Optimization of energy performance investments of buildings

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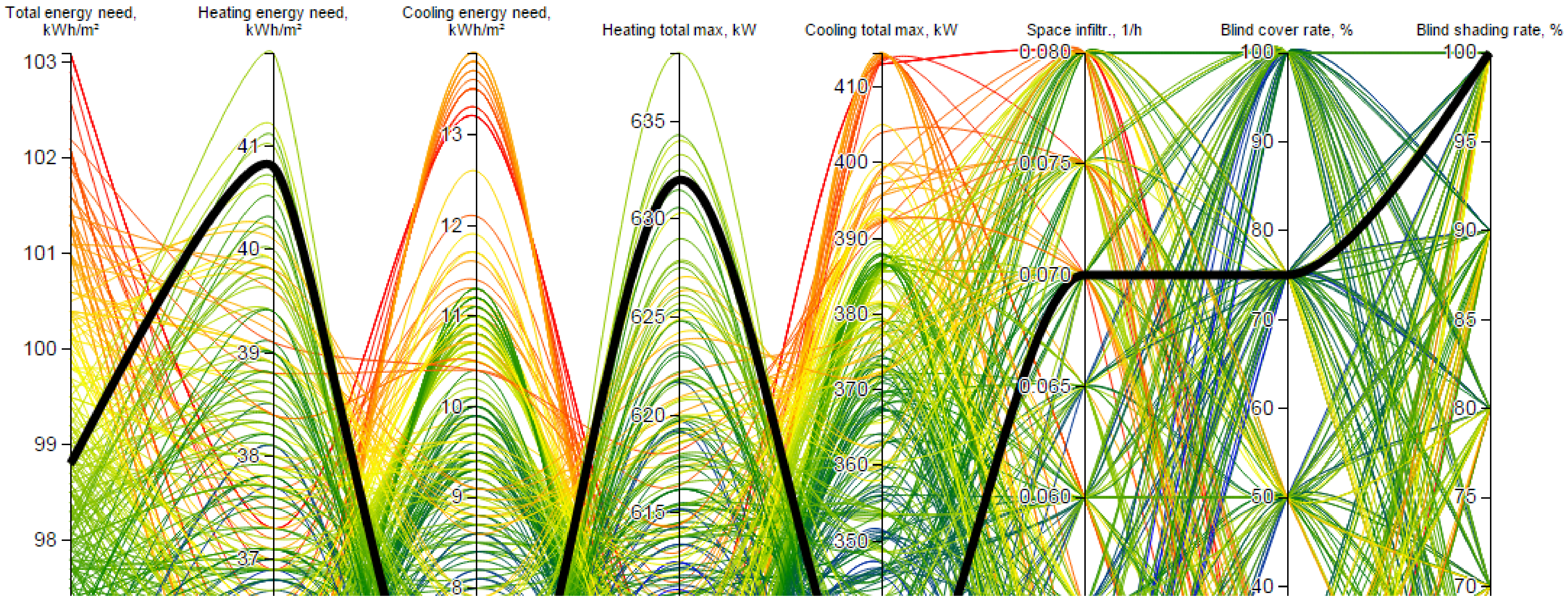
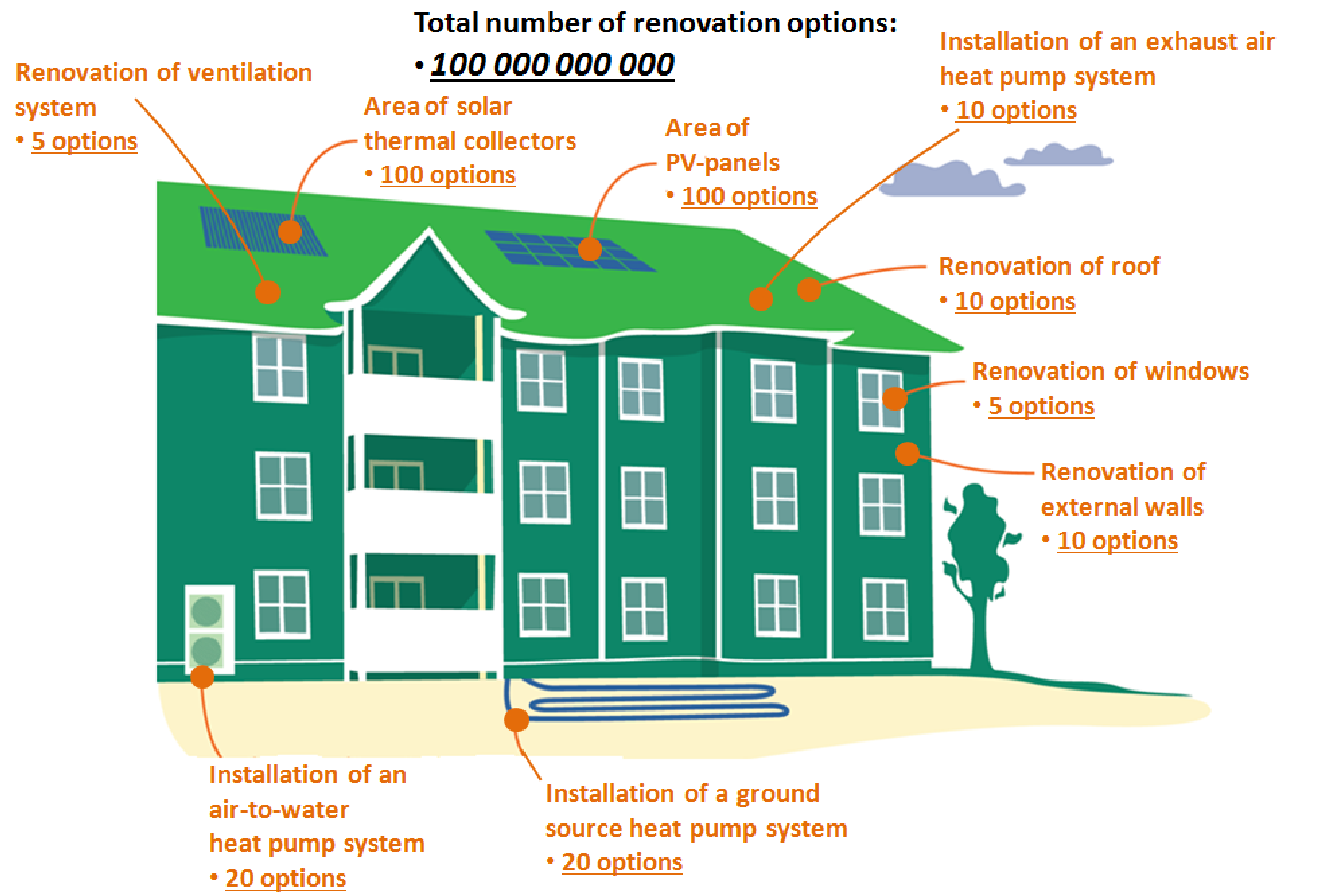
Optimization: searching for the best possible solution from a large number of different options



Need for optimization

- Cost-effectiveness and energy performance objectives
  - Cost-optimal nearly zero-energy buildings (nZEBs)
  - Cost-effective renovation of buildings
  - How to achieve as high energy performance as possible with the lowest investment costs possible
- Conventional calculation methods comparing a few potential energy performance improvement measures are not sufficient to determine the optimal solutions
- Simulation-based multi-objective optimization is a superior and cost-effective method to determine the best solutions
- Multi-objective optimization is most effective in the early stage (project planning phase) of projects

Optimized measures in buildings



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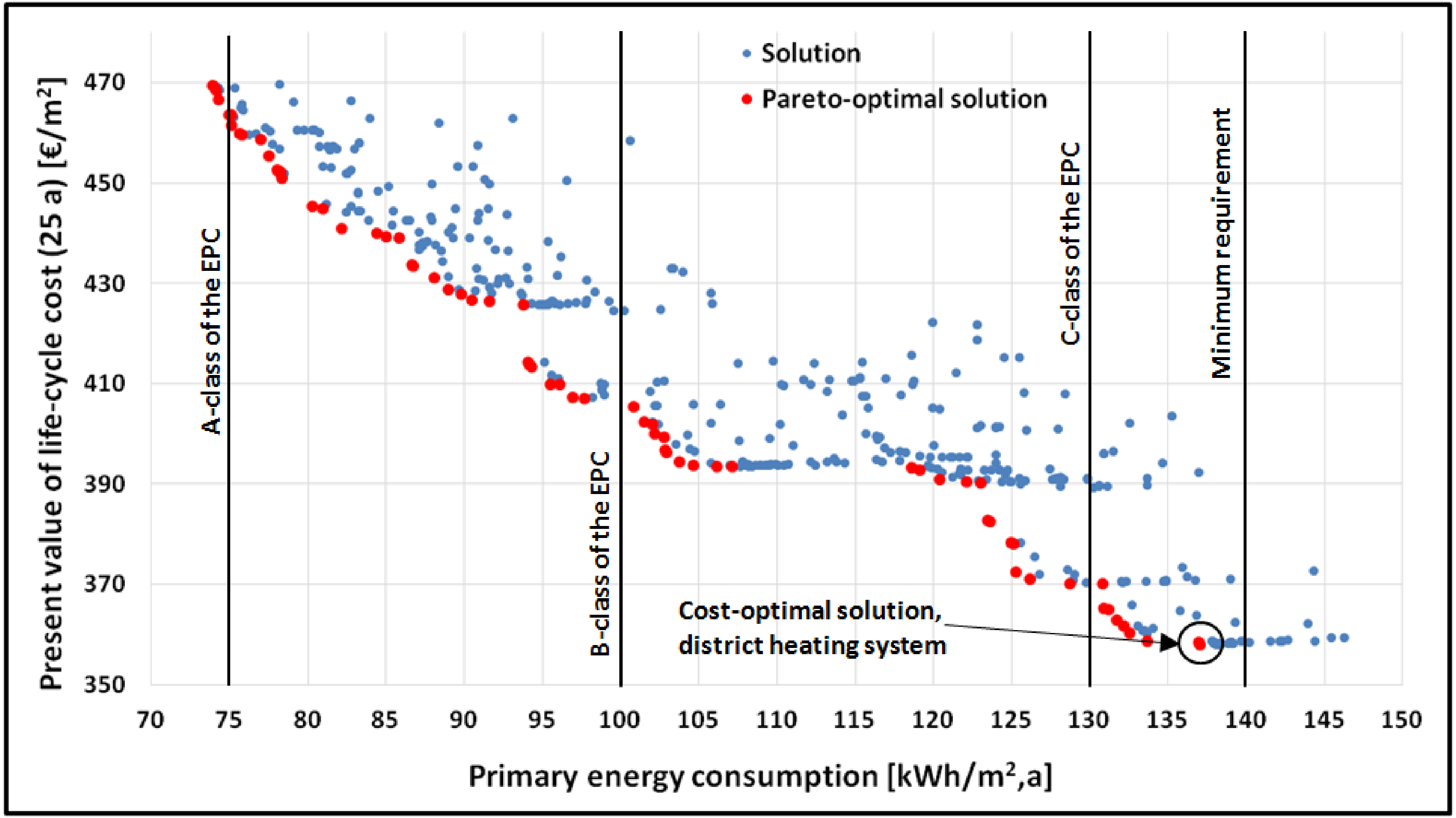
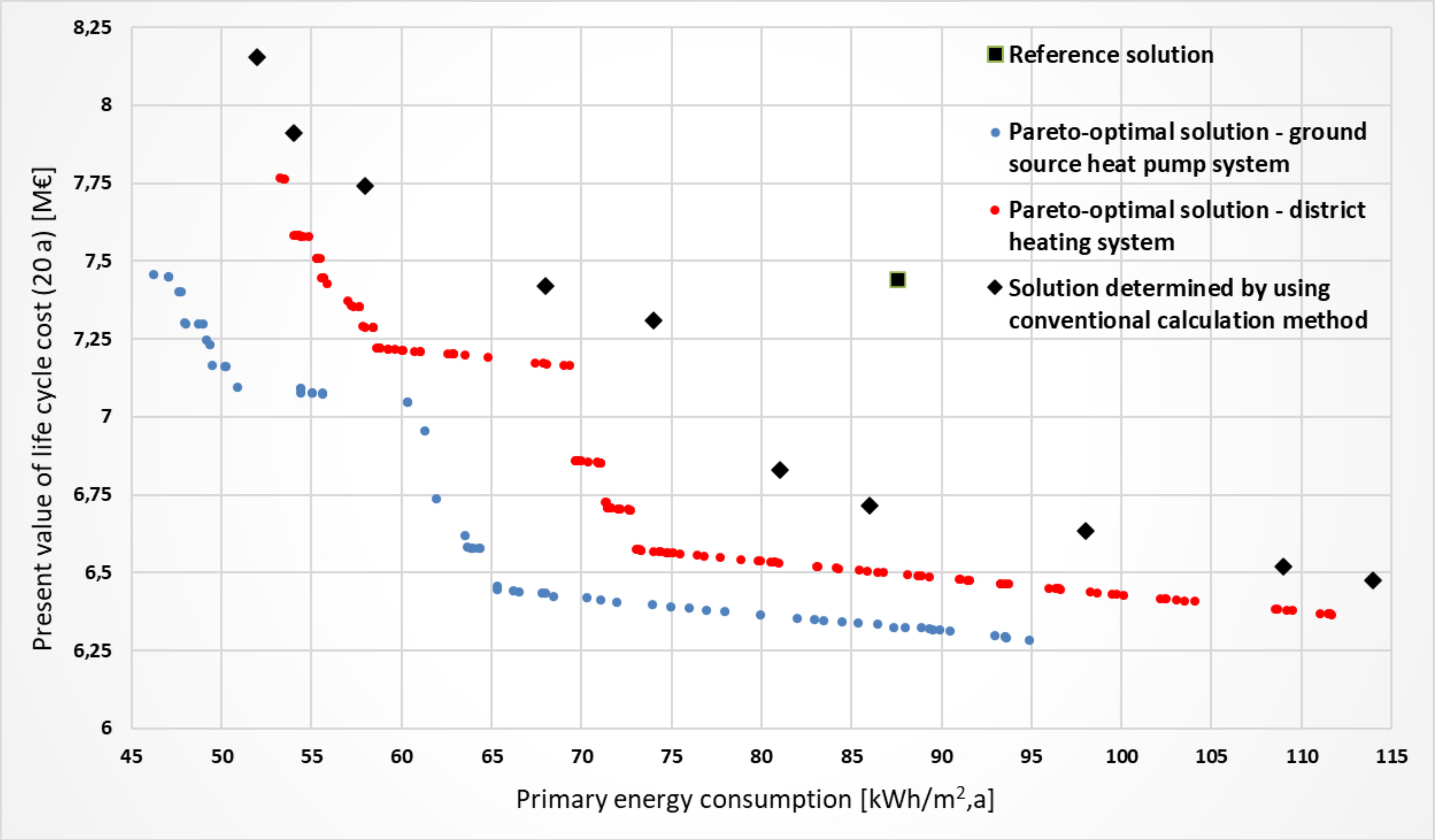
More and more Information and Building Technology

The principle of multi-objective optimization



Optimized vs conventional



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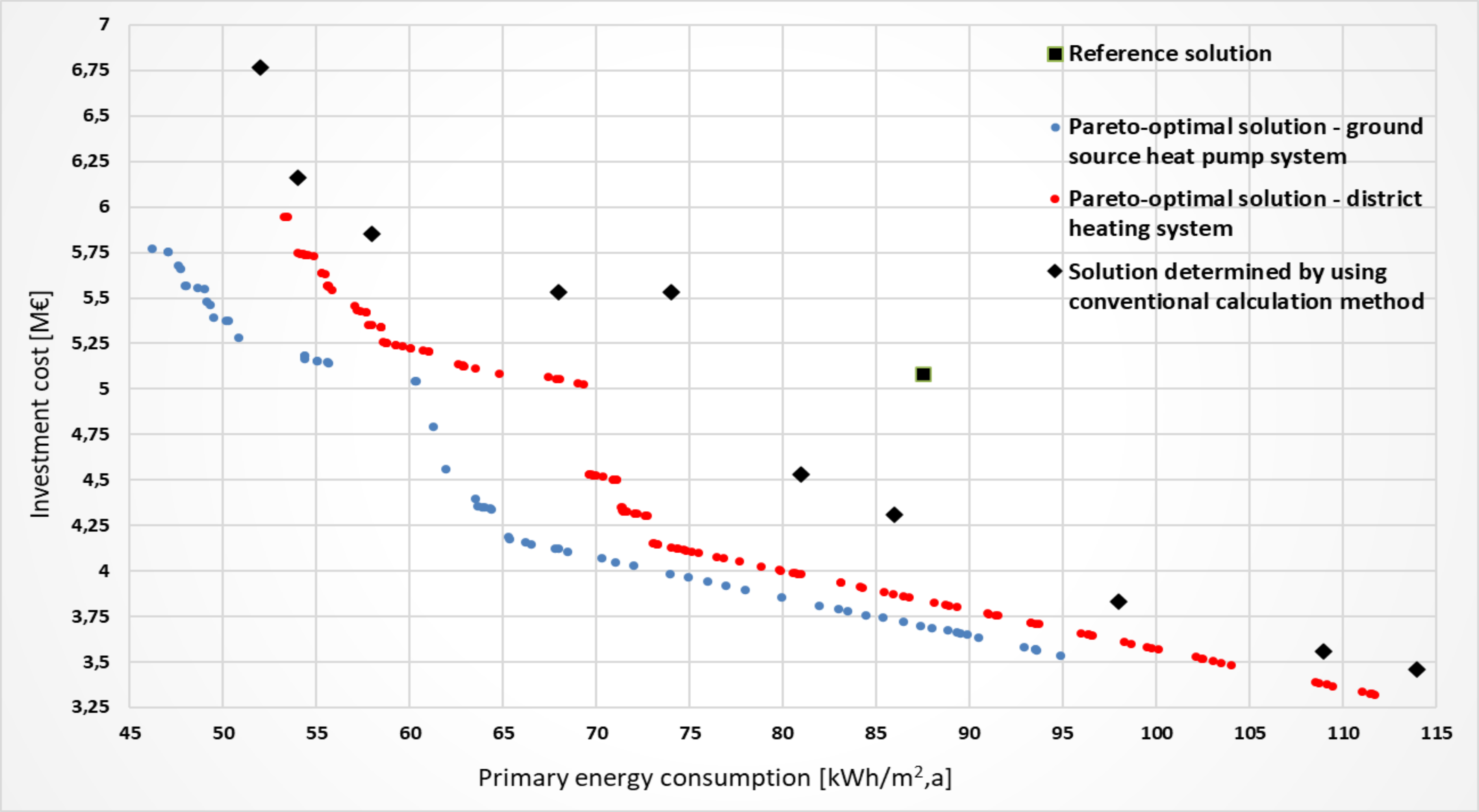
Optimized vs conventional



Renovation case:
Typical Finnish 1960s Apartment Buildings

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Case study:
Typical Finnish 1960s Apartment Buildings

- **Target: To determine the cost-optimal energy performance renovation solutions using MOBO** (Multi Objective Building Performance Optimization, tool developed by Finnish research institution VTT and Aalto University)

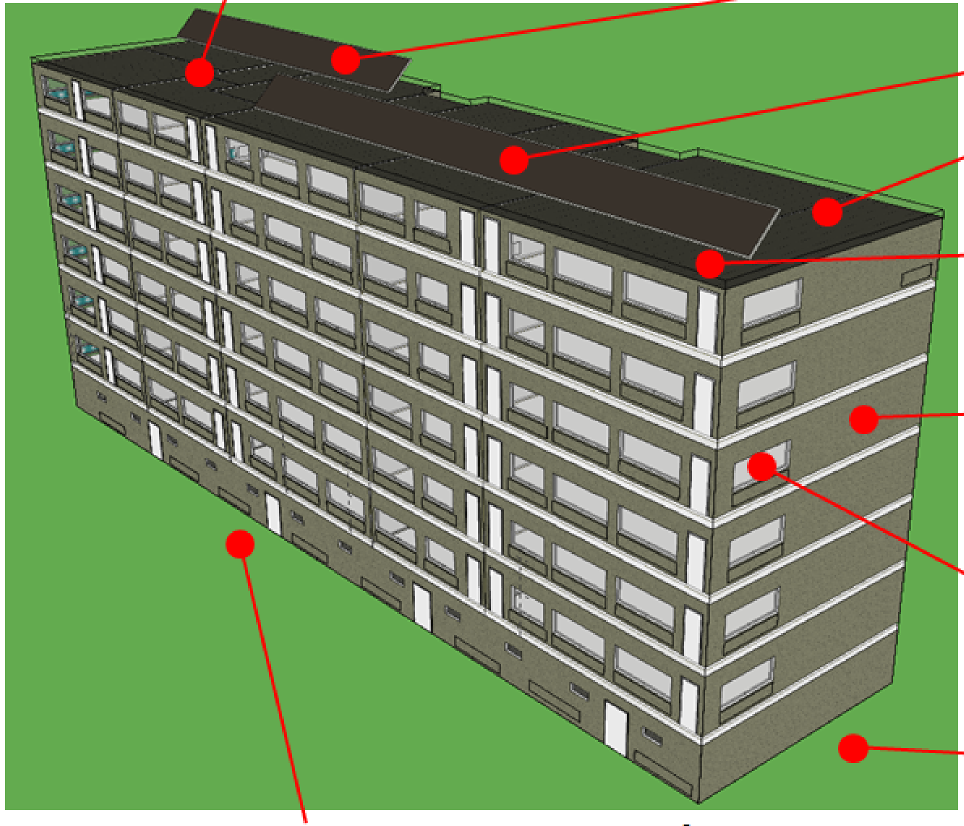
- Extremely time-consuming and difficult to carry out by using conventional research methods
- Energy and condition simulation-based optimization analysis method is applied
- Mathematical algorithm defines the optimal solutions according to the definitions and constraints set by the user

Studied renovation measures

Renovation of the ventilation system
- 72 % heat recovery efficiency

Area of solar thermal collectors (0-$90\ m^2$)

Area of PV-panels (0-$170\ m^2$)



Additional thermal insulation of roof (0-500 mm)

Dimensioning power output of an exhaust air heat pump (EAHP) system (30-40 kW)

Basic refurbishment or additional thermal insulation of external walls (0-200 mm)

Basic refurbishment of original windows or new windows with U-value of 1.0 or 0.8 $W/(m^2K)$

Dimensioning power output of a ground source heat pump (GSHP) system (39-156 kW)

Dimensioning power output of an air-to-water heat pump (A2WHP) system (14-128 kW)

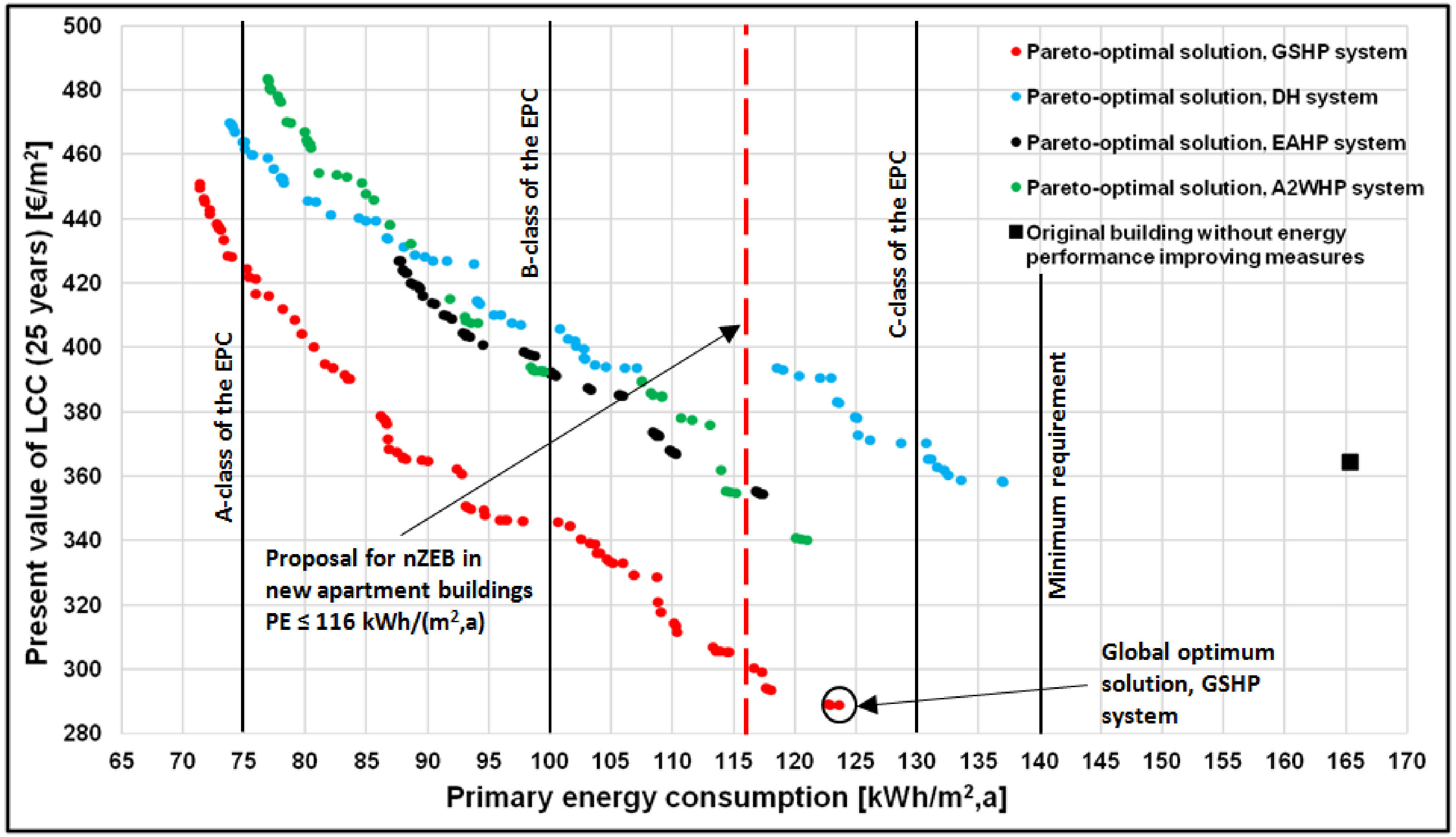
District heating system optimization

- When the district heating system is used as the main heating system, optimized variables are:
  - Area of solar collectors (0-90 m^2)
  - Area of PV-panels (0-170 m^2)
  - Renovation of the ventilation system (→ current mechanical exhaust air ventilation system is replaced with a mechanical supply and exhaust air ventilation system with heat recovery unit (72 % efficiency))
  - Additional thermal insulation thickness of external walls (0-200 mm), or just the basic refurbishment
  - Additional thermal insulation thickness of roof (0-500 mm)
  - Replacement of windows (original windows are repaired and re-sealed, or new windows are installed with the U-value of 1.0 W/(m^2K) or 0.8 W/(m^2K))

Ground source heat pump system optimization

- When the GSHP system is used as the main heating system, optimized variables are:
  - Dimensioning power output of the heat pump system (39-156 kW)
  - Area of PV-panels (0-170 m^2)
  - Renovation of the ventilation system
  - Additional thermal insulation thickness of external walls (0-200 mm), or just the basic refurbishment
  - Additional thermal insulation thickness of roof (0-500 mm)
  - Replacement of windows (original windows are repaired and re-sealed, or new windows are installed with the U-value of 1.0 W/(m^2K) or 0.8 W/(m^2K))

Optimal solutions in the 1960s apartment buildings



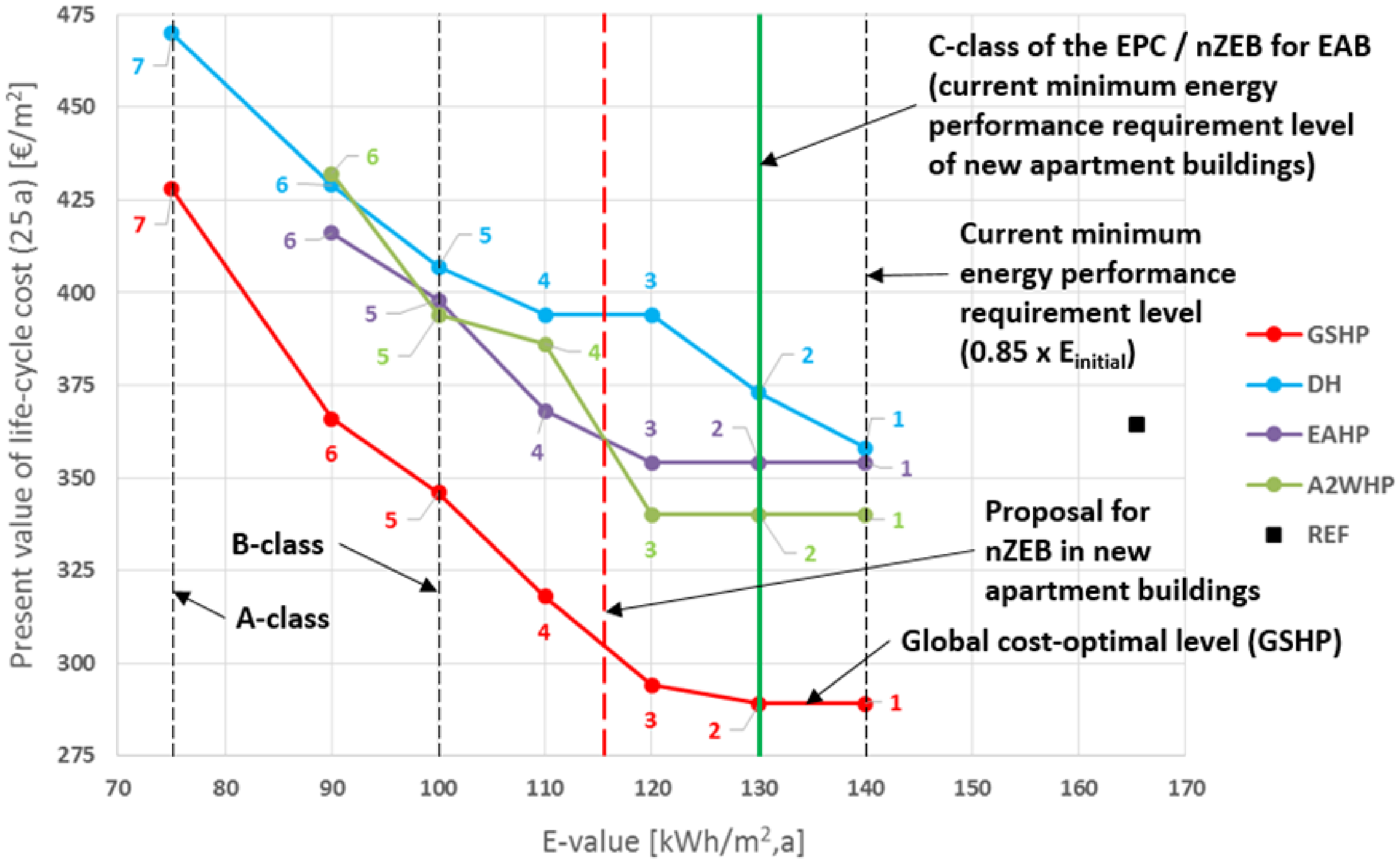
Recommended renovation solutions for the building

Energy class of the EPC, primary energy consumption [kWh/m²,a]	Main heating system	Power output of the heat pump system [kW]	Area of PV-panels [m²]	Thickness of additional thermal insulation of external walls [mm]	Thickness of additional thermal insulation of roof [mm]	Windows, U-value [W/m² K]	Renovation of the ventilation system	NVP of LCC [€/m²]	IC [€/m²]
140 (minimum requirement)	GSHP	94	170	0	+250	2.5 (original)	No	289	150
130 (C-class)	GSHP	94	170	0	+250	2.5 (original)	No	289	150
120	GSHP	130	160	0	+400	2.5 (original)	No	294	161
110	GSHP	150	170	0	+350	1.0 (new)	No	318	199
100 (B-class)	GSHP	70	160	0	+150	2.5 (original)	Yes	346	251
90	GSHP	73	170	0	+250	1.0 (new)	Yes	366	288
75 (A-class)	GSHP	70	170	+150	+350	1.0 (new)	Yes	428	383

Recommended renovation solutions for the district heating system

Energy performance target level, E-value [kWh/m²,a]	Main heating system	Area of PV-panels [m²]	Thickness of additional thermal insulation of external walls [mm]	Thickness of additional thermal insulation of roof [mm]	Windows, U-value [W/m² K]	Area of solar collectors [m²]	Renovation of the ventilation system	NVP of LCC [€/m²]	IC [€/m²]
140 (minimum requirement)	DH	170	0	+300	2.5 (original)	34	No	358	150
130 (C-class)	DH	170	0	+300	1.0 (new)	66	No	373	150
120	DH	170	0	+300	2.5 (original)	34	Yes	394	161
110	DH	170	0	+300	2.5 (original)	40	Yes	394	199
100 (B-class)	DH	160	0	+350	1.0 (new)	60	Yes	407	251
90	DH	170	+100	+250	2.5 (original)	56	Yes	429	288
75 (A-class)	DH	170	+200	+450	1.0 (new)	90	Yes	470	383

A recommendation of a reasonable and cost-effective nZEB energy performance target level for existing Finnish apartment buildings



Renovation case:

Typical Finnish 1970s Apartment Buildings

Optimizing the cost-effectiveness and environmental impact of deep renovations

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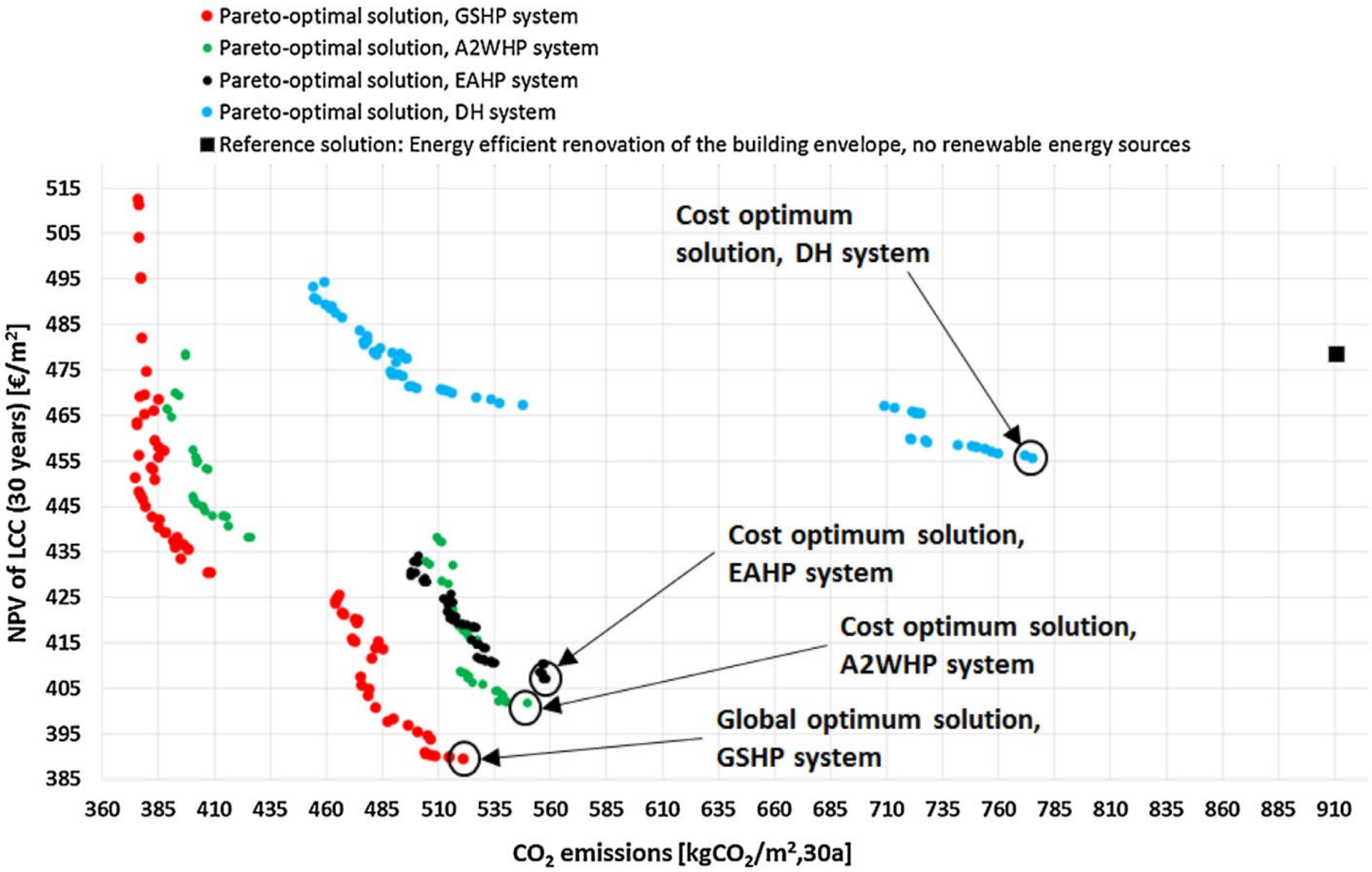
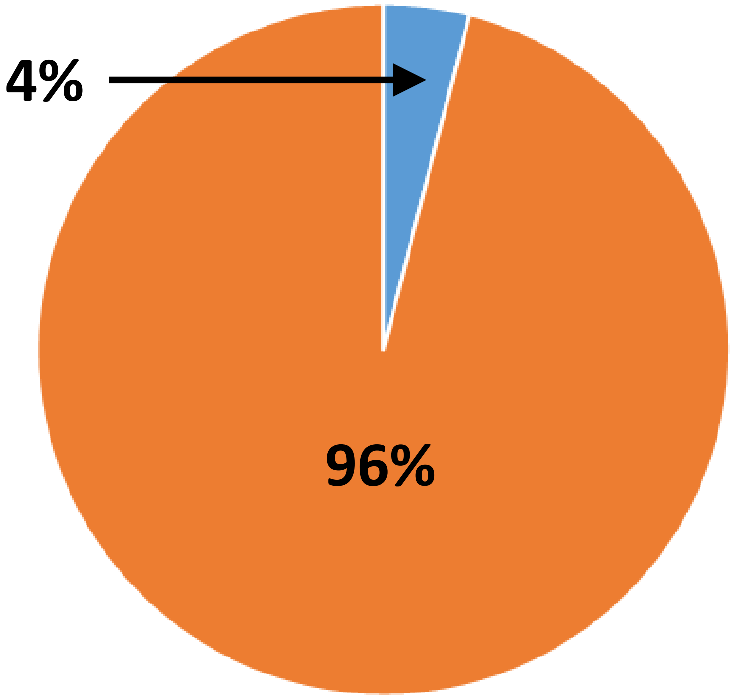
Optimal solutions in the 1970s apartment buildings

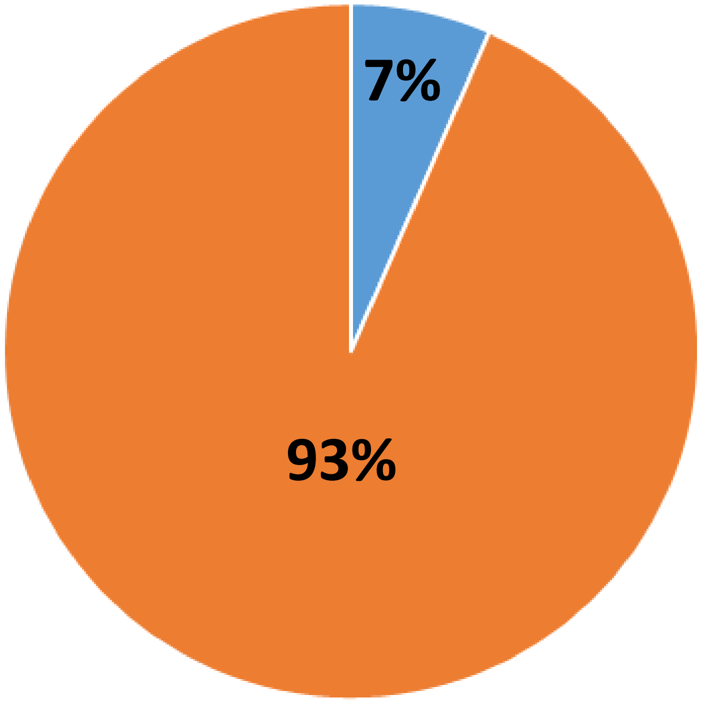


Optimal solutions in the 1970s apartment buildings

The breakdown of CO_2 emissions (30 a) of the reference solution



The breakdown of CO_2 emissions (30 a) of the global optimum solution



- Construction materials, their manufacturing and transportation to site
- Delivered energy consumption

Suitable applications for multi-objective optimization of energy performance of buildings

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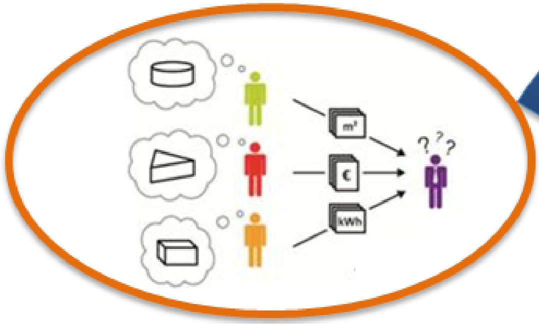
Applications for optimization of energy performance investments of buildings

- New buildings → how to build cost-optimal nZEBs
- All renovation cases → determining various renovation concepts: 1970's apartment buildings, 1980's ABs, etc.
- Concept development of new and existing buildings → how to build and renovate
- Excellent tool in life-cycle projects to determine the targets of the project

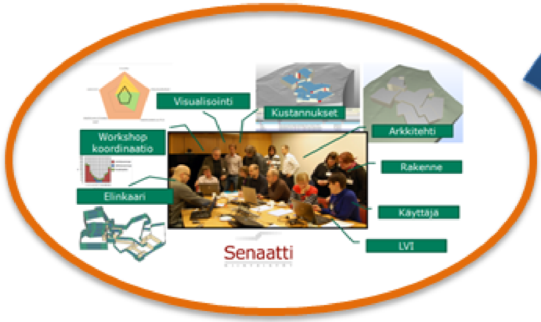
Energy performance optimization and cost-effectiveness

- Maximization of return on investment (ROI)
- Minimization of investment costs in projects
- How to determine the best possible overall solution with a limited investment budget, e.g. 300 000 €?
- Can be used to carry out various sensitivity analyzes, e.g.
  - the effect of the selected interest rate and energy price escalation used in the economic calculations
  - the tolerances in the initial calculation data used in the optimization analysis, such as the investment cost of the GSHP system, etc.

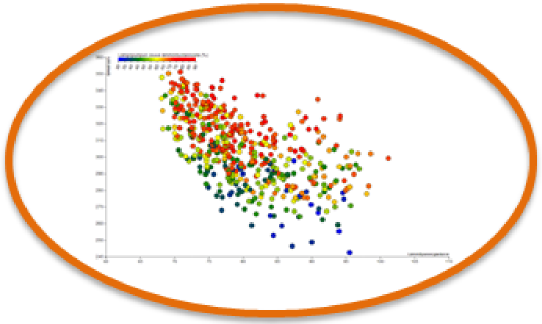
MoNo process and technology leap



Traditional process
1 – 3 solutions



New process
Best available
technology (BIM)
15 – 20 solutions



New process
New technology
100 – 200(00) solutions

Thank you!

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