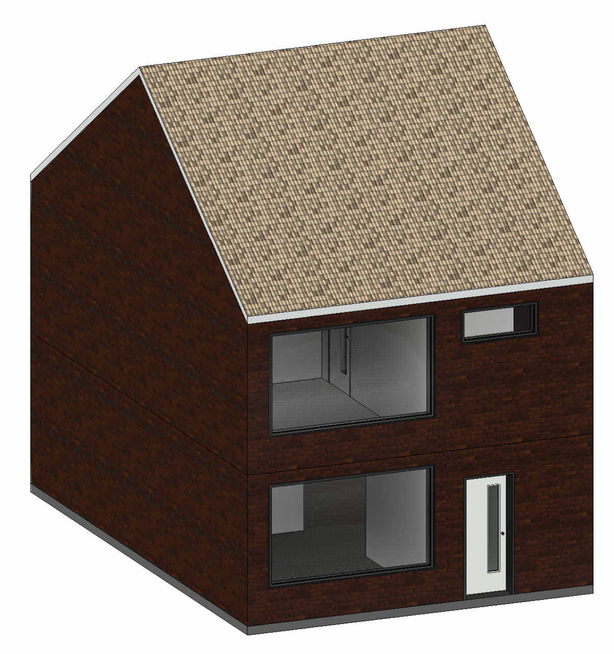


General data		Source
Building type	Single family house	
Building year	1966	
Surface Area	129 m2	
Volume	438 m3	
Internal heat gain	4,5 W/m2	
Structure		
Inner load bearing walls	100mm bricks-40mm cavity–100mm bricks	(AVANES et al., 2018)
Outer load bearing walls	100mm bricks-80mm cavity–100mm bricks	
Ground floor	150mm concrete	
Separating floors	150mm concrete	
Roof	Wooden structure, 18mm wooden beams	
Envelope performance		
External walls	Uninsulated	(WoonWijzerWinkel, 2023)
Windows	Single glass	
Roof	Uninsulated	
Ground floor	Uninsulated	
Infiltration (AC/h)	0,6	See chapter 2.5
HVAC systems		
Ventilation system	Ventilation system A, AC/h= 0,6	See chapter 2.5 (WoonWijzerWinkel, 2023)
Heating system	Gas boiler	
Domestic hot tap water	Gas boiler	
Heat distribution system	Hot water radiators	
Heating supply temperature	70-90 °C	
Temperature (heating)	21 °C	

The original state as starting point:

Uninsulated
depth 6.5-8 meters
width 6 meters
large windows
Gable

shared walls
Gas boiler as heating system



Similar volumes

roof size

&

Energy consumption

2 main renovation strategies can be distinguished

DEEP RENOVATION STRATEGIES

Energy saving >60%

Strategy aims to establish a high energy saving.

SHALLOW RENOVATION STRATEGIES

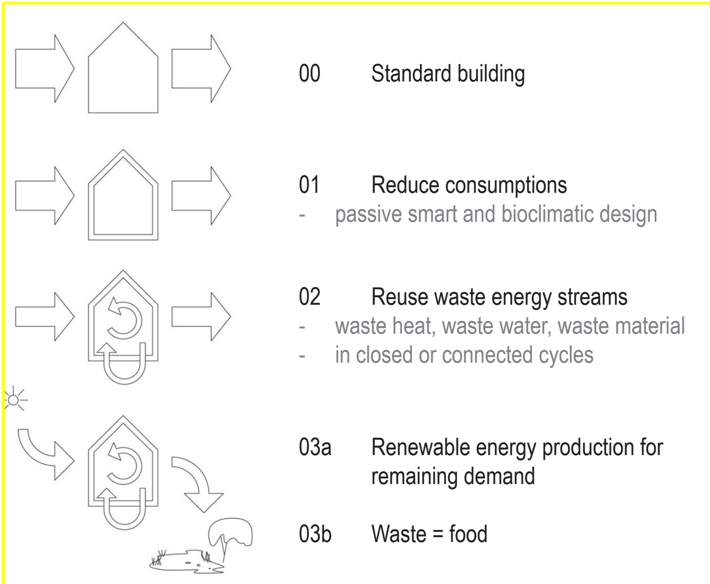
Energy saving 3-30%

Strategy that aims to reduce energy use at low costs, cost effective measures.

Different selection procedures for deep and shallow renovation strategies

Deep renovation, aim carbon neutral

Stepped approach



(adapted from Tillie et al., 2009)

Shallow renovation, aim cost effective

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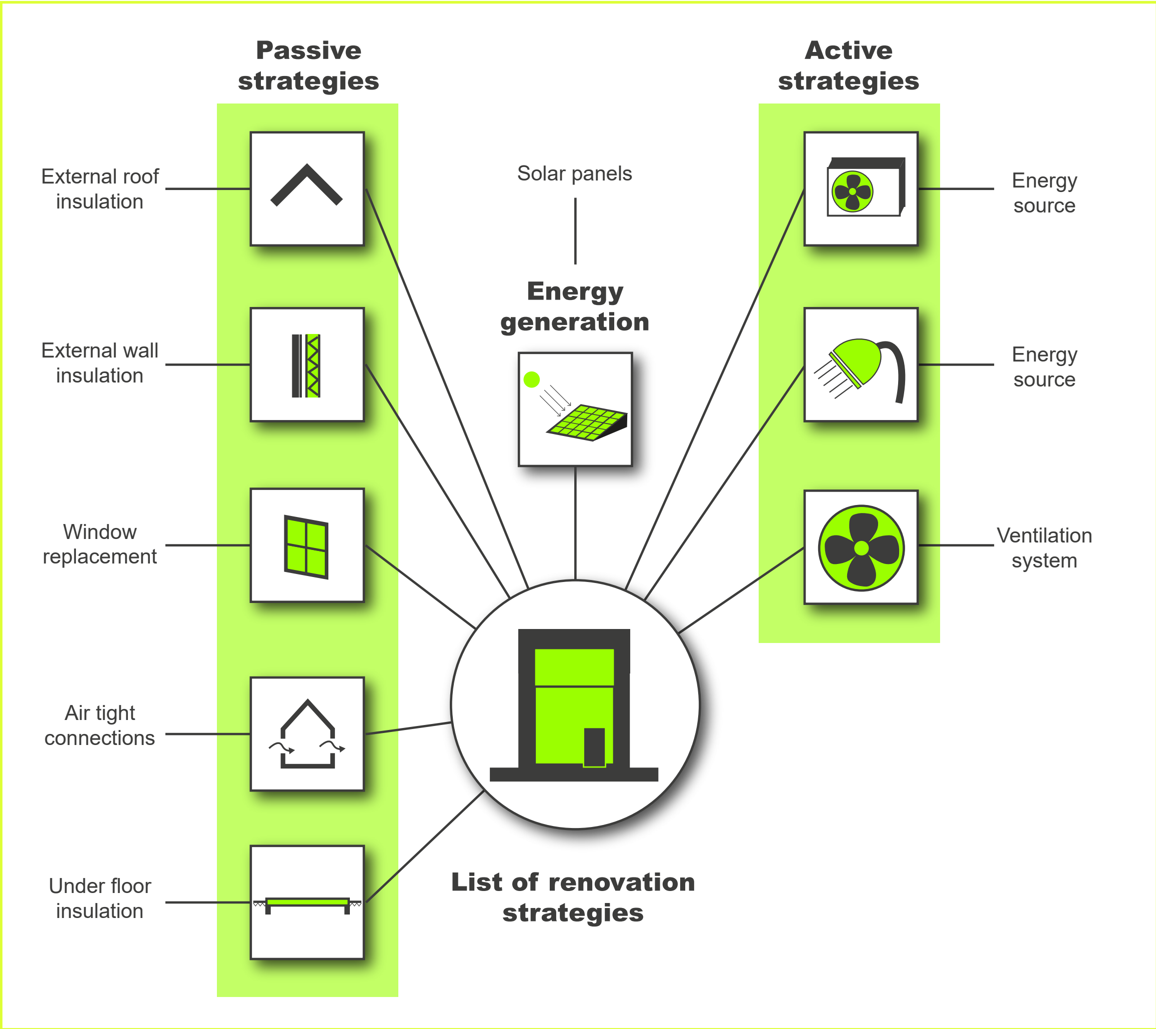
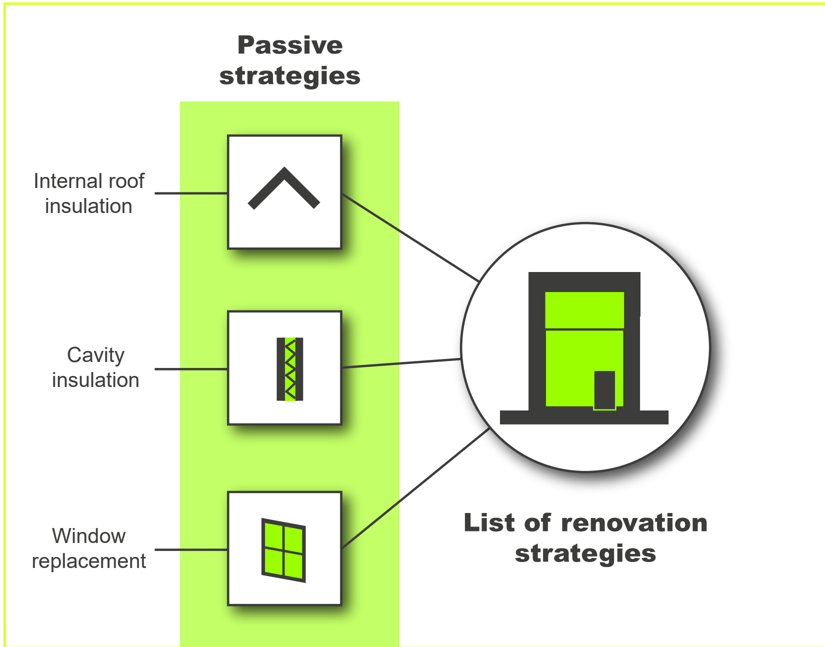
- costs and energy saving
- Desire of house owners

Most impactfull parameters

Deep renovation strategies



Shallow renovation strategies



Strategies translated into renovation measures

- Variety in performance is key to find optimal solutions
- Assessing multiple renovation measures

Shallow renovation measures				
Envelope measures	Insulation in Rc value (m²K/W) and windows in U value (W/m²K)			
Reference code:	**Level 0,1C**	**Level 0,1R**	**Level 0,1W**	**Level 0,1**
	Cavity ins.	**Roof ins.**	**Window replacement**	**All measures**
Roof		3,5		3,5
External walls	1,86			1,86
Windows			1,2	1,2
Infiltration (AC/h)	0,8	0,8	0,8	0,4
Deep renovation measures				
Envelope measures	Insulation in Rc value (m²K/W) and windows in U value (W/m²K)			
Reference code:	**Level 1 ''minimum"**		**Level 2 moderate**	**Level 3 high**
	70-90 °C (1)	*50 °C (1.1)*	*'new build"*	*'streefwaarden"*
Roof	2	3,5	6	8
External walls	1,3	1,7	4,5	6
Windows	1,2	1,2	1,2	1
Ground floor	2,5	3,5	3,5	3,5
Source	Building code	(WoonWijzerWinkel, 2023)	(Standaard En Streefwaarden Voor Woningisolatie, n.d.)	(Standaard En Streefwaarden Voor Woningisolatie, n.d.)
Infiltration (AC/h)	0,6	0,6	0,3	0,2
HVAC measures				
Ventilation				
Ventilation system A	Natural supply and exhaust through windows AC/h = 0,6			
Ventilation system C	With CO2 sensors at windows, AC/h = 1,05			
Ventilation system D	With heat recovery efficiency 80%, AC/h = 1,05			
Heating and tap water system				
Option 1: Heatpump	COP 3			
Option 2: electric boiler	COP 1			
Energy generation				
Building scale option 1	Photovoltaic (PV) panels Orientation east-west, 100% covered roof			
Building scale option 2	Photovoltaic (PV) panels Orientation south-north, 100% covered roof			
Building scale option 3	Photovoltaic (PV) panels Orientation south, 50% covered roof			

Renovation strategies deep renovation

Baseline

Shallow renovation strategies, consider single measures

Shallow renovation strategies, consider combining measures

Deep renovation strategies

Current state renovation strategies	
	Current state
Elec. Boiler	A
Gas boiler	A
	2 strategies

Shallow renovation strategies			
Single measures			
	Passive measures, envelope		
	Cavity	Roof	Windows
Gas boiler	A	A	A
	3 strategies		

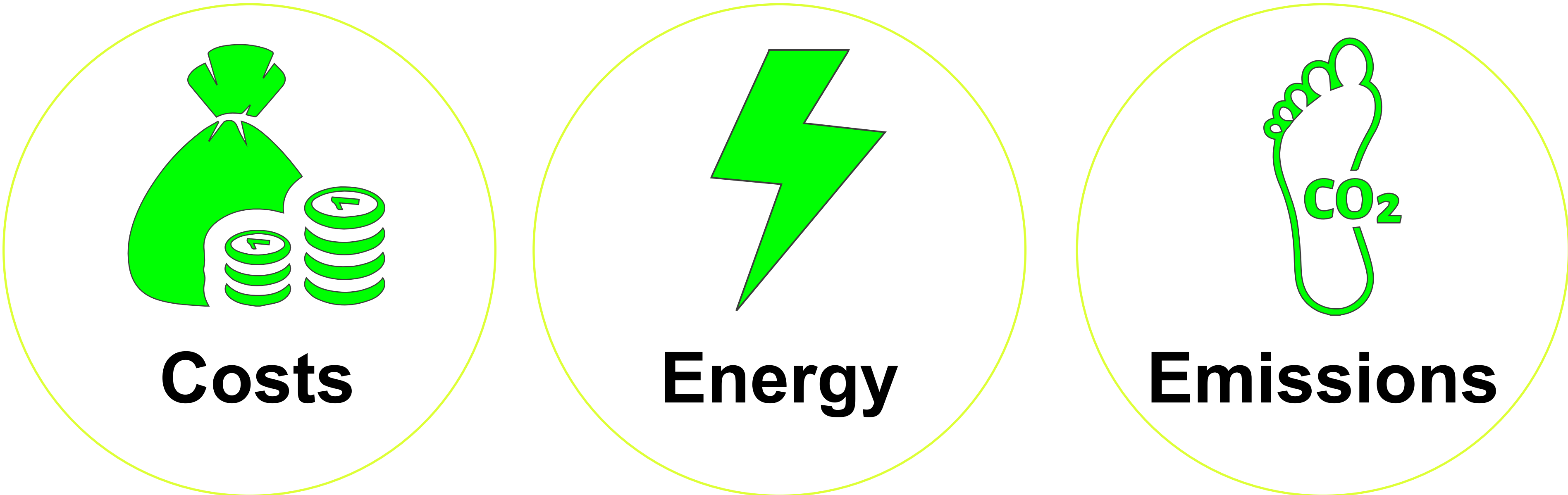
Combined measures	
	Passive measures, envelope
	Cavity + Roof + Windows
Elec. Boiler	A/C/D
Gas boiler	A/C/D
	6 strategies

Deep renovation strategies			
	Passive measures, envelope		
	level 1	*level 2*	*level 3*
Heat pump	A/C/D	A/C/D	A/C/D
Elec. Boiler	A/C/D	A/C/D	A/C/D
Gas boiler	A/C/D	A/C/D	A/C/D
	27 strategies		

How can the performance of renovation strategies be assessed?

Main criteria in decision-making

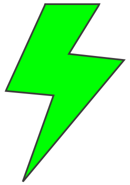
Assessment on 3 criteria



Holistic performance of renovation strategies can be obtained through assessing costs, energy and emissions.

Performance estimated with software and manual calculations

Requires the use of multiple software and a high level of data.

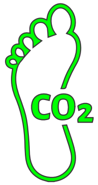


Design builder
Manual calculation

HEATING DEMAND
TAPWATER

RVO
Excluded

INVESTMENT COSTS
OPERATIONAL COSTS



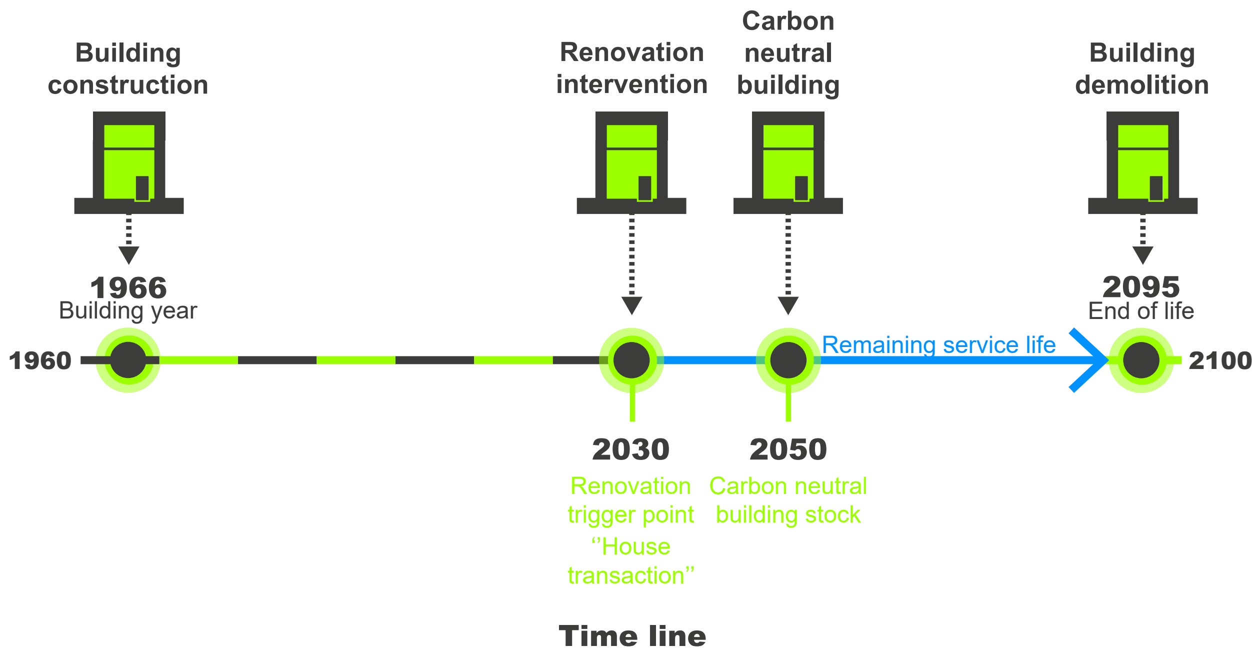
One Click LCA
Manual calculation

EMBODIED CARBON
OPERATIONAL CARBON

	One Click LCA	Design Builder	Excel (mannual calculation)
Heating demand		X	
DHW			X
Embodied carbon	X		
Operational carbon			X
Energy saving			X
Recurrent embod-ied carbon	X		X
Costs			X
Recurrent costs			X
Building life cycle			X
Energy generation			X

Assessment period

Taking into account a buildings life cycle



Performance of renovations strategies

Reference code

The reference number for the level of insulation are (also presented in table 9):

1 minimum insulation;
1.1 minimum insulation in case of a heat pump;
2 moderate insulation;
3 high insulation;
Current state absence of insulation measures

The reference for the ventilation systems are:

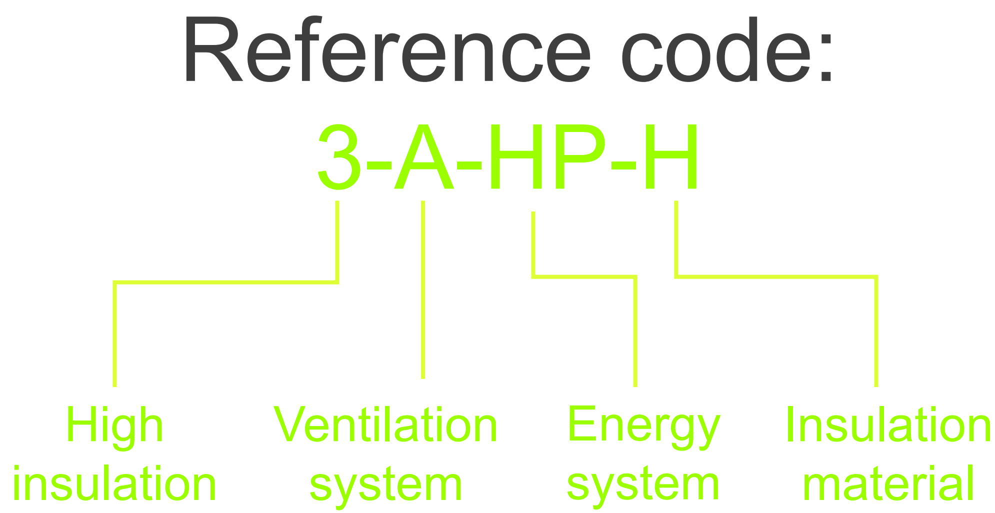
A system A natural ventilation;
C system C, mechanical exhaust and natural supply;
D system D mechanical with heat recovery.

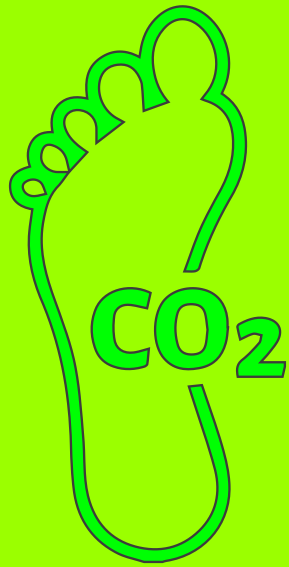
The reference for the energy systems are:

EB electric boiler;
HP heat pump;
GB gas boiler.

The reference for the different insulation materials are:

H Hard insulation, EPS;
S Soft insulation, glass wool;
O Organic insulation, cellulose.

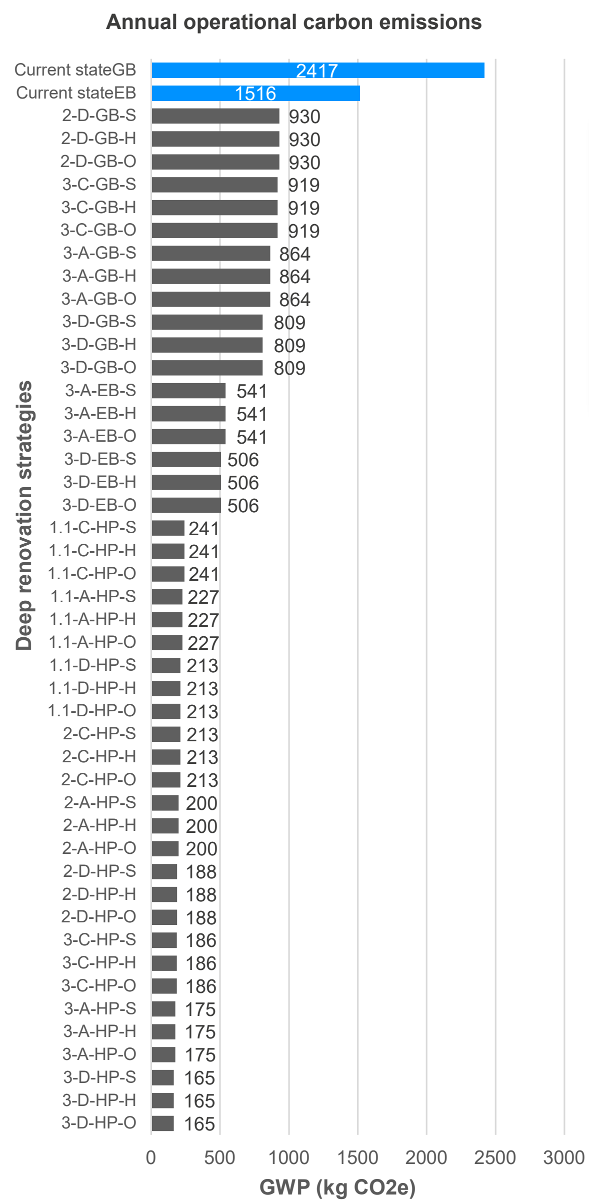


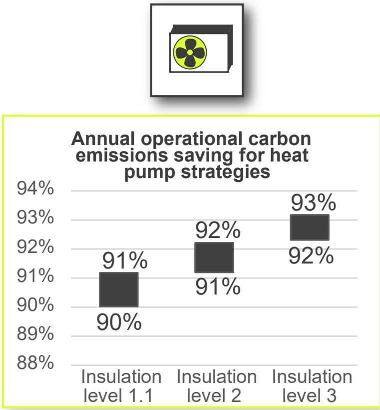


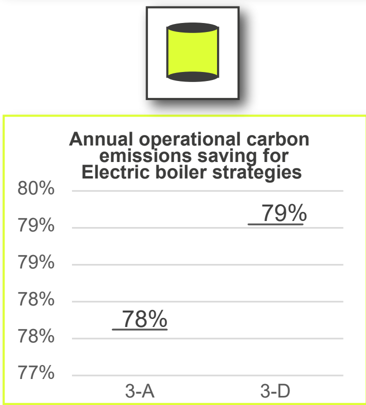
Emissions

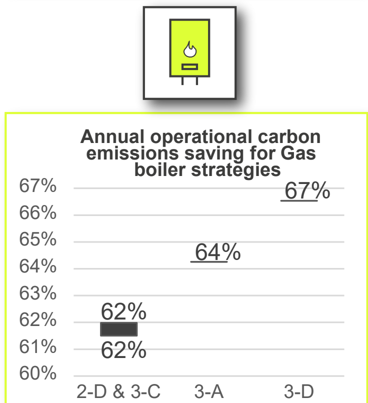
Operational carbon performance

Deep renovation strategies



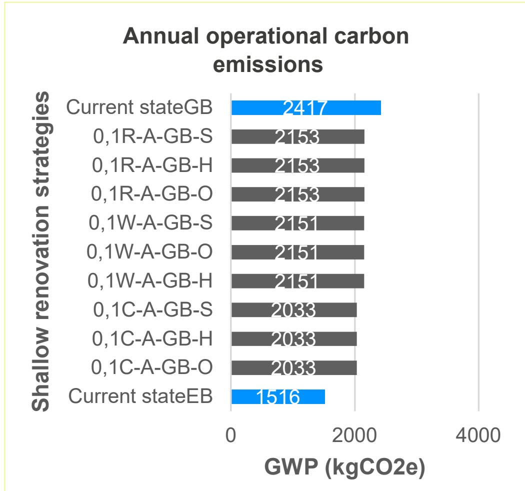






- Operational carbon factor (electricity and gas) influences the results the most.
- Relation between energy system and operational carbon emissions
- Measure (DEEP) that leads to a low operational carbon performance is
  - a heat pump
- Measure (Shallow) that leads to a low operational carbon performance is cavity insulation
- Due to a reduction in energy consumption

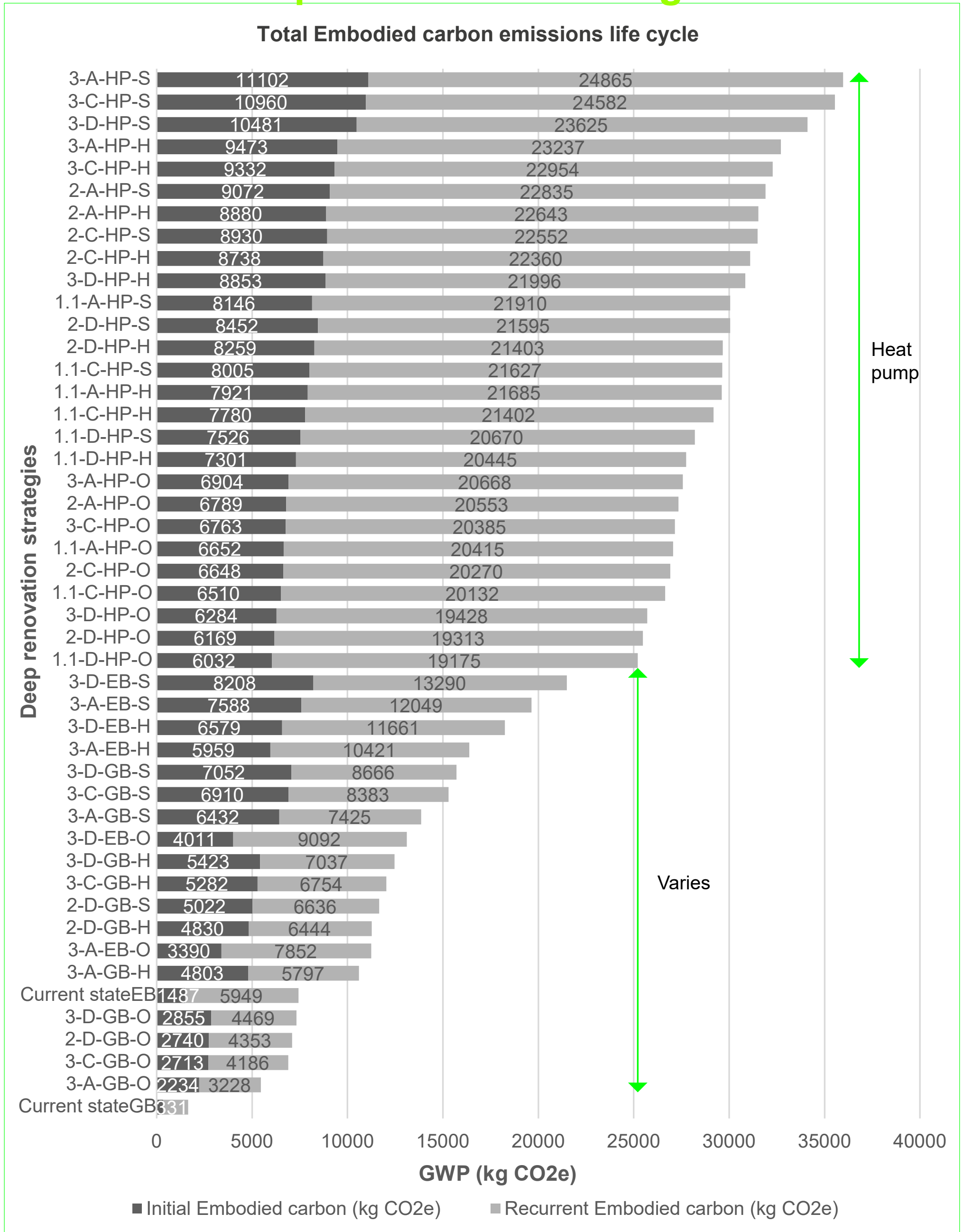
Shallow renovation strategies



Emissions

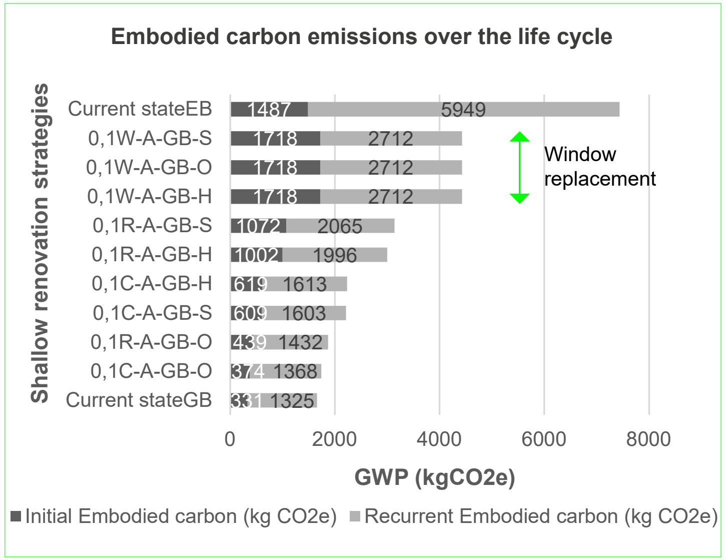
Embodied performance

Deep renovation strategies



- Embodied carbon is mainly determined by the recurrent embodied carbon (in a building life span of 65 years).
- Services are responsible for the majority of emissions, due to their short life span (15 years)
- Measure (deep) that leads to highest emissions is a heat pump
- Measure (shallow) that leads to highest emissions is window replacement

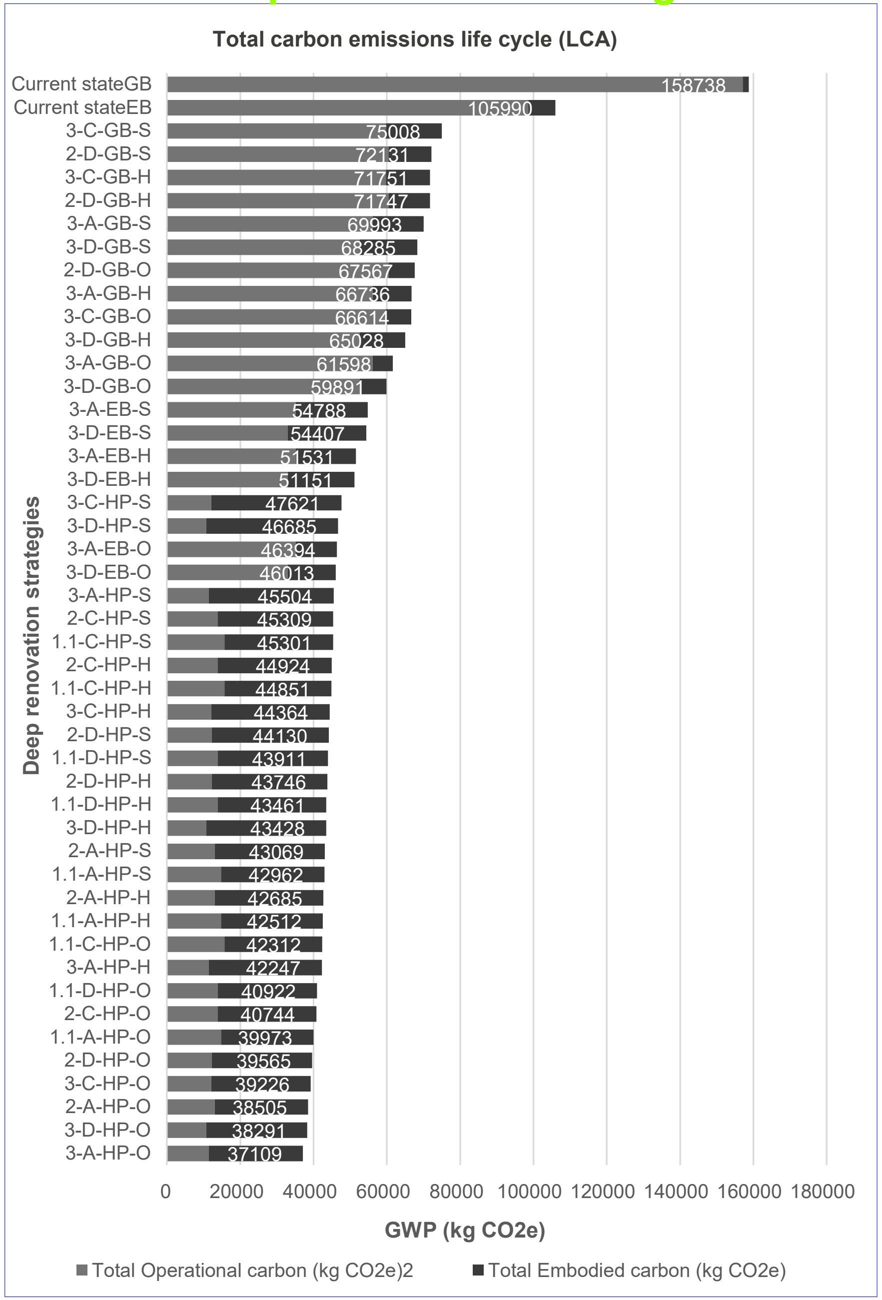
Shallow renovation strategies



Emissions

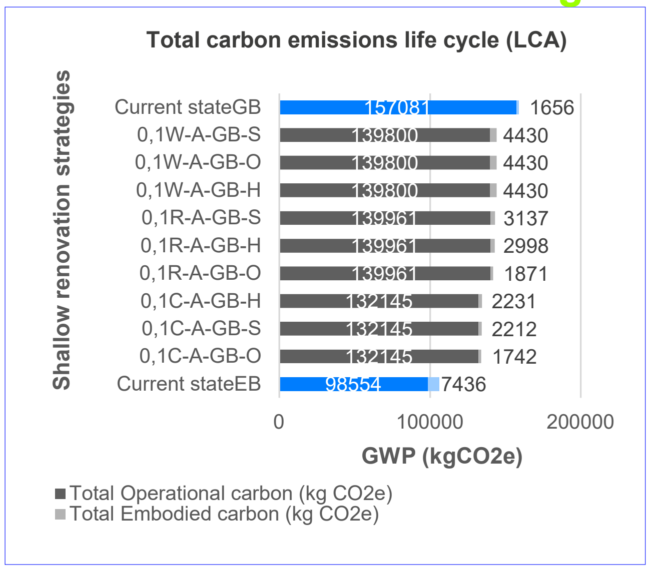
Operational and embodied performance (LCA)

Deep renovation strategies

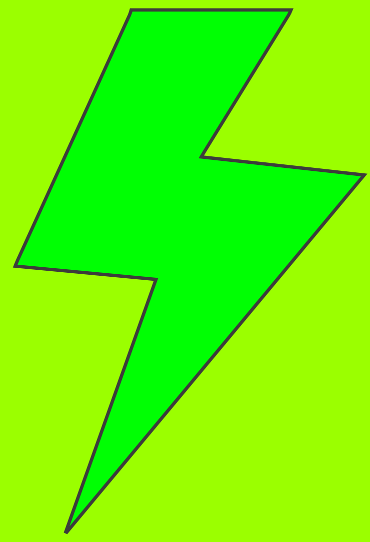


- Operational carbon acts as a representative for total emissions, in shallow renovations
- In deep renovations, the importance to assess the embodied carbon grows. Especially strategies that consider a heat pump show high embodied emissions.
- The embodied emissions can be influences by increasing the service life of services or reducing the emissions related to the production

Shallow renovation strategies



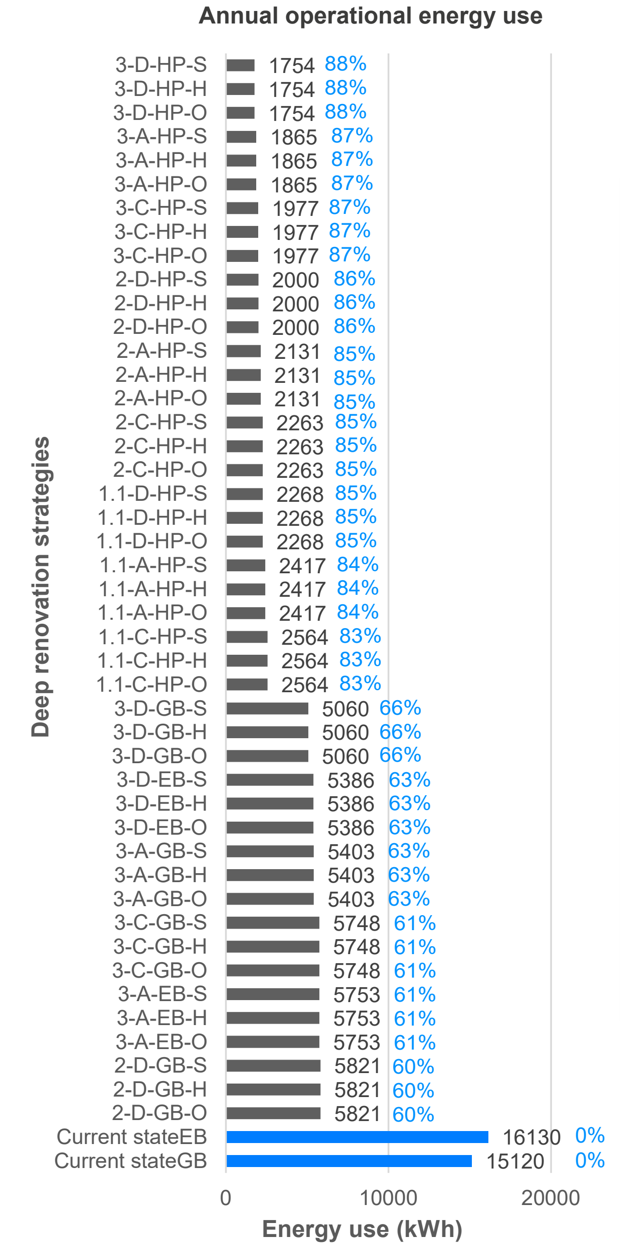
Emissions

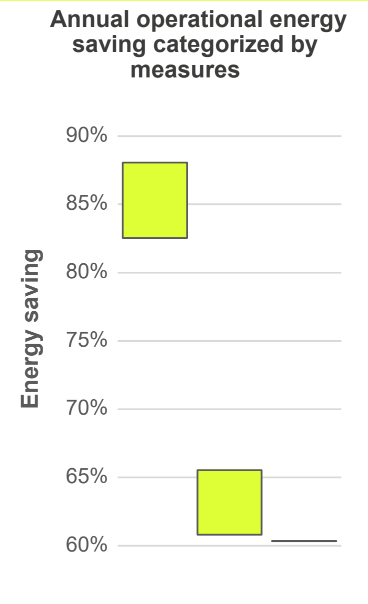


Energy

Operational energy performance

Deep renovation strategies



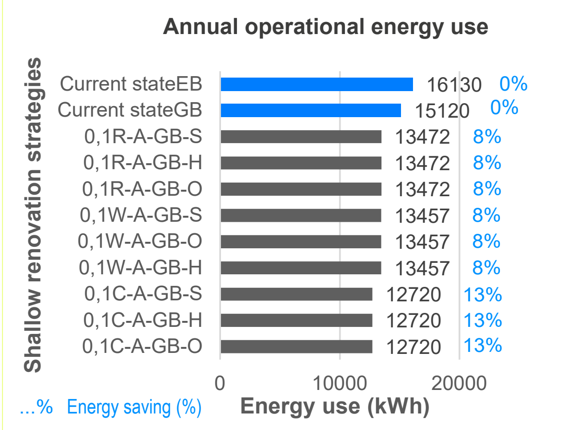


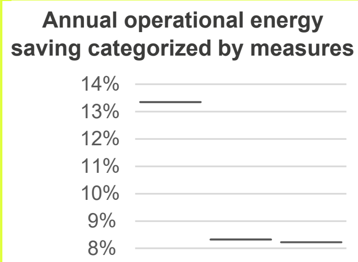
	HP	3-GB & 3-A/D-EB	2-D-GB
saving min	83%	61%	60%
saving max	88%	66%	60%

...% Energy saving (%)

- Deep strategies considering a heat pump result in the highest (83%-88%) energy saving.
- A shallow renovation is achieved by executing a single measure or two measures, From all measures cavity insulation results in the highest energy reduction (13% energy saving)

Shallow renovation strategies



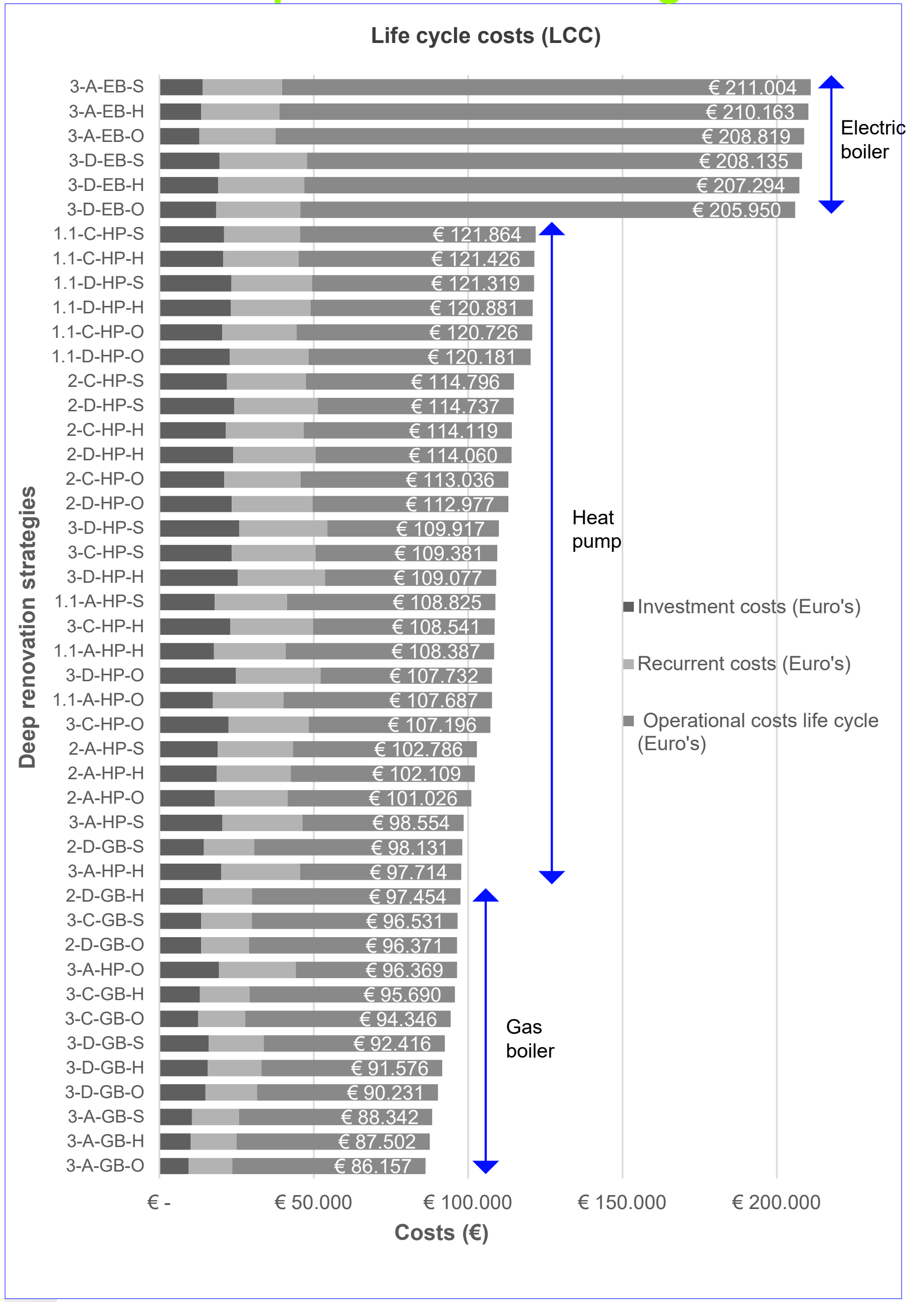


	Cavity ins.	Window rep.	Roof ins.
saving min	13%	8%	8%
saving max	13%	8%	8%

Costs

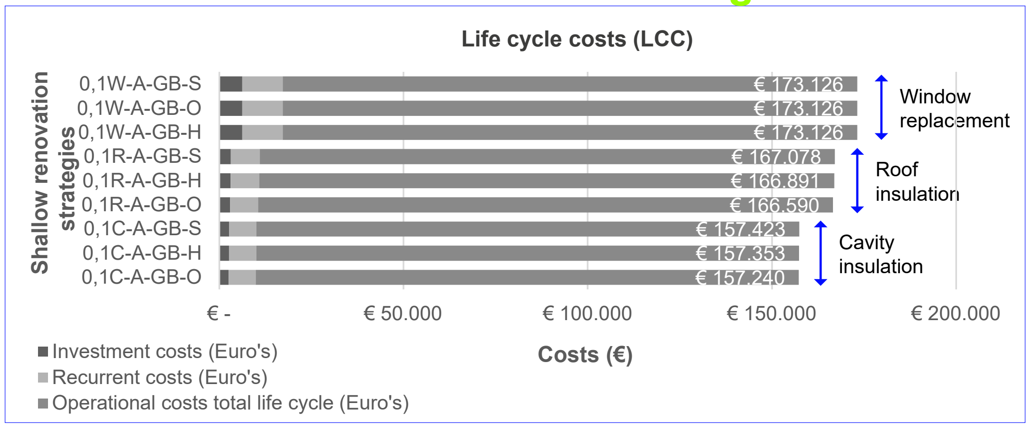
Life cycle costs

Deep renovation strategies

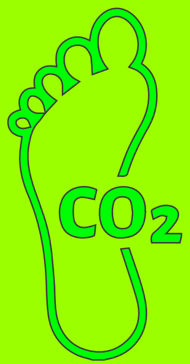


- LCC is mainly influenced by operational costs
- Which is higher for energy systems that use electricity, and highest for strategies that consider an electric boiler.
- cavity insulation results in lowest LCC due to a high energy saving.

Shallow renovation strategies

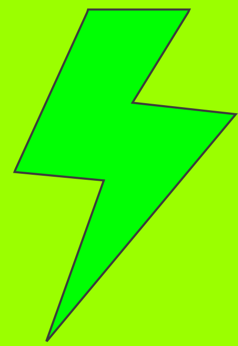


Holistic performance



Emissions

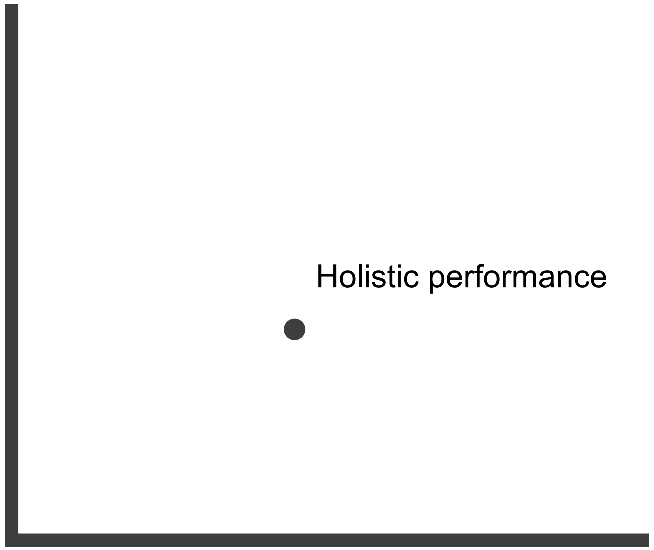
Costs



Energy

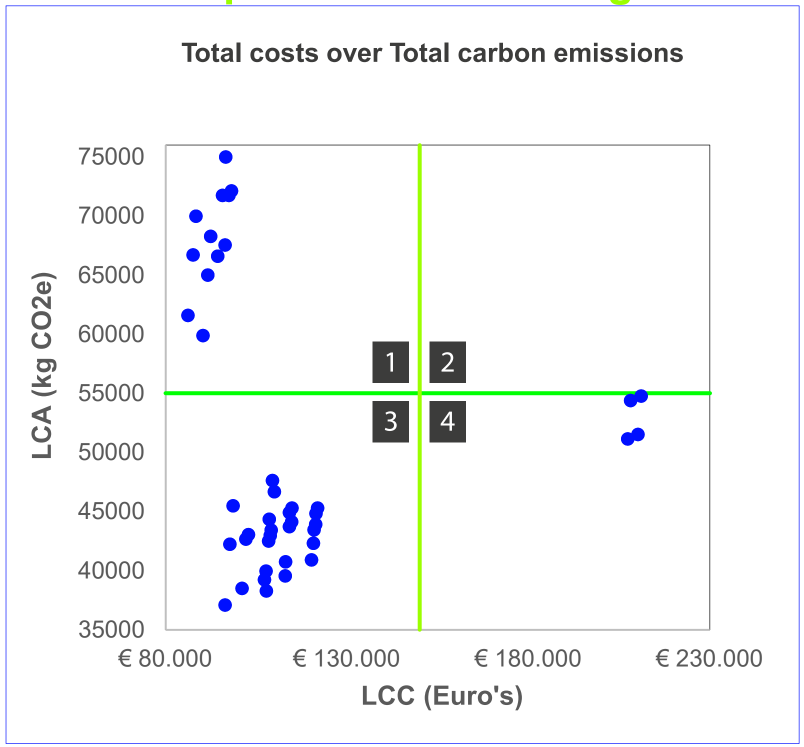
Holistic performance - Scatter plot LCA and LCC

LCA = OPERATIONAL CARBON + EMBODIED CARBON



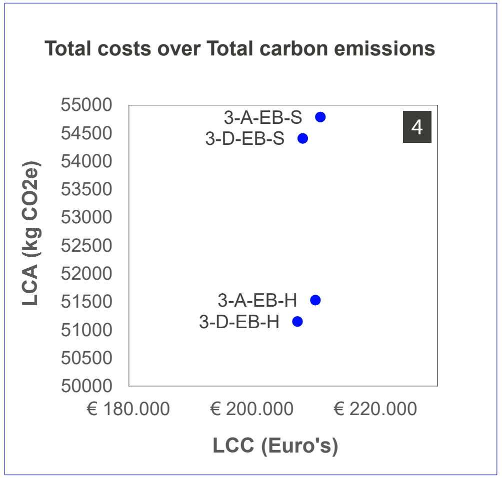
LCC = OPERATIONAL COSTS+ REPLACEMENT MATERIALS + INVESTMENT MATERIALS

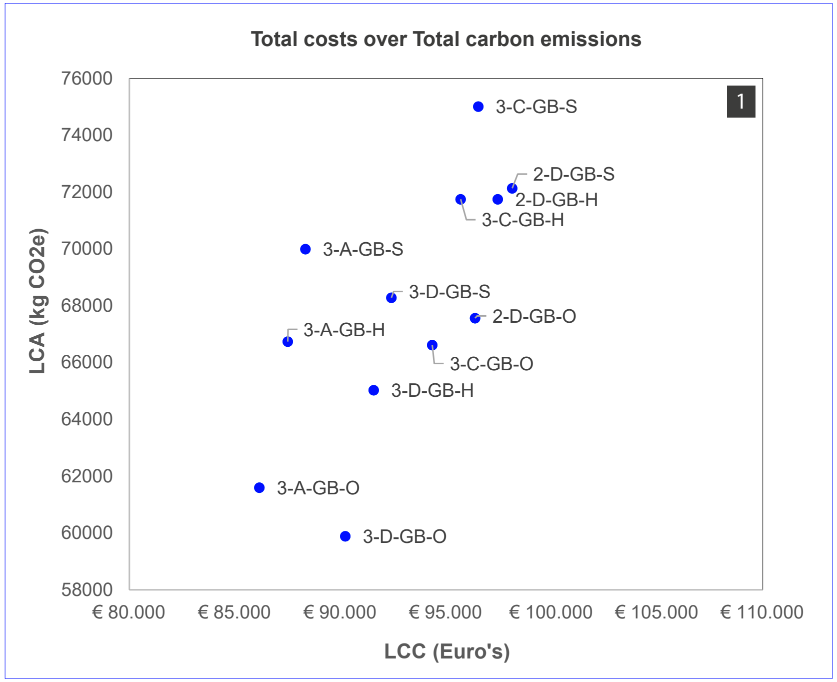
Deep renovation strategies

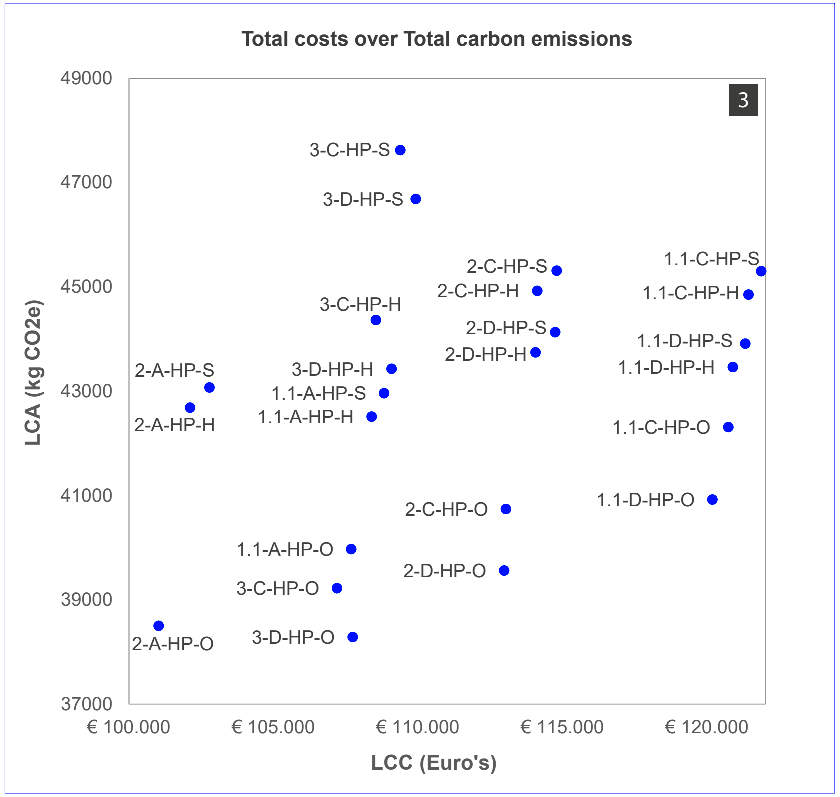


Scatter plot DEEP renovation strategies, LCA and LCC

- Strategies that result in low carbon emissions and low costs, al contained a heat pump.
- High emissions and low costs relate to gas boilers.
- High costs and moderate carbon emissions related to electric boilers, costs is influenced by the energy price.







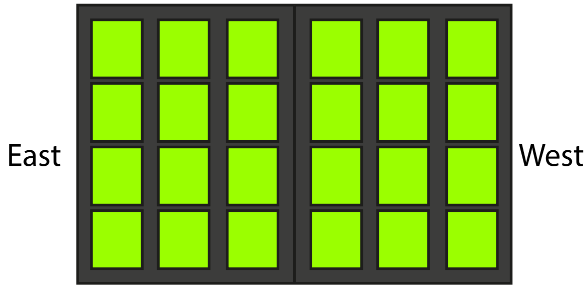
- Similar roof angle

Generation potential dependent on:
- Surface area
- orientation
- PV type

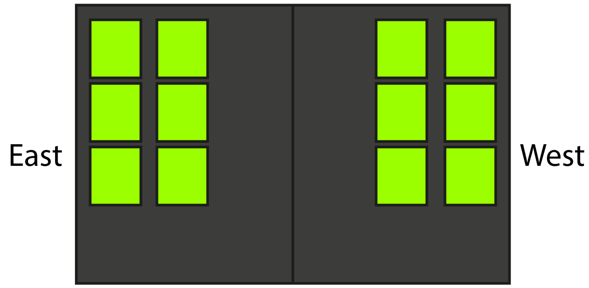
Concept 1 can compensate for strategies that consider:
- heat pump
- high insulation, D or A ventilation

Concept 2 and 3 can compensate for strategies that consider:
- heat pump

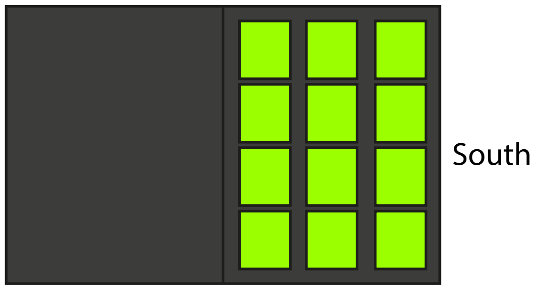
Concept 1



Concept 2



Concept 3



But what happens to the life cycle performance if renovation is performed in steps?

Renovation scenarios

The deployment of renovation is influenced by 3 factors:

Renovation level	Renovation execution	Trigger points

Resulting in various possible renovation scenarios

"Renovation scenarios refer to alternative situations to evaluate their potential to meet renovation objectives"

Where situations refer to the deployment of renovation

Stepped renovation

Trigger points

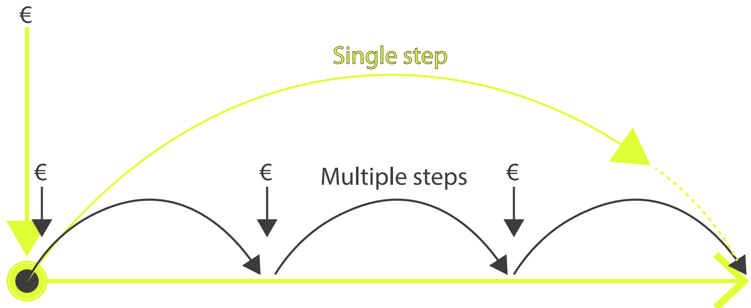
budget influences when
renovation will take place

Renovation levels

Shallow renovation 3-30%
Moderate renovation 30%-60%
Deep renovation >60%

Limited budget

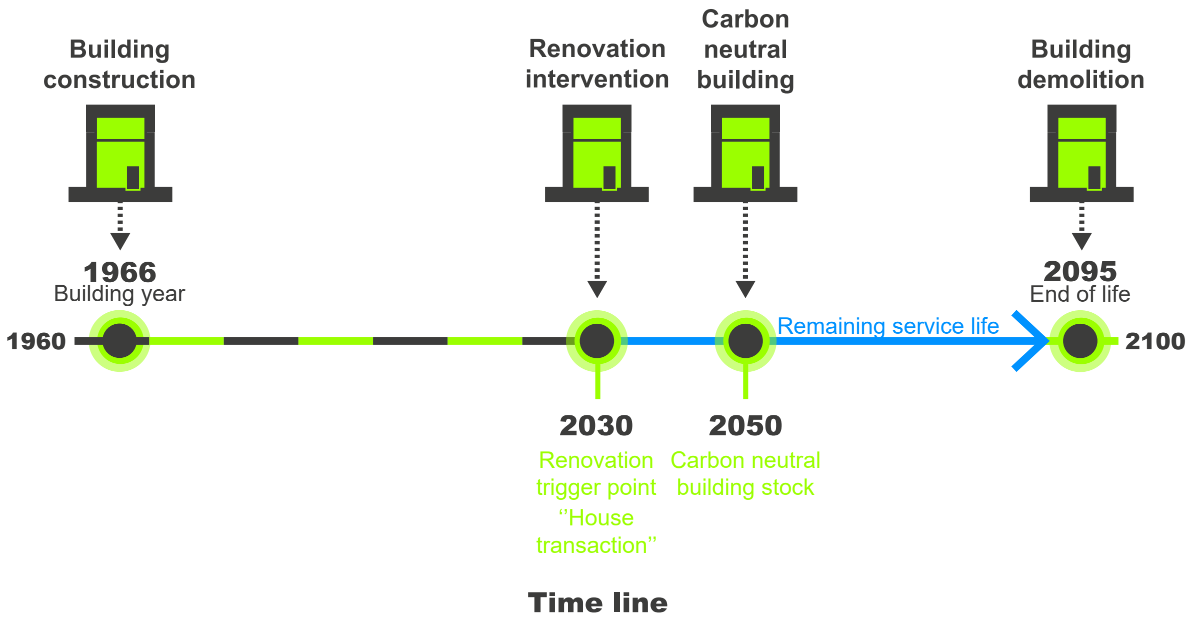
Renovation execution



Single step
Multiple steps

Life cycle planning

1. Determine the remaining life span of the building



2. Predict when renovation interventions occure

Trigger points	Year
Change of tenancy	2038
House transactions	2030
Lifetime of infrastructure	2015
Lifetime of heating appliances	2033

(Kruit et al., 2020)

Trigger points for the majority of resi-dential buildings in Europe

Stepped renovation assessment

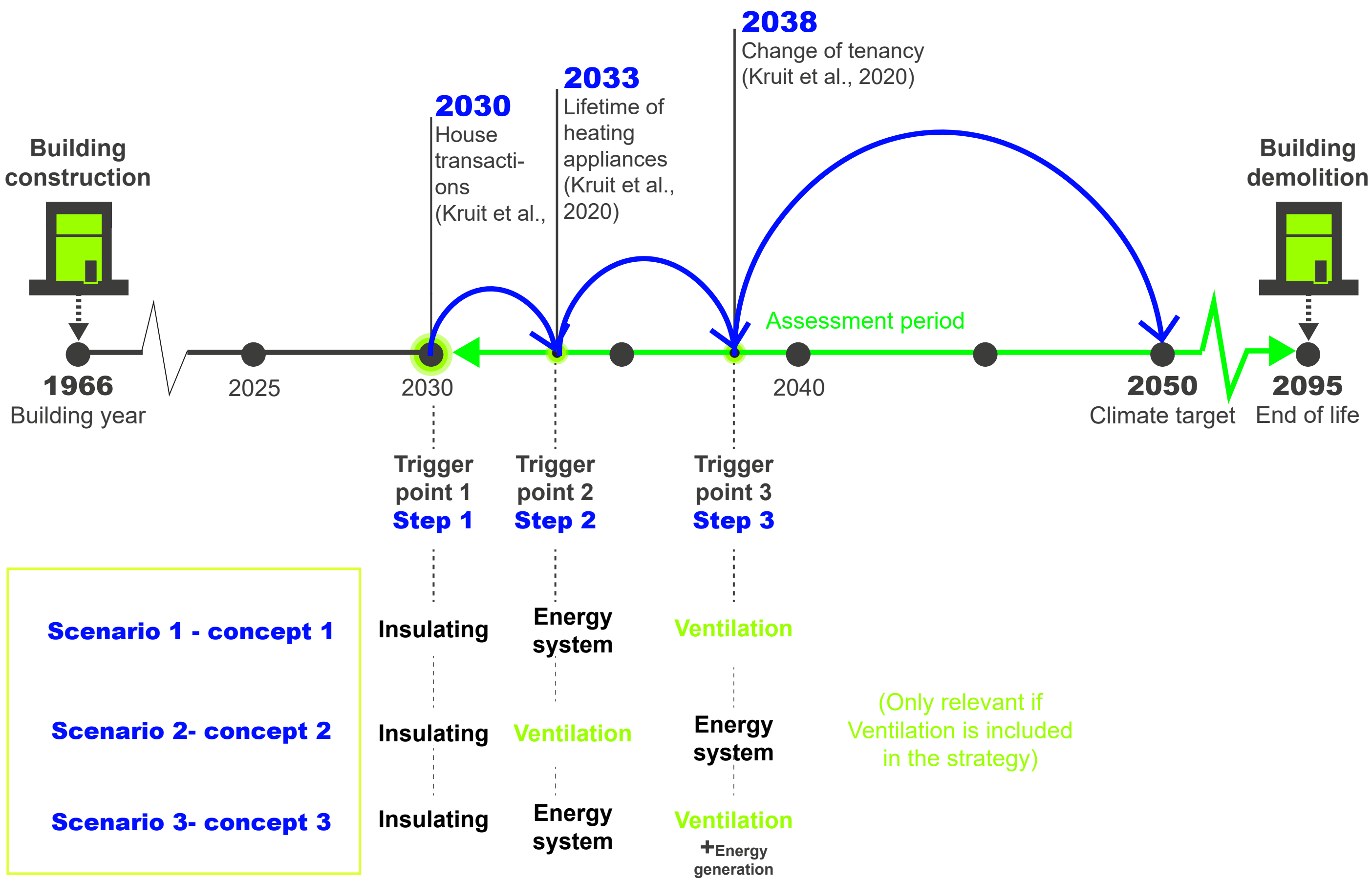
Assessed strategies

1.1 - A - HP -O

3 - D - HP - O

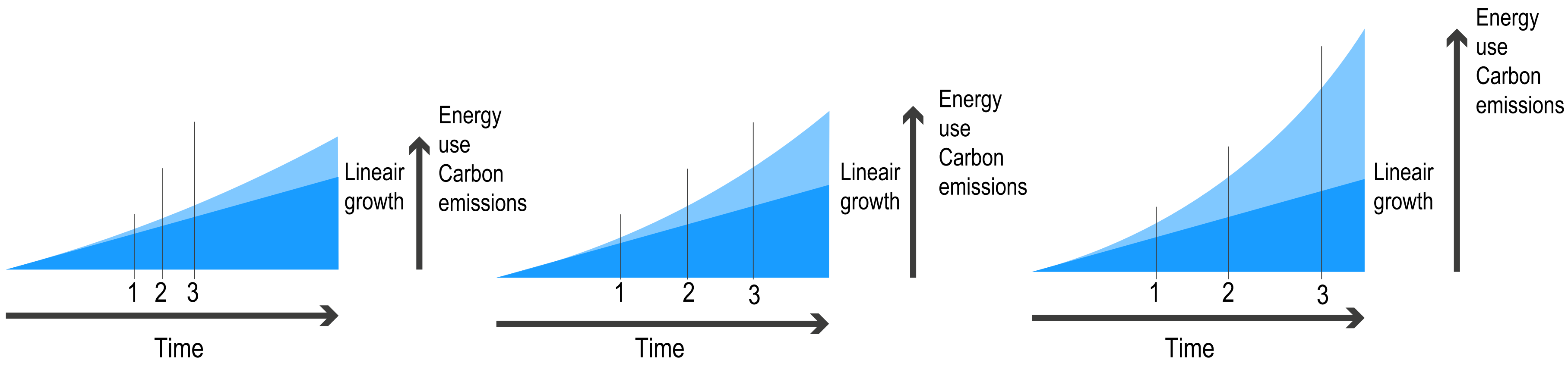
3 - D - EB - H

Life cycle prediction, houses EU



Assessed scenarios

Steps in relation to performance



Renovation in steps
Renovation single go

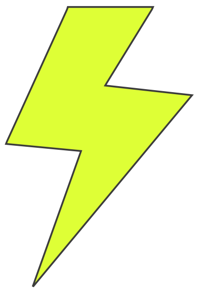
How can design contribute to decision making in renovation?

Decision making in renovation

Decision-making in renovation can be supported by:

Providing insight in the performance of renovation strategies

Main criteria in decision-making?



Energy performance

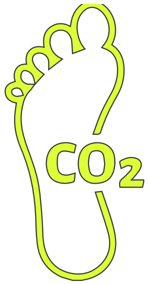
↓

Decision makers

Costs performance

↓

Decision makers



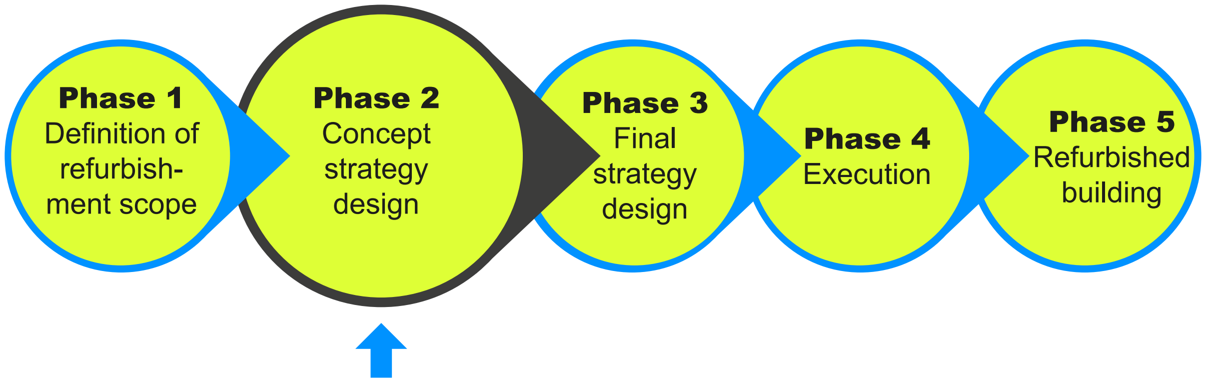
Carbon performance

↓

Climate target

Who benefits from support in decision-making?

Decision makers with large portfolios in particular need support in long term decision-making.

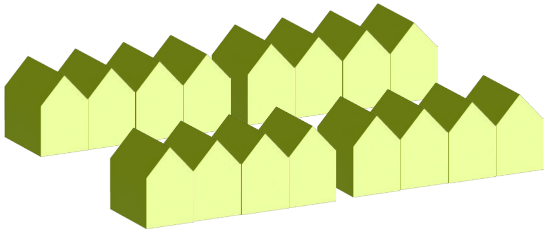


What is needed?

There is a need for decision support tools, that provide insight in the performance of a renovation on energy use, carbon emissions and costs.

Support tools for decision making should not be time consuming.

Tools that consider long-term strategies, for partial refurbishment. To support long term financial planning in renovation.



Decision makers with a large building portfolio

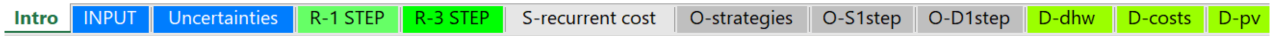
Uncertainty in tool

DATA	Data on carbon emissions and costs fluctuates
Representative outcomes	A simplefied assessment does not represent the real performance

TOOL Setup

Excel worksheets

R results
O overview
S simulation
D data



Tool setup:

Input and uncertainties > case specific data required from decision maker

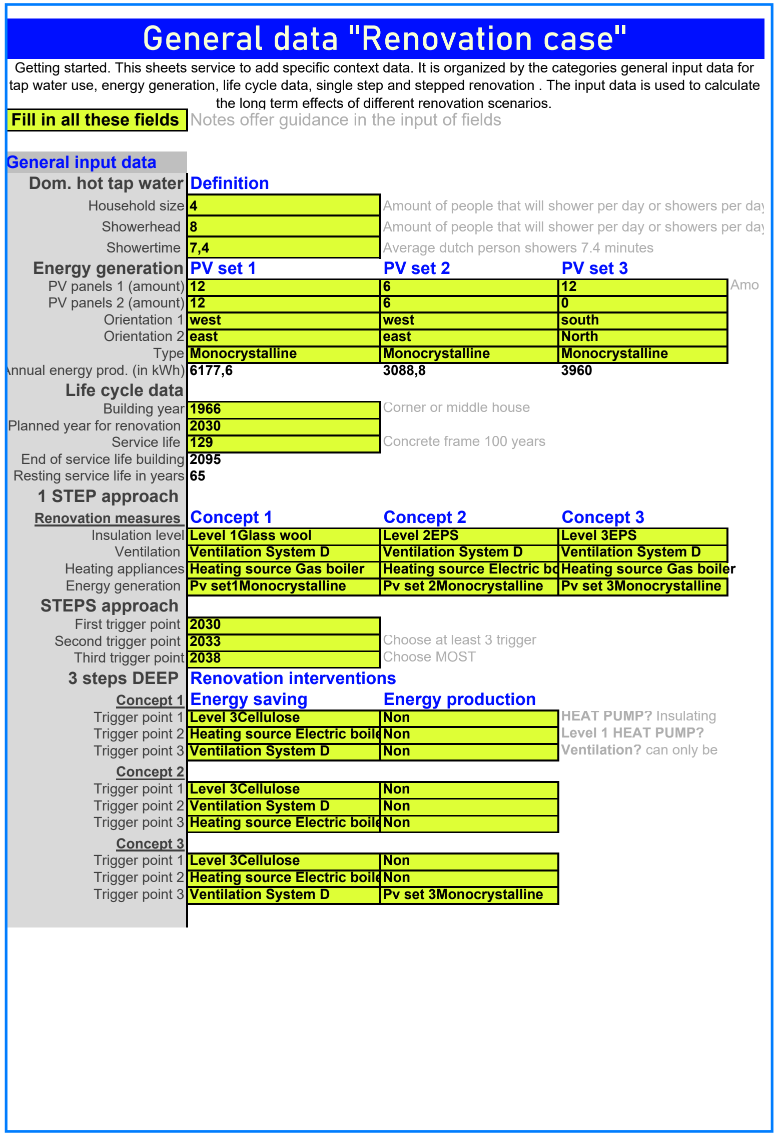
Performance assessment results overview

Recurrent costs, overview costs over time for budget planning

Overview of the strategies

Data, overview of the data

- Simple interface, minimum input fields
- Option for one step or steps re-novation
- Graphical repre-sentation of the input values

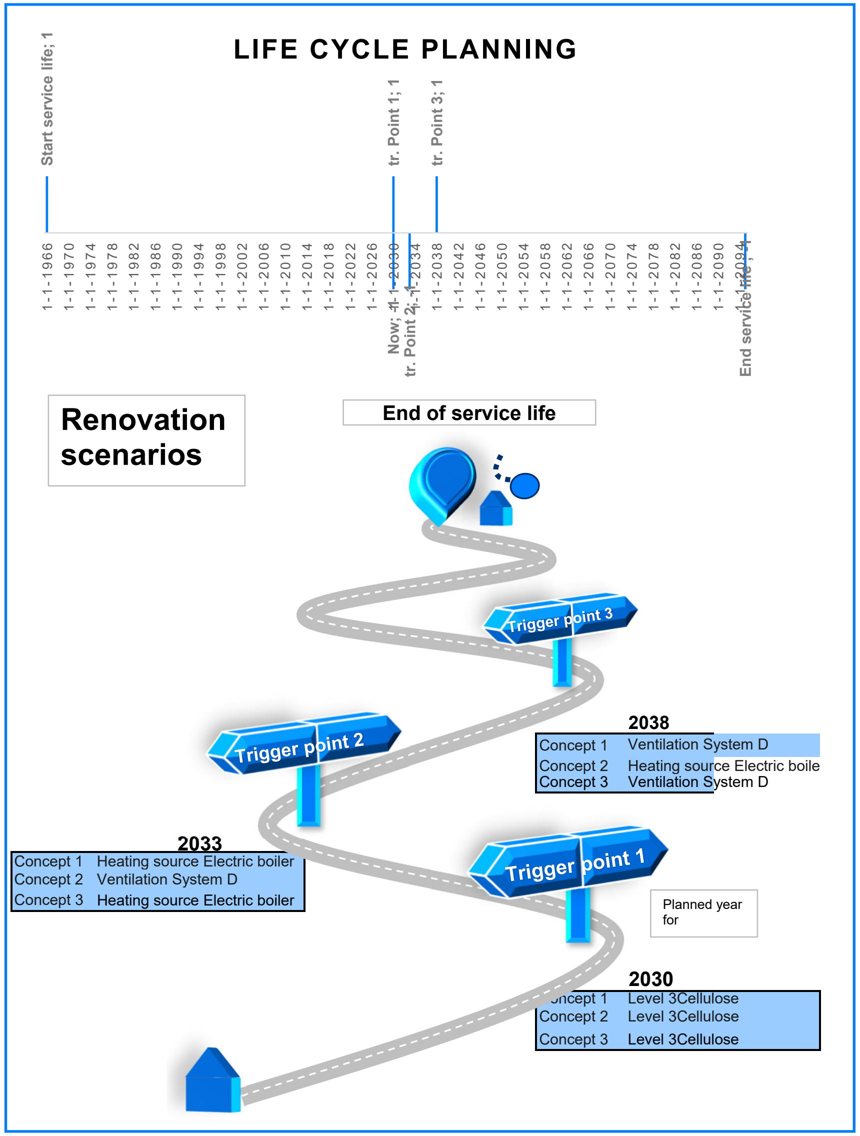


General data "Renovation case"

Getting started. This sheets service to add specific context data. It is organized by the categories general input data for tap water use, energy generation, life cycle data, single step and stepped renovation . The input data is used to calculate the long term effects of different renovation scenarios.

Fill in all these fields | Notes offer guidance in the input of fields

General input data				
Dom. hot tap water	Definition			
Household size	4	Amount of people that will shower per day or showers per day		
Showerhead	8	Amount of people that will shower per day or showers per day		
Showertime	7,4	Average dutch person showers 7.4 minutes		
Energy generation	PV set 1	PV set 2	PV set 3	
PV panels 1 (amount)	12	6	12	Amo
PV panels 2 (amount)	12	6	0	
Orientation 1	west	west	south	
Orientation 2	east	east	North	
Type	Monocrystalline	Monocrystalline	Monocrystalline	
Annual energy prod. (in kWh)	6177,6	3088,8	3960	
Life cycle data				
Building year	1966	Corner or middle house		
Planned year for renovation	2030			
Service life	129	Concrete frame 100 years		
End of service life building	2095			
Resting service life in years	65			
1 STEP approach				
Renovation measures	Concept 1	Concept 2	Concept 3	
Insulation level	Level 1Glass wool	Level 2EPS	Level 3EPS	
Ventilation	Ventilation System D	Ventilation System D	Ventilation System D	
Heating appliances	Heating source Gas boiler	Heating source Electric bo	Heating source Gas boiler	
Energy generation	Pv set1Monocrystalline	Pv set 2Monocrystalline	Pv set 3Monocrystalline	
STEPS approach				
First trigger point	2030			
Second trigger point	2033	Choose at least 3 trigger		
Third trigger point	2038	Choose MOST		
3 steps DEEP	Renovation interventions			
Concept 1	Energy saving	Energy production		
Trigger point 1	Level 3Cellulose	Non	HEAT PUMP? Insulating	
Trigger point 2	Heating source Electric boile	Non	Level 1 HEAT PUMP?	
Trigger point 3	Ventilation System D	Non	Ventilation? can only be	
Concept 2				
Trigger point 1	Level 3Cellulose	Non		
Trigger point 2	Ventilation System D	Non		
Trigger point 3	Heating source Electric boile	Non		
Concept 3				
Trigger point 1	Level 3Cellulose	Non		
Trigger point 2	Heating source Electric boile	Non		
Trigger point 3	Ventilation System D	Pv set 3Monocrystalline		



Life cycle path by input values

TOOL Design

- Results are significantly influences by data on carbon emissions and costs. And are case specific.
- factors that influence costs and emissions the most are included in the tab.
- Uncertainty tab > reduces uncertainty in data
- Allows use of case specific data
- Or updated data

Change the operational carbon emissions for electricity and natural gas

Change the costs for materials and services

Change the carbon emissions for services

Uncertainty "Reducing data uncertainty"

Getting started. This sheet offers the possibility to reduce uncertainties related to the data used in the tool. It is organized by the categorize general input data for the renovation, the building, and the objectives of the renovation. Then the selection of renovation scenario follows and at last the life cycle data is used to calculate the long term effects of different renovation scenarios.

Fill in all these fields Notes offer guidance in the input of fields

General input data	Definition			Investment (€)		Replacement (€)
CO2 emission factors						
Electricity	0,094	kg / kWh				
Natural gas	1,788	0,16 kg / m3				
Costs materials and services						
Heat pump system (air-water)				12236	1	4460
Gas boiler (HR ketel)				2380	1	1779
elec boiler				5852	1	4400
Ventilation system D				5453	1	1300
Ventilation system C				3043	1	577
Solar panels - monocristaline				248	m2	
Solar panels - Polycrystalline			Conversion	190	m2	
Glass wool	91	m2	0,01	9100	m3	
EPS	91	m2	0,022	4136	m3	
Cellulose	63	m3		63	m3	
Glass wool (cavity)	12	m2	0,06	200	m3	
EPS (cavity)	23	m2	0,05	460	m3	
Cellulose (cavity)	63	m3		63	m3	
Double glazed windows (HR++)				168	m2	
Triple glazed windows (HR+++)				207	m2	
CO2 emissions of measures	**GWP (kg CO2e)**					
2 - Heat pump system	4381					
2 - Gas boiler	331					
2 - elec boiler	1487					
2 - Ventilation system D	620					
2 - Ventilation system C	479					
Monocrystalline	259					
Polycrystalline	197					
Double glazed windows (HR++)	1387					
Triple glazed windows (HR+++)	1405					

Performance results renovation in steps

- Automatically finds correspon-ding data
- Generates a report
- Represents the data in values and graphs
- Takes into account time

Tab R-3 step

Report generated by TOOL

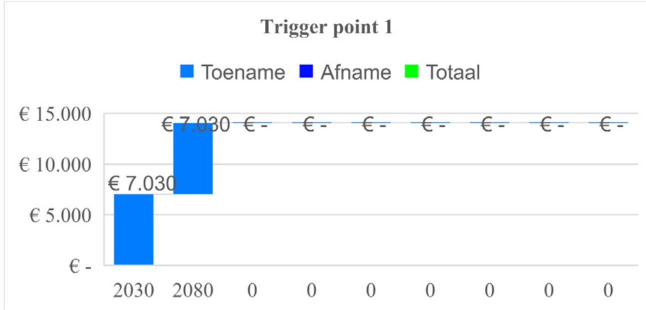
Recurrent costs

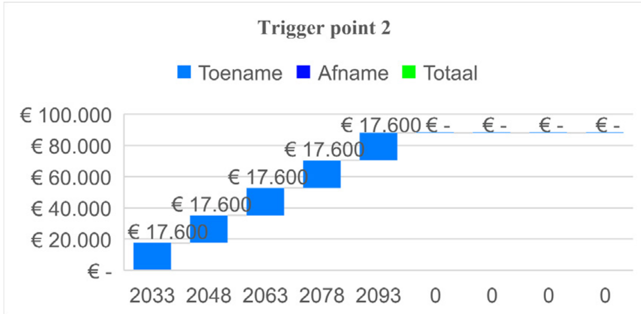
Costs over time

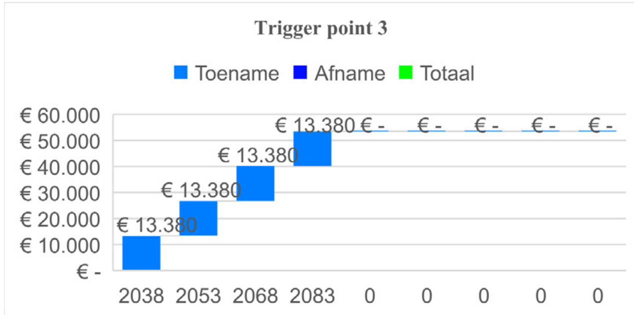
- Automatically finds correspon-ding data
- Generates a report
- Represents the data in values and graphs
- Takes into account time

Tab S-recurrent, costs

Year	T 1	Year	T2	Year	T3
2030	€ 7.030	2033	€ 17.600	2038	€ 13.380
2080	€ 7.030	2048	€ 17.600	2053	€ 13.380
0	€ -	2063	€ 17.600	2068	€ 13.380
0	€ -	2078	€ 17.600	2083	€ 13.380
0	€ -	2093	€ 17.600	0	€ -
0	€ -	0	€ -	0	€ -
0	€ -	0	€ -	0	€ -
0	€ -	0	€ -	0	€ -
0	€ -	0	€ -	0	€ -







Design limitations

- Simple interface, minimum input fields
- Ventilation not assessed as a single step
- Insulation measures are combined in one step
- Doesn't use dynamic data, for example for the operational carbon or costs
- Recurrent costs, only for the 3 step option
- Not all carbon emissions are included, only assesses the insulation, and units for services
- Does not take into account the current state
- Can similute up to 3 concepts

It is possible to manually add the performance of the assessed building

Change the performance of the current state here!

Matching strategies found for each trigger point

			Renovation strategy reference	Annual Operational energy use (kWh)	Annual Operational carb	Embodied carbon (CO2e kg/year)	Total Carbon emissions per year (kg CO2e/y	Energy saving (%)	Cost estimation Investment (euro's)	Replacement factor	Service life	Replacement cost
Current			Current stateGB	15120	2417	0	2417	-3%	€ 1.779	4	15	€ 7.116
Concept 1	3	Level 1 (He	1.1-A-GB-S	#N/B	#N/B	#N/B	#N/B	#N/B	€ 5.615	1	55	€ 5.615
	10	Ventilation S	1.1-C-GB-S	#N/B	#N/B	#N/B	#N/B	#N/B	€ 3.043	2	25	€ 1.154
	52	Heating sou	1.1-C-HP-S	2564	241	378	619	83%	€ 12.236	3	15	€ 13.380
Concept 2	3	Level 2Cellu	2-A-GB-O	6225	995	65	1060	58%	€ 5.692	1	50	€ 5.692
	10	Ventilation S	2-D-GB-O	5821	930	90	1020	60%	€ 5.453	2	25	€ 2.600
	52	Heating sou	2-D-HP-O	2000	188	360	548	86%	€ 12.236	3	15	€ 13.380
Concept 3	3	Level 1 (He	1.1-A-GB-O	#N/B	#N/B	#N/B	#N/B	#N/B	€ 5.046	1	50	€ 5.046
	10	Ventilation S	1.1-C-GB-O	#N/B	#N/B	#N/B	#N/B	#N/B	€ 3.043	2	25	€ 1.154
	52	Heating sou	1.1-C-EB-O	#N/B	#N/B	#N/B	#N/B	#N/B	€ 5.852	3	15	€ 13.200

PV PANELS	Energy generation (Kwh)	Carbon emissions PV	Investment Costs PV panels	Service life	Replacement factor	Replacement cost
Current	0	0				
Concept 1	5544	10258	9821	20	3	29462
	0	0	0	0	0	0
	0	0	0	0	0	0
Concept 2	2772	5129	4910	20	3	14731
	0	0	0	0	0	0
	0	0	0	0	0	0
Concept 3	3762	5129	4910	20	3	14731
	0	0	0	0	0	0
	0	0	0	0	0	0

Conclusion

How can renovation strategies support decision-making, in reducing the total carbon emissions over a buildings life cycle, in the Netherlands?

Total carbon emissions

Total carbon emissions can be reduced by reducing energy consumption first. Or generating energy.

The second step is to reduce the embodied carbon. Especially in building that already perform well in terms of energy consumption.

The embodied carbon is reduced by using services with a high service life or with low carbon emissions.

Life cycle planning

Furthermore, the selection of renovation measures is dependent on budget for renovation and influences total carbon emissions.

Therefore the life cycle of a building should be planned.

This can be done by determining when budget for renovation is high, trigger points.

Support tool

Decision makers can be supported by making the performance of renovation strategies on multiple criteria accessible

By using a simplified assessment method of renovation strategies

That provides insight in total carbon emissions and takes into account life cycle planning.

Due to data uncertainty, the method should provide flexibility to adapt to new data, without losing its simplicity.

So ...

What does it mean for decision-makers

Small investments go a long way...

Is there a chance to renovate do it,

it will save emissions in the end,
compared to waiting

Should I wait to invest in future energy systems, that provide higher energy saving?

It's an option, but the longer renovation is avoided, the harder it becomes to compensate for emissions now

How can I gain insight in the carbon emissions of strategies?

By first planning the life cycle of a building, to determine the budget for renovation and possible renovation measures

Then selecting measures on their energy saving, and last choosing products with long life spans or low carbon emissions.

TOWARDS A ZERO CARBON EXISTING BUILDING STOCK

MADEVI SEWNATH - MASTER THESIS

P5 | 16-01-2023