Aalto University
School of Science
and Technology

BUILDING ENERGY OPTIMISATION- SELECTION OF HEATING SYSTEMS

Ala Hasan, PhD
Aalto University
School of Science and Technology
Department of Energy Technology

Introduction

In the design of buildings and related heating/cooling systems, it is normally first to work on reducing the energy need on the building side (e.g. better windows, more tightness, more insulation etc). Then to go for investigation on the energy systems.

But this is not the optimal method because the problem should be taken integrally as one-problem (building + systems + production).

Questions

- **to what extent we shall invest in better quality (and more expensive) components in the building envelope?**
- **where and when we shall look at the energy conversion and production systems?**
- **what are the optimal combinations of renewable energy types, Heating/cooling systems and building envelope components if the target is minimising one or more objectives (e.g. energy, emissions, costs, thermal discomfort etc)?**
- **…**
- **How?**

Multi-objective Combined Simulation and Optimisation (Simulation-Based Optimisation)

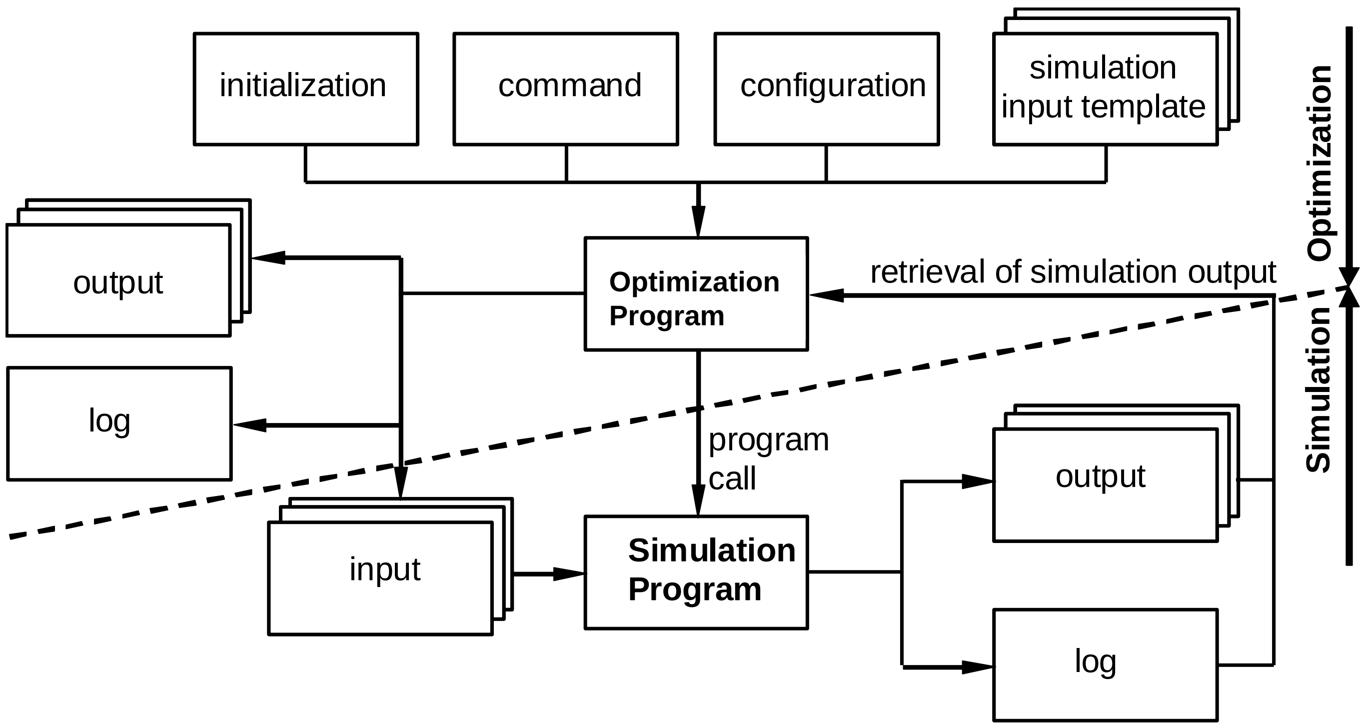
Objective:

minimisation of: energy consumption, investment cost, CO_2 emissions, LCC, …
maximisation of: efficiency, indoor comfort, …

Variable parameters:

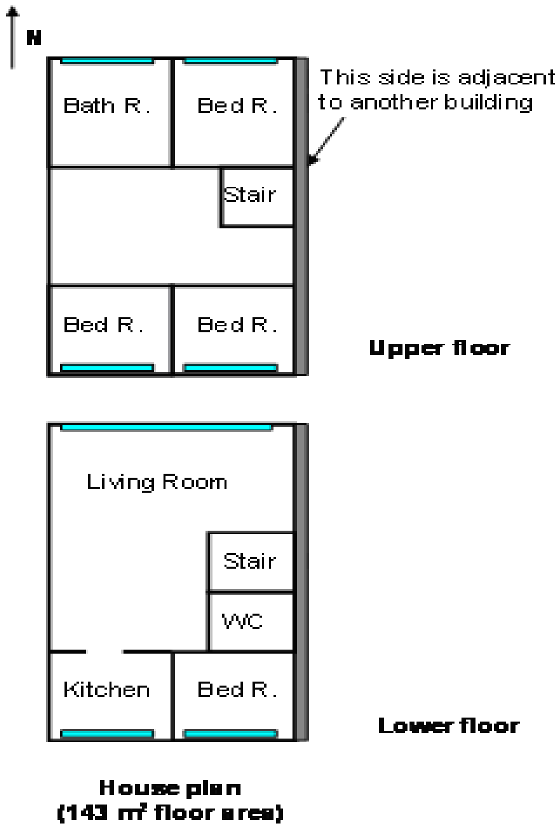
building envelope parameters, heating/cooling system types and components, control, HVAC equipments, energy production …

METHOD


initialization
command
configuration
simulation
input template
Optimization
output
Optimization
Program
retrieval of simulation output
log
program
call
Simulation
output
input
Simulation
Program
log

Case Study

A typical attached Finnish house
Helsinki weather file
Heating system to keep indoor air temperature at 21 C
AHU with supply air temp. 18 C at 0.65 ach
Hourly profiles for internal gains



INITIAL DESIGN OF THE HOUSE

U-values according to Finnish building code (C3-2007)

	External Wall	External Ceiling	External Floor	Window
U-value (W/m^2K)	0.24	0.15	0.24	1.4

Heat Recovery 70%

Building tightness n50= 4 ach

Problem Formulation

Minimisation of two objective functions:

- CO_2 emissions for heating energy
- Investment cost of the design variables

Design Variable	Variable Type	Initial design	Lower Bound	Upper Bound
Insulation thickness in external wall (m)	Continuous	0.124	0.024	0.424
Insulation thickness in roof (m)	Continuous	0.21	0.11	0.51
Insulation thickness in floor (m)	Continuous	0.14	0.04	0.44
Window type	Discrete	1	1	5
Heat recovery type	Discrete	1	1	3
Shading type	Discrete	1	1	2
Building tightness type	Discrete	1	1	5
Heating/cooling system type	Discrete	1	1	5

8 x 8 x 8 x 5 x 3 x 2 x 5 x 5 = 384 000
384 000 x 2 minutes = 533 days!!!

Heading/Cooling systems

Type	System	Electric Radiator	Water Radiator	Floor Heating	Floor Cooling	Efficiency [%]	Emission Coeff. $kgCO_2$ /kWh
1	Direct Electric Heating (no cooling)	Yes				100	0.459
2	Oil Boiler (no cooling)		Yes			90	0.267
3	District Heating (no cooling)		Yes			100	0.226
4	GSHP (no cooling)			Yes		300	0.459
5	GSHP with free cooling			Yes	Yes	300	0.459

GSHP: Ground Source Heat Pump
CO2 emissions is due to Space heating and DHW heating

Window Type	U-Value $W/m^2.K$	Shortwave Shading Coeff.
1	1.4	0.656
2	1.1	0.656
3	1	0.53
4	0.85	0.482
5	1.1	0.437

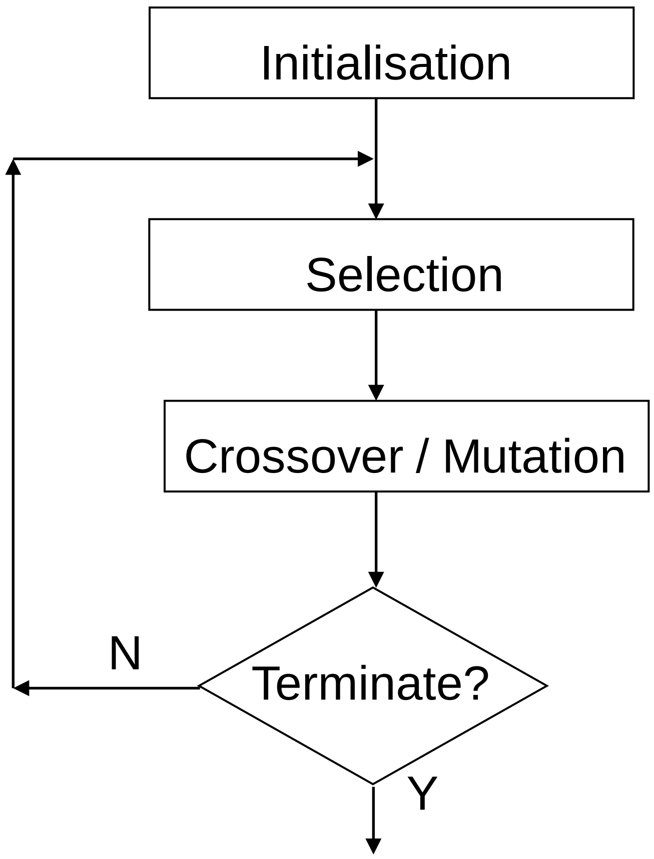
Heat recovery Type	Efficiency (%)	
1	60	plate type
2	70	rotary type
3	80	rotary type

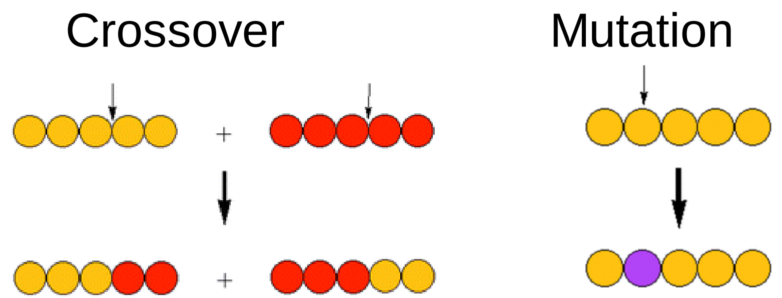
Window Shading	Total Shading coeff.	Shortwave Shading Coeff.	
1	0.14	0.09	External blind, horizontal laths
2	1	1	No shading

Building Tightness	n50 (ach)
1	4
2	3
3	2
4	1
5	0.5

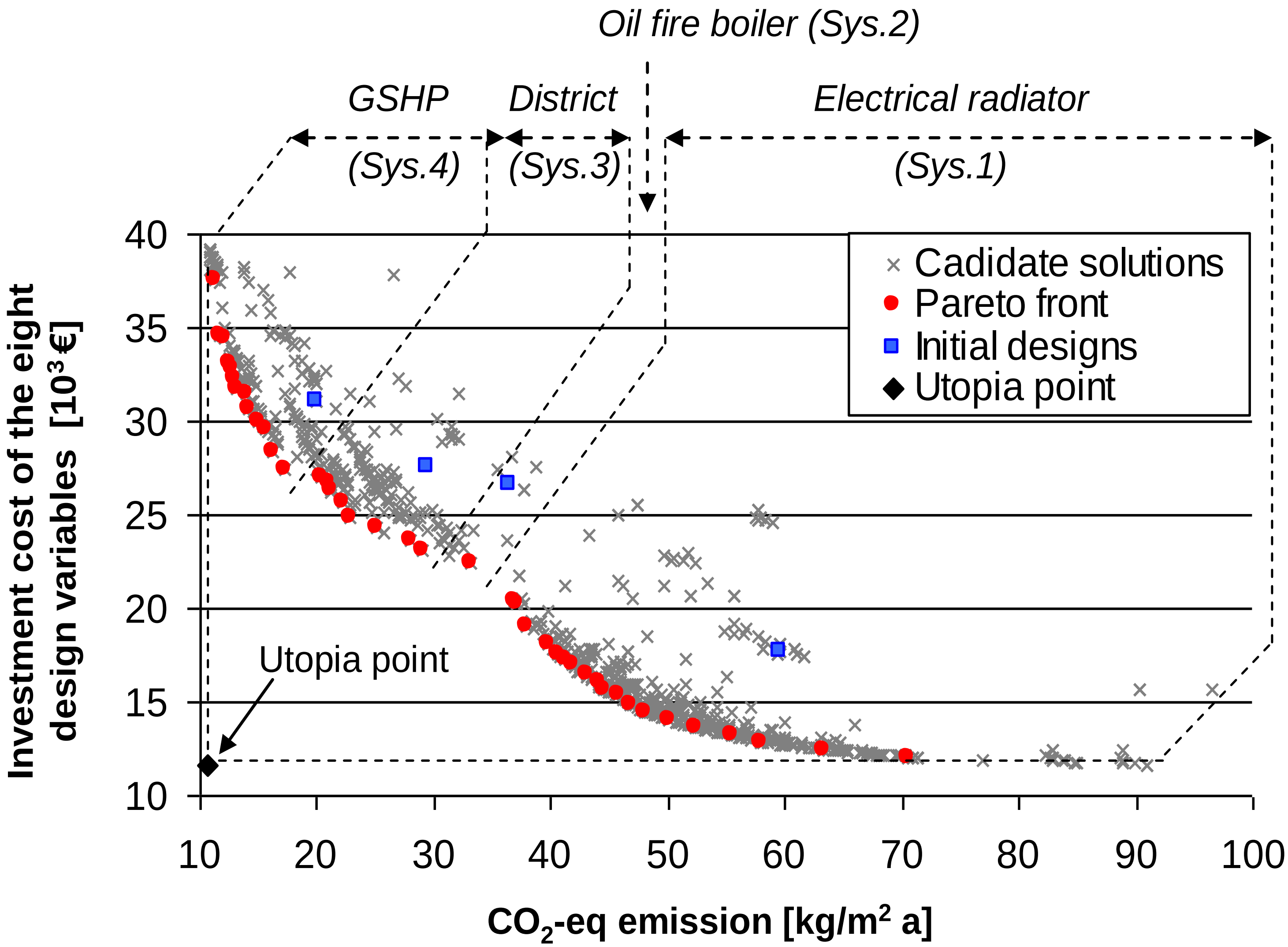
PRINCIPLES OF GENETIC ALGORITHM

A population of abstract representations (chromosomes) of candidate solutions (individuals) evolves toward better solutions

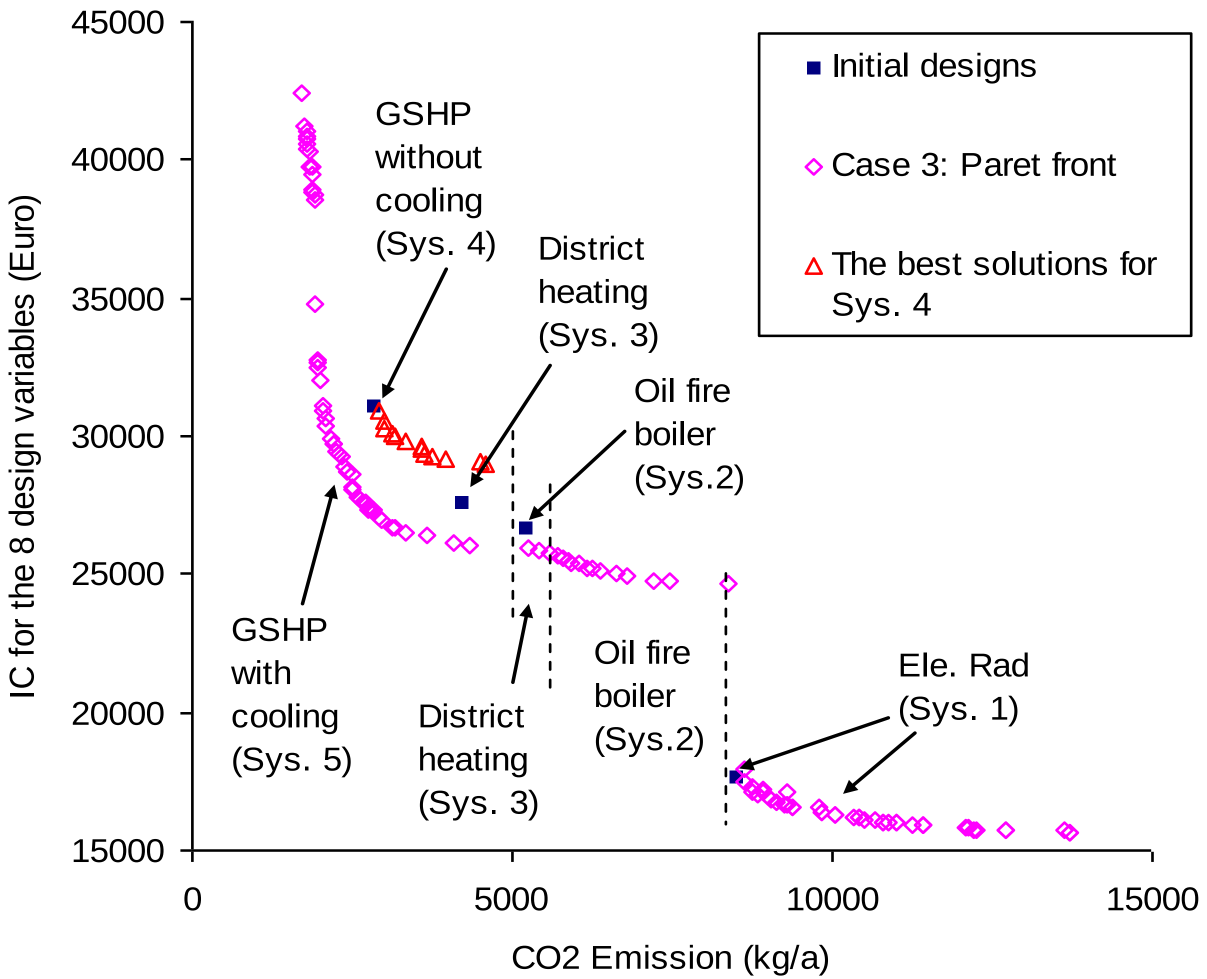




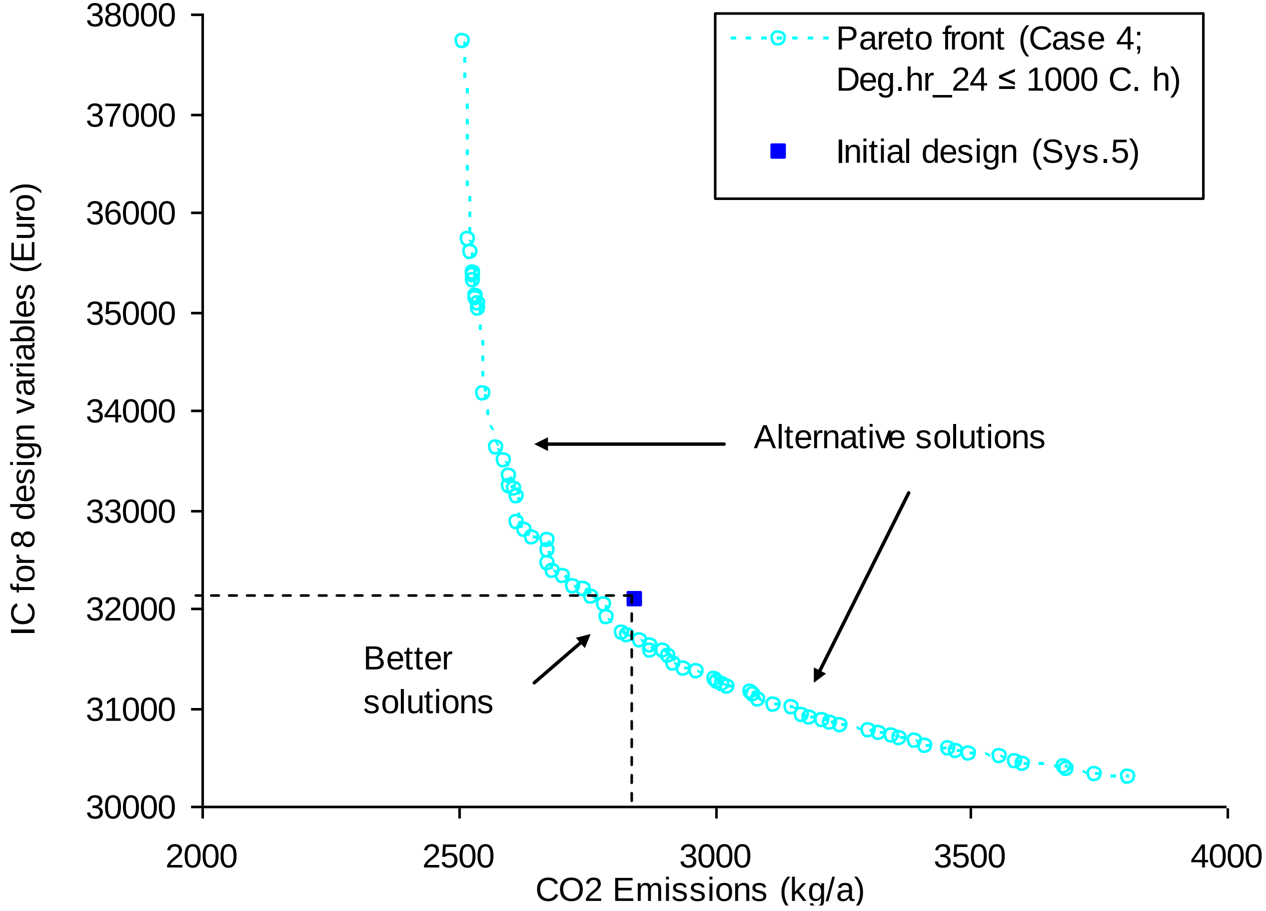
RESULTS



Note: deg.hr_24 < 6500 C.h **1010 Iterations**



Note: constraint deg.hr_24 < 2400 C.h **2787 Iterations**



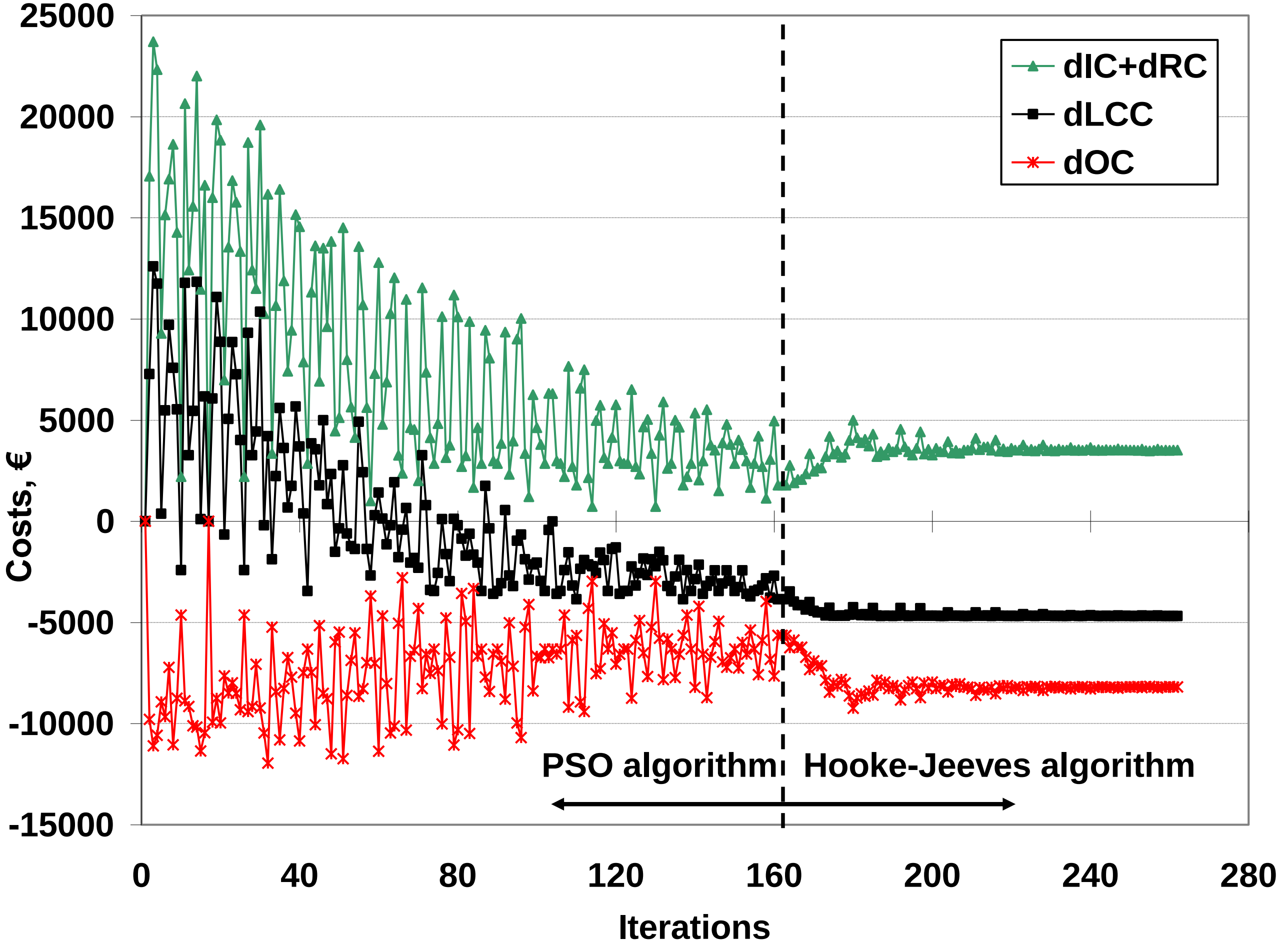
Note: Constraint deg.hr_24 < 1000 C.h **3500 Iterations**

MINIMISATION OF LIFE CYCLE COST OF A DETACHED HOUSE USING COMBINED SIMULATION AND OPTIMISATION

Single objective function:

dLCC = dIC + dOC + dRC

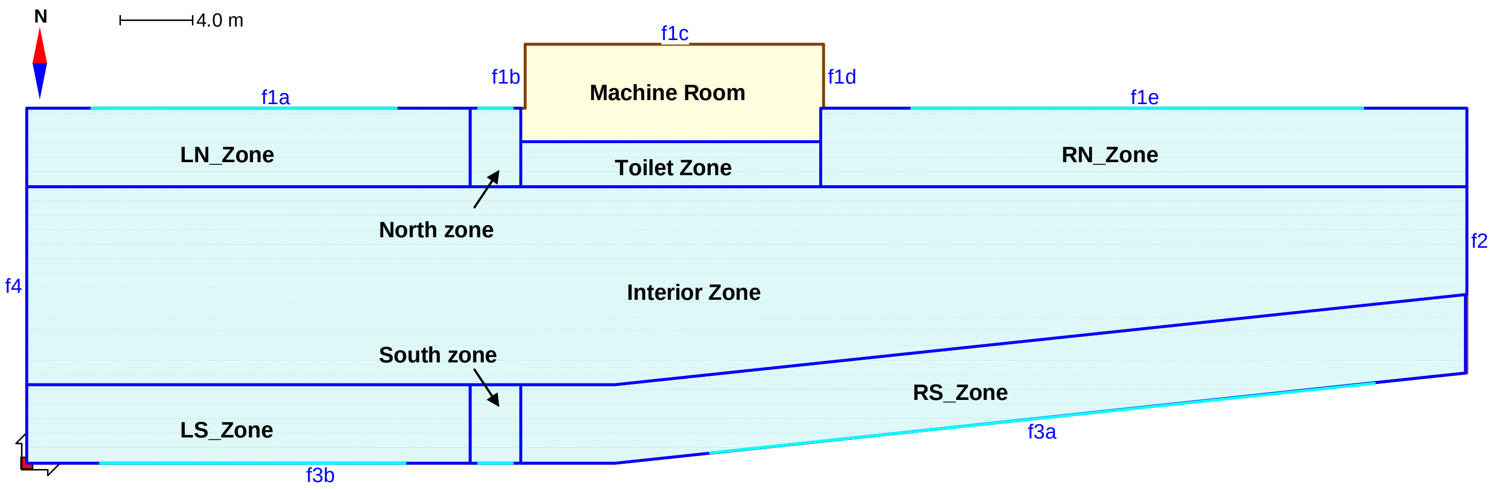
dIC	difference in investment cost for specified items
dOC	difference in operating cost due to difference in electric energy consumption of the heating system
dRC	difference in replacement cost due to replaced items in specified years



262 iterations
Approx. 3hrs

Iteration runs for the minimisation of dLCC

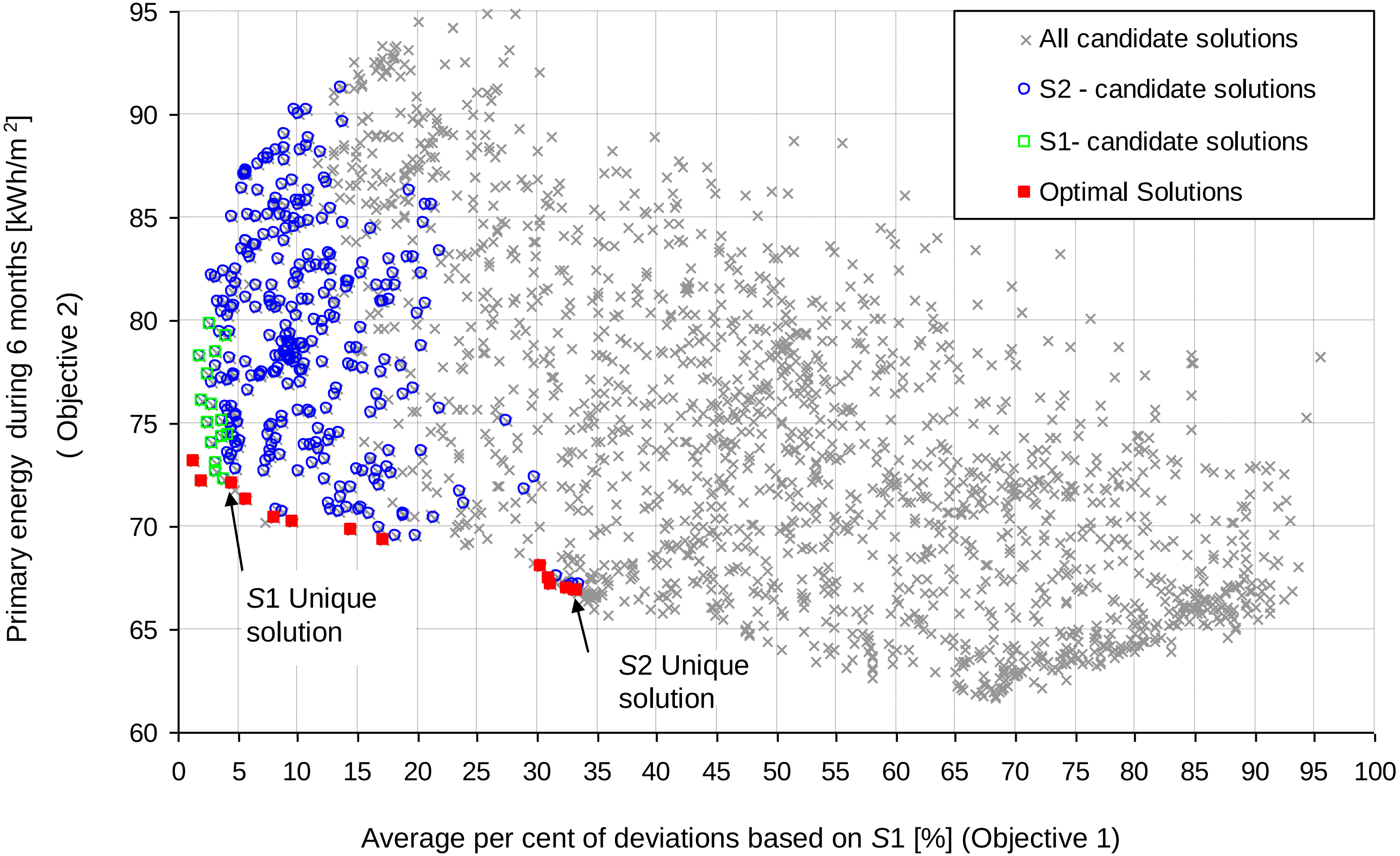
Optimal Solutions for High Level Thermal Comfort in Office Buildings



24 design variables

		ID	Design Variables	Initial	Min.	Max.
AHU	Supply air Temp. Profile	X1	Tsupply at To <= 16 C	18	16	24
		X2	Tsupply at To >= 24 C	18	16	24
	Night Ventilation Control Strategy	X3	Minimum To (for night ventilation) (C)	12	5	20
		X4	Minimum temperature difference (Tr - To) (C)	2	1	3
		X5	Minimum Tr (at night ventilation) (C)	22	18	24
		X6	Supply air temp. drop during night ventilation (C)	10	5	10
		X7	Start hour (before the occupied period) (h)	7	0	7
		X8	Stop hour (after the occupied period) (h)	6	0	6
North Office	Cooling Beam	X9	Maximum power of cooling beam (W)	250	200	600
		X10	dT(coolant) at max power (C)	4	2	5
		X11	dT(coolant - zone air) at max power (C)	8	6	9
	Water Radiator	X12	Night set-back temp. of the water radiator (C)	21	18	21
		X13	Set-point temp. of the water radiator (C)	21	20	21.5
		X14	Dead band of the water radiator (C)	2	0.3	3
	Window	X15	Glazing U-value of the north facade (W/m2K)	1.1	1	2.5
		X16	Internal Shading	Medium	Light	Dark
South Office	Cooling Beam	X17	Maximum power of cooling beam (W)	300	200	600
		X18	dT(coolant) at max power (C)	4	2	5
		X19	dT(coolant - zone air) at max power (C)	8	6	9
	Water Radiator	X20	Night set-back temp. of water radiator	21	18	21
		X21	Set-point temp. of the water radiator (C)	21	20	21.5
		X22	Dead band of the water radiator (C)	2	0.3	3
	Window	X23	Glazing U-value of the south facade (W/m2K)	1.1	1	2.5
		X24	Internal Shading:	Medium	Light	Dark

RESULTS



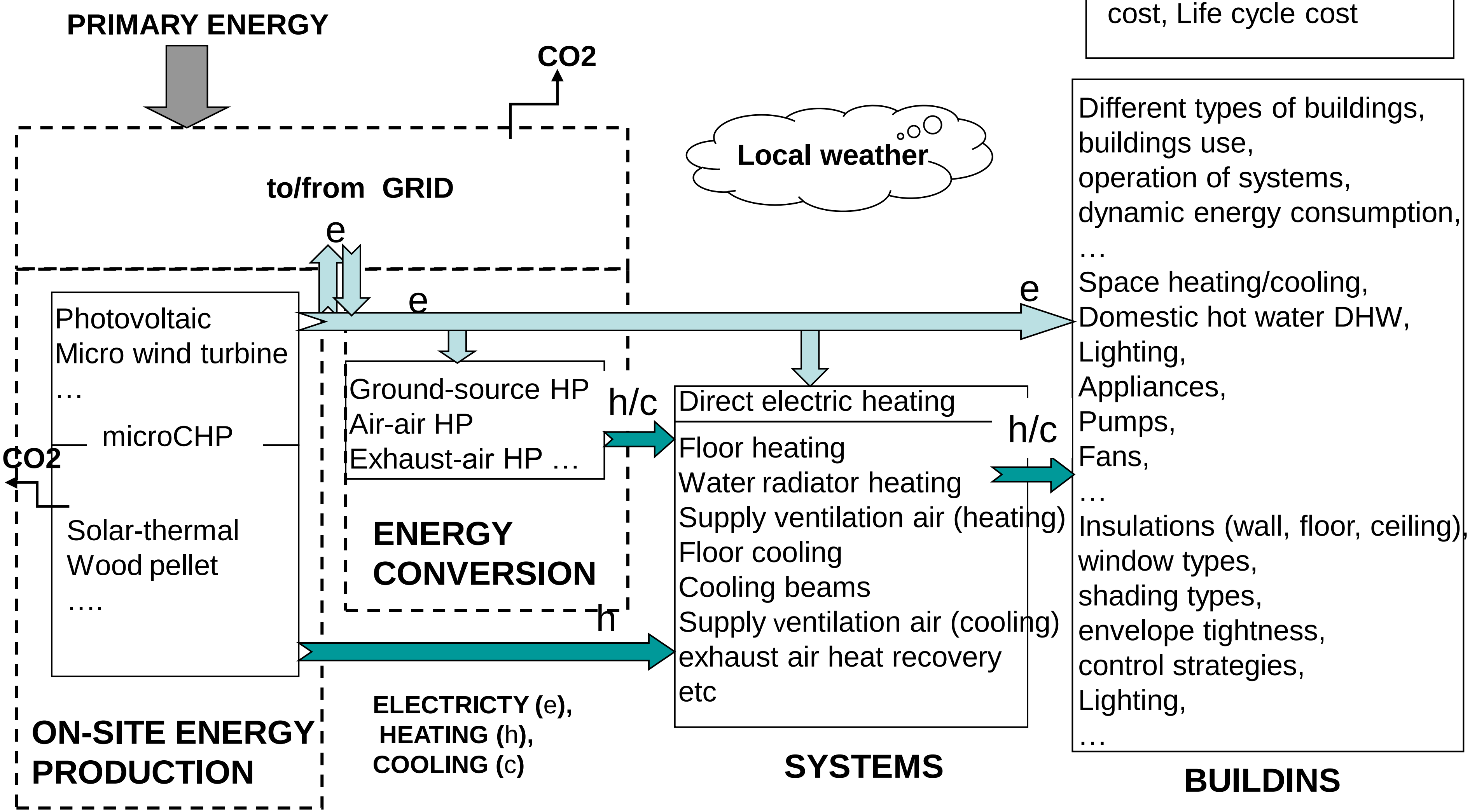
The trade-off relation between the primary energy consumption and the average percent of thermal comfort deviations

ZEB Concepts

Recast of the EPBD "All new buildings to be nearly zero energy buildings by the end of 2020"

Zero Energy Buildings Concepts
Net Zero Energy Buildings Concepts
Zero Emission Buildings Concepts
Net Zero Emission Buildings Concepts

Academy of Finland Research Fellow Position 2010-2015: Optimal Multi-Objective Design of Integrated Renewable Energy Systems and Buildings



ZERO (or NET ZERO) ENERGY BUILDINGS