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Robustness of multi-objective optimization of building refurbishment to suboptimal weather data

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TU/e

Introduction

EU Directive 31/2010

Cost optimal

Aim

EU Directive 31/2010 and Delegated Regulation EU 244/2012:

- Requisites for new and renovated existing buildings defined as cost-optimal
- All new buildings n-zeb by 2020
- Incentives for renovation of existing into n-zeb

Introduction

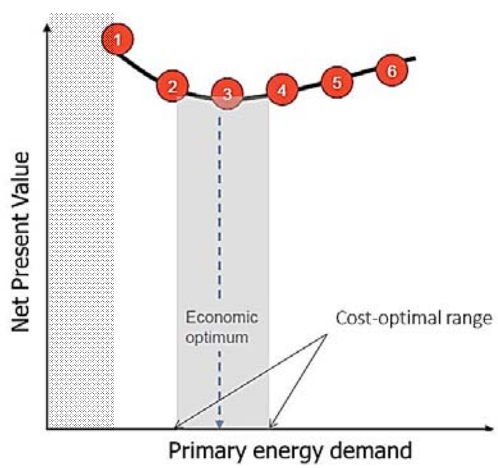
EU Directive 31/2010

Cost optimal

Aim

Cost-optimal:

- Among all possible ESMs, the designer should find those that optimizes some competitive goals, such costs and primary energy (Pareto Front) – Multi Objective Optimization.
- The Cost-optimal is the level of minimum Net Present Value in the Pareto Front.



Boermans et al., 2011

Introduction

EU Directive 31/2010

Cost optimal

Aim

Aim of the work:

- Imprecise input data can affect the robustness of the optimization approach and modify the optimal solutions
- Weather data (Test reference year) should be developed to be representative of the climatic conditions of the location.

How much the method for the definition of the TRYs can affect the optimal configurations?

The case of Trento (Italy)

INPUT DATA
Building features
Economic data
Weather data

MULTI-OBJECTIVE OPTIMIZATION

OA
Optimization Algorithm

BES
Building Energy Simulation

PARETO FRONT
Optimal solutions & Cost-optimal

Method

Weather data

Residential buildings

Energy saving measures

Multi-objective optimization

Weather data:
The representativeness of weather inputs is a key aspect to obtain reliable building simulation results and optimization.

TRY can be defined according to different methods and depend on the length of the multi-year weather data series.

Optimization has been repeated for Trento TRY obtained from data series of different lenghts (from 10 to 5 years)

No. years	10	9	8	7	6	5
Reference data for the TRY definition	96-98, 2002-08	96, 97, 2002-08	96, 97, 2002, 2004-08	96, 97, 2002-06	96, 97, 2002, 03, 07, 08	97, 2003-06

Method

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No. years	10	9	8	7	6	5
HDD_{18} (K d)	2499	2674	2167	2759	2298	2657
ΔHDD_{18} (%) **2509**	-0.40	6.58	-13.63	9.96	-8.41	5.90
Daily I_{sol} (MJ m^{-2})	7.98	7.49	6.15	7.09	6.51	7.70
Δ (%) **7,16**	11.5	4.7	-14.0	-0.8	-9.0	17.0

Method

Weather data

Residential buildings

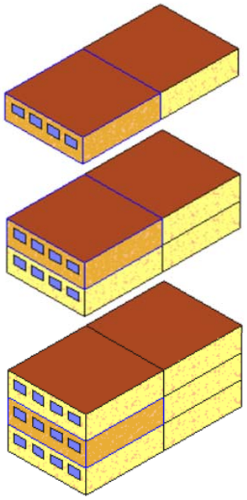
Energy saving measures

Multi-objective optimization

Reference starting configuration (100 m^2, 3 m height):

- Three typologies: semi-detached house (S/V = 0.97 m^{-1}), penthouse (S/V = 0.63 m^{-1}) and intermediate flat in multi-story buildings (S/V = 0.3 m^{-1}).
- The considered configurations have windows only in one façade (east or south). Features typical till the '70s.

Opaque Envelope	
d (m)	0.20
λ ($W\ m^{-1}\ K^{-1}$)	0.25
R ($m^2\ K\ W^{-1}$)	0.80
κ ($kJ\ m^{-2}\ K^{-1}$)	150
ρ ($kg\ m^{-3}$)	893
c ($J\ kg^{-1}\ K^{-1}$)	840



Method

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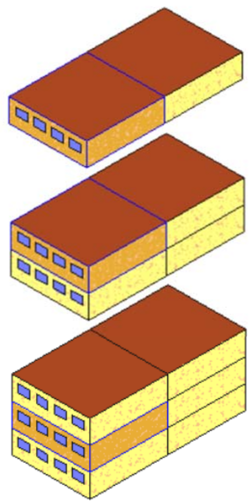
Windows	
Glazing: Single-pane	
U_{gl} (W m^{-2} K^{-1})	5.69
SHGC	0.81
Frame: Standard Timber	
U_{fr} (W m^{-2} K^{-1})	3.20
A_f/A_{win} (%)	19.9



Method

- Weather data
- Residential buildings
- Energy saving measures
- Multi-objective optimization

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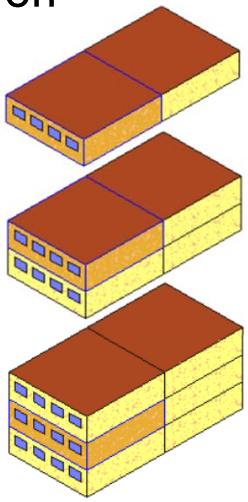
- Three typologies: semi-detached house (S/V = 0.97 m^{-1}), penthouse (S/V = 0.63 m^{-1}) and intermediate flat in multi-story buildings (S/V = 0.3 m^{-1}).
- The considered configurations have windows only in one façade (east or south). Features typical of 1970s.
- A standard boiler coupled with radiators and on-off system regulation

Infiltration Rate (ACH)
Intermediate flat in multistory
0.06
Semi-detached houses
0.13
Penthouses
0.20



Method

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Residential buildings

Energy saving measures

Multi-objective optimization

Energy saving measures to be combined:

- Additional insulating layer of EPS with thermal conductivity 0.04 W m^{-1} K^{-1} (from 1 to 20 cm) on the external surface of:
  - non-adiabatic walls
  - exposed ceiling
  - floor (only for the semi-detached houses);
- High performance frames and glazings (i.e., double or triple pane with either high or low solar heat gain coefficients);
- Modulating or condensing boiler, equipped with a climatic adjustment of the supply temperature;
- Mechanical ventilation with heat recovery system.

Prices from regional price list and the national authority of gas and electricity. Investment analysis lifespan 30 years.

Method

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Multi-objective optimization

Elitist Non-dominated Sorting Genetic Algorithm: with some code customizations regarding sampling, crossover, mutation and selection procedures.

1. First generation selection by Sobol (n=128 individuals)
2. NPV and primary energy (EPh) evaluation
3. Selection of m dominant solutions (temporary Pareto-Elite)
4. Selection of (n – m) couples of parents by Tournament selection without replacement (1 from each 4-plets)
5. New generation by weighting average of parents
6. Mutation on 20 % of the children
7. Step 2 again for the new generation
8. Selection of dominant solutions from the new generation and the previous Elite
9. Again from step 4 on

Results

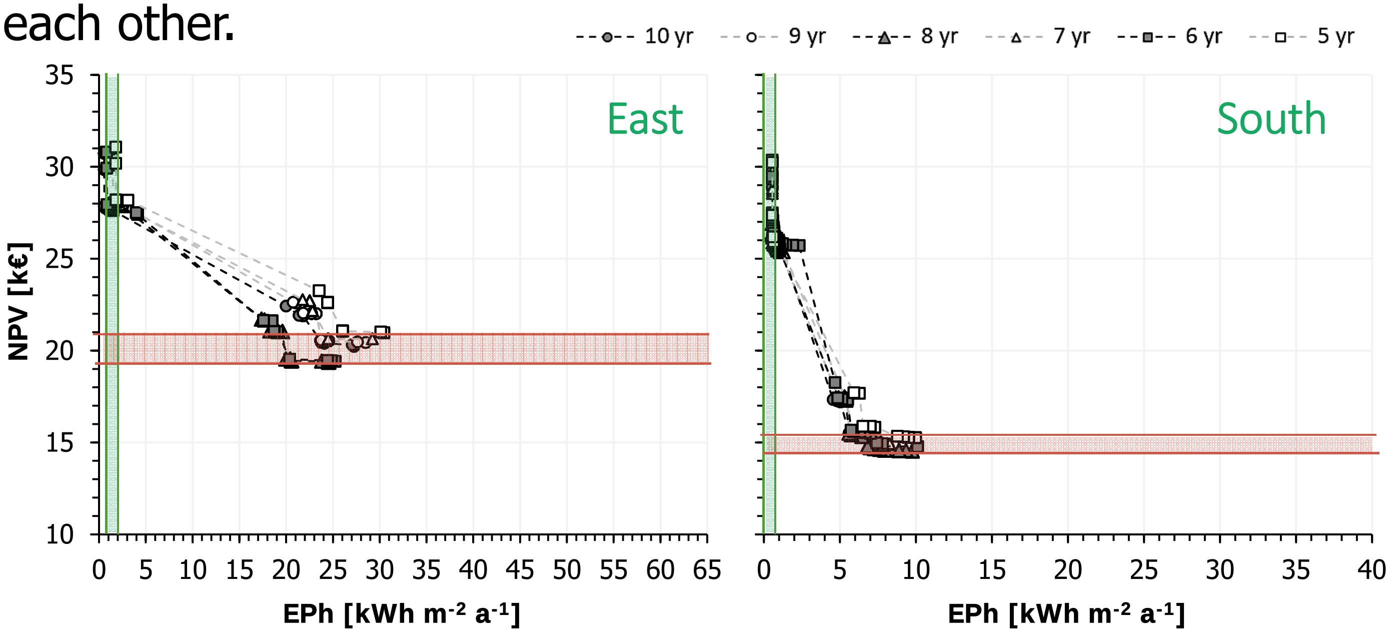
S/V = 0.30 m^{-1}

S/V = 0.63 m^{-1}

S/V = 0.97 m^{-1}

Pareto front:

two groups: optimal solutions with mechanical ventilation system (MVS) in the higher-left part of the diagram and those with natural ventilation in the lower-right part.
In some cases, Pareto fronts for different TRY intersect each other.



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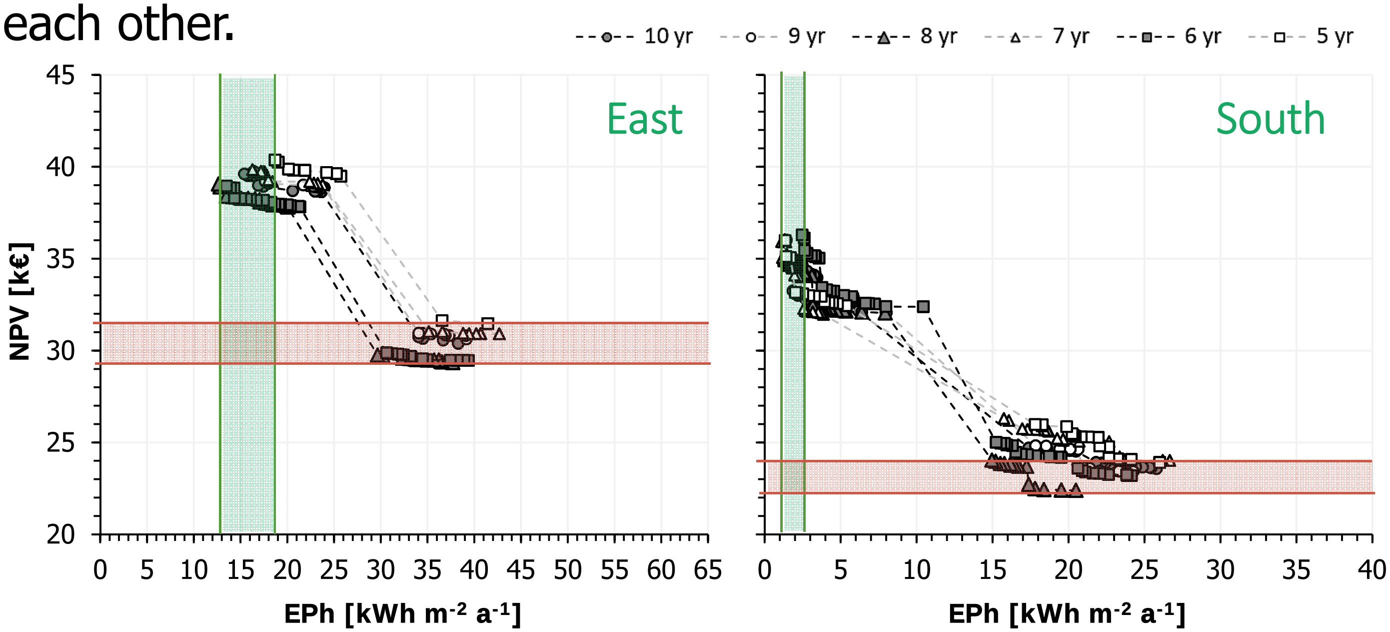

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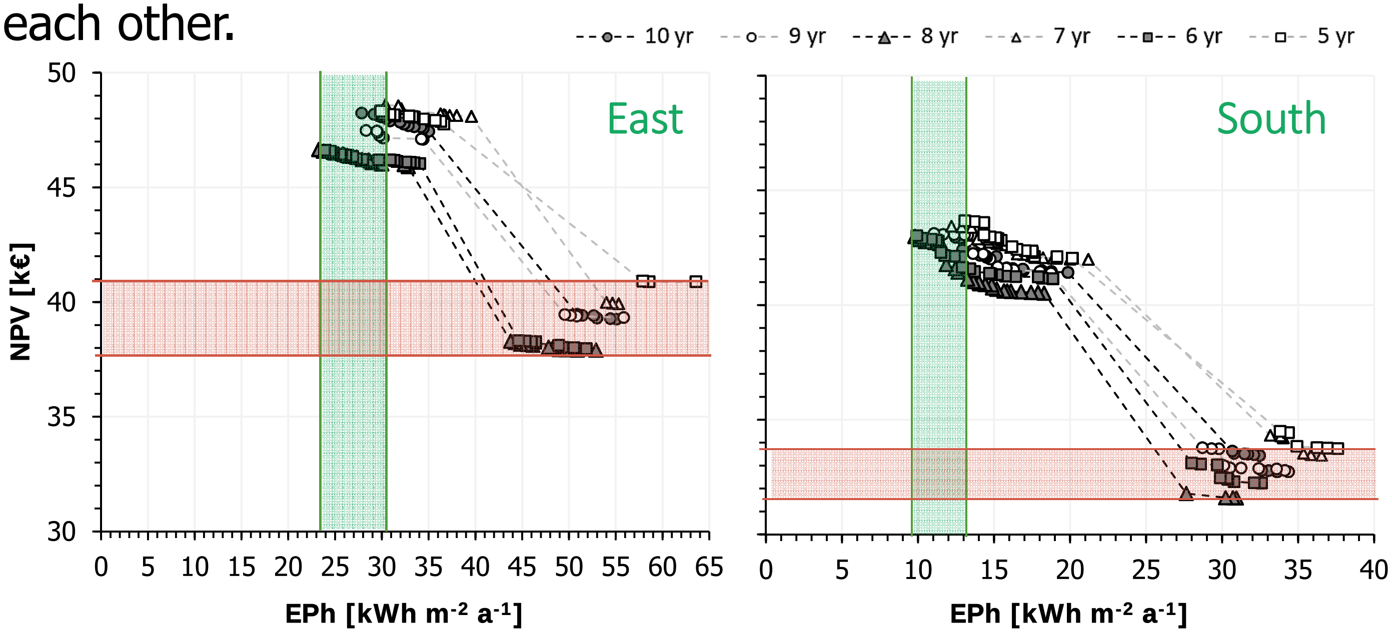

Results

Optimal solutions in reducing NPV

	East windows orientation						South windows orientation					
	Insulation thickness [cm]			Win	Boiler	Ven	Insulation thickness [cm]			Win	Boiler	Ven
	Wall	Roof	Floor				Wall	Roof	Floor			
Intermediate flat in multi-story buildings S/V = 0.30 m^{-1}												
10 yr	19			DH	Std	Nat	17			DH	Std	Nat
9 yr	18			DH	Std	Nat	18			DH	Std	Nat
8 yr	18			DH	Std	Nat	12			DH	Std	Nat
7 yr	18			DH	Std	Nat	18			DH	Std	Nat
6 yr	17			DH	Std	Nat	13			DH	Std	Nat
5 yr	18			DH	Std	Nat	17			DH	Std	Nat
Penthouse S/V = 0.63 m^{-1}												
10 yr	18	17		DH	Cond	Nat	17	15		DH	Std	Nat
9 yr	18	17		DH	Cond	Nat	19	15		DH	Std	Nat
8 yr	18	17		DH	Mod	Nat	19	15		DH	Std	Nat
7 yr	16	15		DH	Cond	Nat	17	16		DH	Std	Nat
6 yr	17	16		DH	Mod	Nat	16	16		DH	Std	Nat
5 yr	18	18		DH	Cond	Nat	16	17		DH	Std	Nat
Semi-detached houses S/V = 0.97 m^{-1}												
10 yr	19	19	18	DH	Mod	Nat	17	18	17	DH	Mod	Nat
9 yr	16	17	17	DH	Cond	Nat	17	17	17	DH	Mod	Nat
8 yr	16	15	16	DH	Cond	Nat	17	16	17	DH	Mod	Nat
7 yr	18	18	17	TH	Mod	Nat	18	17	17	DH	Mod	Nat
6 yr	17	17	15	DH	Cond	Nat	17	17	17	DH	Mod	Nat
5 yr	17	18	17	DH	Mod	Nat	18	16	18	DH	Mod	Nat

Results

Optimal solutions in reducing EP_h

	East windows orientation						South windows orientation					
	Insulation thickness [cm]			Win	Boiler	Ven	Insulation thickness [cm]			Win	Boiler	Ven
	Wall	Roof	Floor				Wall	Roof	Floor			
Intermediate flat in multi-story buildings S/V = 0.30 m^{-1}												
10 yr	20			TH	Cond	MVS	13			TH	Cond	MVS
9 yr	20			TH	Std	MVS	13			TH	Std	MVS
8 yr	20			TH	Std	MVS	13			TH	Std	MVS
7 yr	20			TH	Cond	MVS	15			TL	Cond	MVS
6 yr	20			TH	Cond	MVS	20			TL	Cond	MVS
5 yr	20			TH	Cond	MVS	19			TL	Cond	MVS
Penthouse S/V = 0.63 m^{-1}												
10 yr	20	19		TH	Cond	MVS	20	20		TH	Cond	MVS
9 yr	19	19		TH	Cond	MVS	20	20		TH	Mod	MVS
8 yr	20	20		TH	Cond	MVS	20	20		TH	Cond	MVS
7 yr	20	19		TH	Cond	MVS	20	20		TH	Cond	MVS
6 yr	19	19		TH	Cond	MVS	20	20		TH	Cond	MVS
5 yr	19	19		TH	Cond	MVS	20	20		TH	Cond	MVS
Semi-detached houses S/V = 0.97 m^{-1}												
10 yr	20	20	20	TH	Cond	MVS	19	19	18	TH	Cond	MVS
9 yr	18	18	19	TH	Cond	MVS	19	19	19	TH	Cond	MVS
8 yr	19	19	20	TH	Cond	MVS	19	20	19	TH	Cond	MVS
7 yr	19	20	19	TH	Cond	MVS	19	19	19	TH	Cond	MVS
6 yr	19	19	19	TH	Cond	MVS	19	19	20	TH	Cond	MVS
5 yr	18	20	19	TH	Cond	MVS	19	19	19	TH	Cond	MVS

Conclusions

Overview

Outcomes

Overview:

- the effects of insufficiently long historic weather series in the TRY definition have been assessed
- the robustness of a genetic algorithm, the Elitist Non-dominated Sorting Genetic Algorithm, in multi-objective optimizations for building energy refurbishment to suboptimal TRY has been considered
- the optimal retrofit solutions for six reference buildings have been determined and compared for TRYs obtained from weather series of different lenghts for Trento

Conclusions

Overview

Outcomes

Outcomes:

- Pareto fronts, in some cases, lead to different optimal values and to different optimal configurations:
- (a) minimum NPV is sensitive to the TRY especially for East orientation and larger S/V
- (b) minimum Eph increases with S/V and is sensitive to TRY, more for East and larger S/V
- As for the optimal ESMs configurations:
    - the insulation level and the boiler replacement have the largest variability, especially for NPV optimization
    - the selection of the best solution for window substitution is more robust to the weather inputs
    - as regards the ventilation, there is no sensitivity at all for the considered buildings

THANK YOU FOR YOUR ATTENTION!

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