



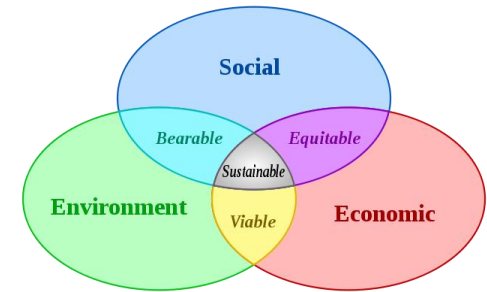
Youssef Hamadi, Microsoft Research

SMARTBUILDINGS

The Optimization for Sustainable Development Project

Vision

Computer scientists can — and should — play a key role in increasing the efficiency and effectiveness of the way we **manage and allocate our natural resources**, while enriching and **transforming Computer Science**.



Research agenda

The design of **efficient policies** to manage natural resources translates into **decision procedures** for large-scale optimization, in a highly dynamic and uncertain environment (stochastic), which combines a mixture of discrete and continuous effects (multi-objective) → Long term fundamental research on stochastic multi-objective algorithms.

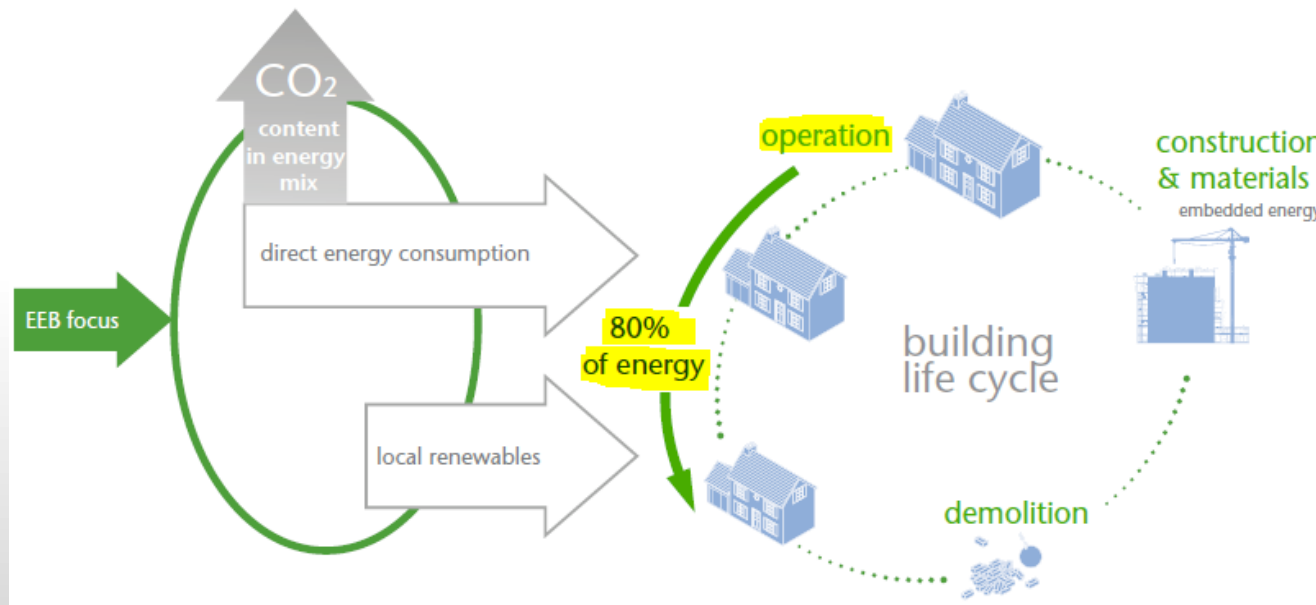
Application domains

- Outages of nuclear power plants,
- Smart-grid,
- Waste management,
- Building industry,
- Etc.



SmartBuildings: Context and Motivation

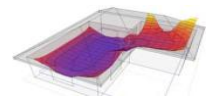
- Buildings worldwide account for 40% of global energy consumption*
- Resulting carbon footprint, significantly exceeding those of **all transportation** combined
- Buildings operation represents 80% of energy consumption:



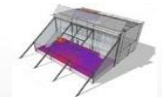
*World Business Council for Sustainable Development.

The State of the Art, BEMS

- Building Energy Modelling..
 - Heat transfer mechanisms: Conduction, Convection, Radiation
 - Control volumes and the conservation of Mass/Energy
 - Time dependent, air migration between zones
 - Electric light adjustment
- .. and Simulation:
 - Location – weather data
 - Orientation
 - Comfort level
 - Over a year



Thermal insulation



Natural light



Spatial integration



buildings.energy.googleusercontent.com/data/energyplusweatherdata.kml

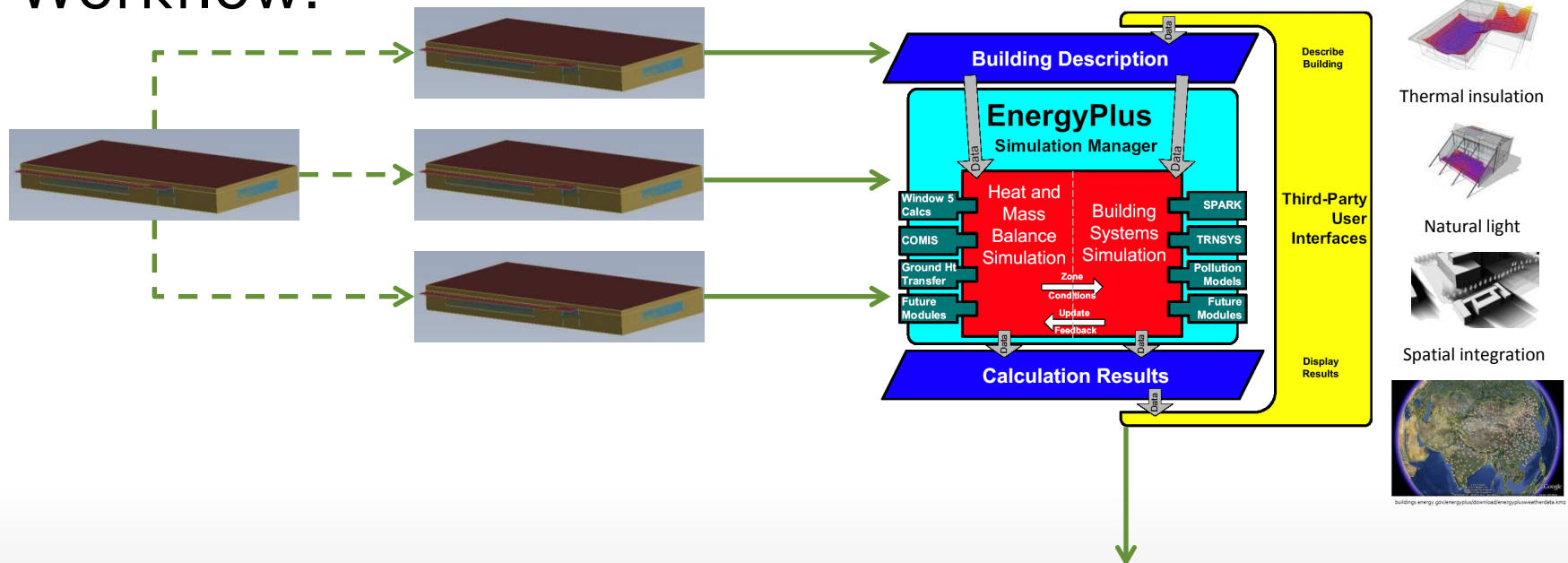
Building Energy Modelling and Simulation

- Early 1970s: energy crisis
 - Major component: building energy consumption
- Late 1970s: **BLAST** – *Building Load Analysis and System Thermodynamics*
 - U.S. Department of Defense (DOD)
- Early 1980s: **DOE-2** – Analysis of building energy consumption
 - U.S. Department of Energy (DOE)
- 2001: **EnergyPlus** – Analysis of energy consumption and thermal load simulation
 - Merging of BLAST and DOE-2
 - by U.S. Department of Energy (DOE)
 - Active community, regular workshops, tutorials, etc.
 - Journals, conferences *Building Simulation*, *SimBuild*, *e-Sim*, etc.
 - E.g. [Building Simulation 2009](#) = 218 articles + 100 posters.



The State of the Art

Workflow:



Baseline Description	Net Present Value	Discounted Payback Period	Savings to Investment Ratio	Adjusted Internal Rate of Return	Energy Use Reduction		CO2 Emissions Reduction	
					MMBtu	%	Metric Tons	%
Baseline 1	\$6,775	11.88	1.339	9.87%	1365.2	15.47%	224.73	18.27%
Baseline 2	\$2,604	5.93	2.302	13.63%	800.0	9.06%	42.56	3.46%
Baseline 3	\$10,689	3.98	3.138	16.13%	1082.6	12.27%	133.64	10.87%
Baseline 4	(\$1,450)	NEVER	0.974	7.83%	2730.4	30.94%	449.46	36.54%

SmartBuildings

- Objective. **Automatically discover the most efficient variations of a given building design**
- Approach
 - Non intrusive - minimize aesthetic impact, e.g., can only change inner layers of materials
 - Assume 'don't care' variables in any design..
 - Designer gives Constraints which define a search space
- Exploit critical points
 - Thermal efficiency of walls and windows
 - Windows and doors placement and size
 - Building orientation
 - HVAC placements
- **Multi-objective optimization problem**
 - Thermal efficiency vs. Construction cost

SmartBuildings: Modelling I

- Orientation of the building:
 - 1 variable: [0, 359] //restrict or set if urban constr.
- Per external wall:
 - 8 variables: [0, 32] //up to 8 inner insulation layers

#	Cost	TR	#	Cost	TR	#	Cost	TR
1	1.67	1.10	12	2.77	2.55	23	5.99	1.15
2	2.30	1.50	13	2.97	2.50	24	6.24	1.20
3	2.42	1.53	14	3.12	1.20	25	6.34	1.60
4	2.48	1.50	15	3.35	1.20	26	7.64	2.15
5	2.62	2.00	16	3.87	2.10	27	8.55	2.65
6	2.62	2.00	17	4.08	2.00	28	8.92	2.35
7	2.63	2.00	18	4.58	2.00	29	8.95	2.65
8	2.65	1.26	19	4.71	5.10	30	9.73	3.15
9	2.67	2.50	20	4.74	0.55	31	9.97	1.75
10	2.72	2.04	21	5.35	1.10	32	10.18	1.80
11	2.73	2.50	22	5.82	5.00	33	10.18	2.40

Table 2: Corresponding cost (in €/m²) and thermal resistance (TR in m² · K/W) for each of the insulation materials considered by the optimization process.

SmartBuildings: Modelling II

- Per window

- 1 variable: $[-0.3, 0.3]$
- Hard constraints:
 - Keep aspect ratio
 - Keep center point

//scalability factor



- Remarks

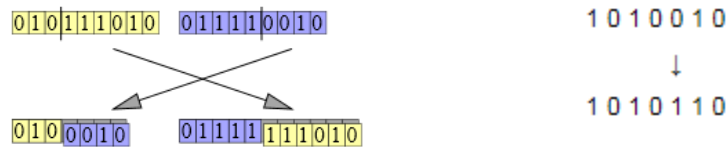
- Large windows are less thermal-efficient than walls
 - -> more energy from HVAC
- Large windows provide more daylighting
 - -> less energy for artificial lightning
 - But, electric lighting produces heat..
 - -> less/more energy from HVAC

SmartBuildings: Search

Genetic Algorithm

- Building = Solution = bit string of the previous variables

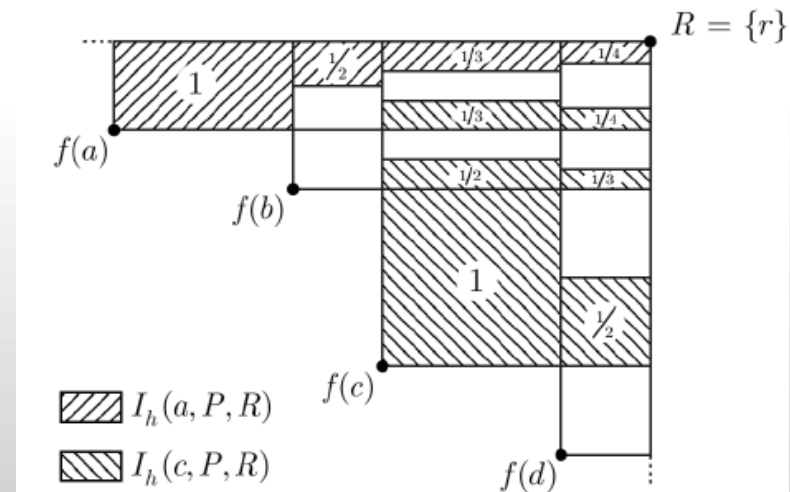
1. Original population size 40
2. 1-point crossover (0.8) + Mutation (0.1) + Ident (0.1)



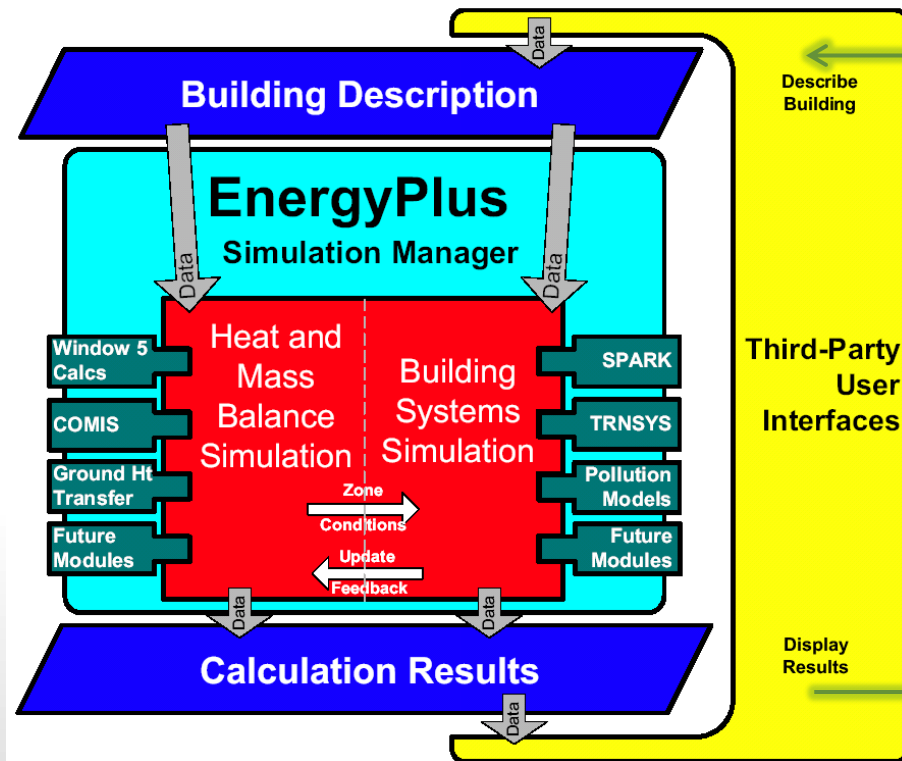
3. 80 new individuals
4. Selection over 40 + 80 individuals

Hype-credit assignment:

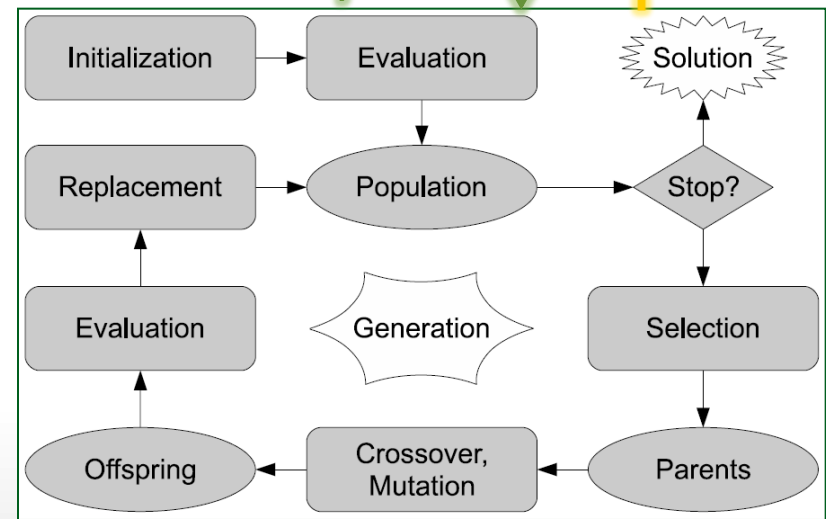
5. New population of size 40



SmartBuildings

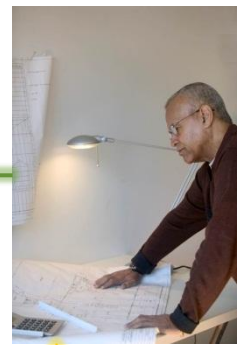


Candidate designs



Evaluation

Original design



Efficient design(s)



Experiments: Settings

- Buildings:
(official DoE Benchmarks)

Building Name	Area (m^2)	Floors	Zs	Ws	SimTime
Large Office	46320	12	19	12	3m17s
Hospital	22422	5	55	40	8m03s
Primary School	6871	1	25	33	4m47s
Midrise Appt.	3134	4	27	42	6m58s
Small Commerce	464	1	6	4	0m50s

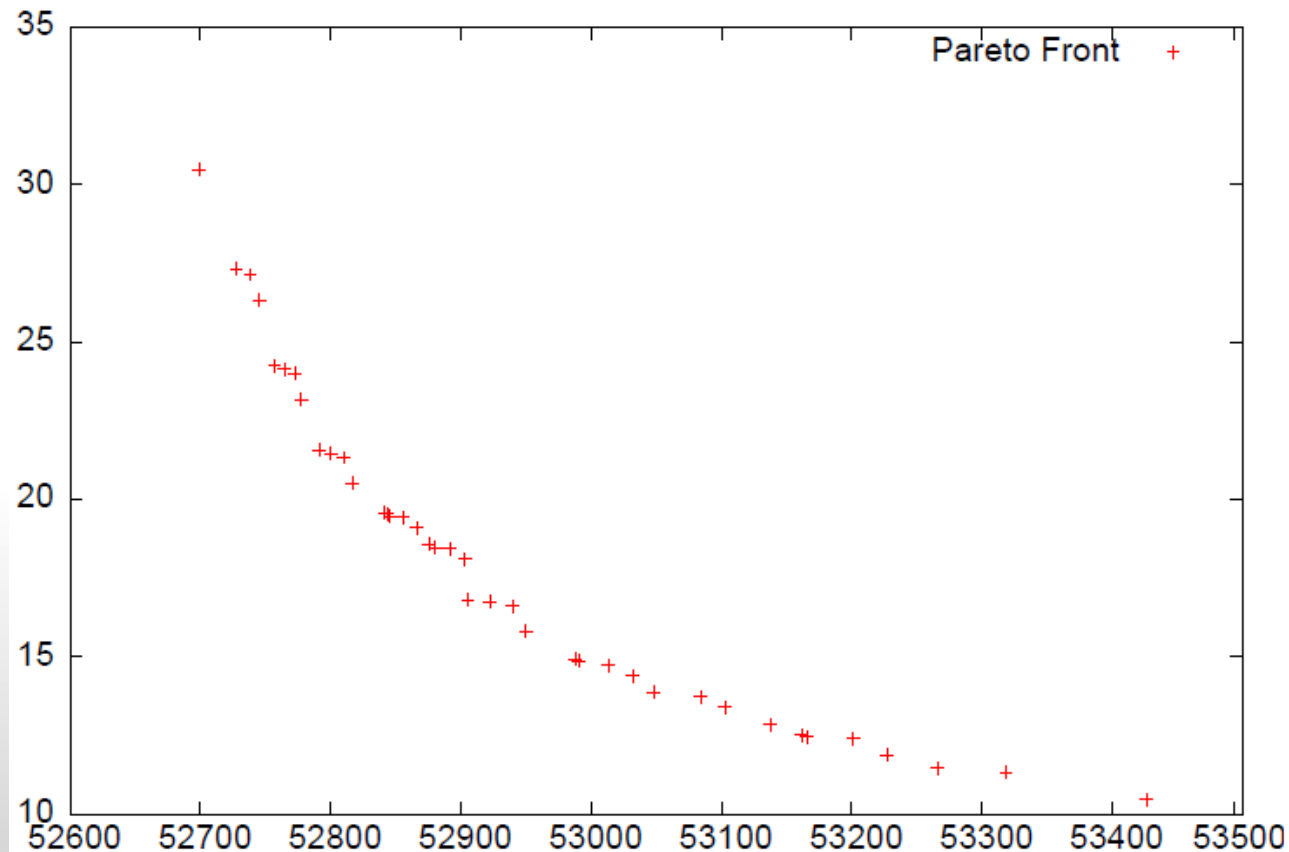
Table 1: Building types and corresponding characteristics (Zs = #thermal zones, Ws = #windows). SimTime represents the average time (over 10 runs) required for a complete simulation of energy consumption, run on a computer with an Intel Xeon 2,33 GHz CPU and 16 Gb of RAM.

- Location: Chicago,
Weather data: O'Hare International Airport
- Settings
 - Objective 1: minimize "Annual Total Site Energy" in kWh
 - Objective 2: minimize sum of costs of materials
 - 75 iterations, i.e., $40+80*75 = 6040$ simulations

Building Name	CPU days
Large Office	13.8
Hospital	33.8
Primary School	20.1
Midrise Appt.	29.2
Small Commerce	3.5

Experiments: more details

- **Small Commerce** (different experimental settings) :



Experiments: Results I

- Small Commerce (3.5 days CPU):

#	Energy (kWh)	Cost (€/m ²)	%gain to O	%gain to L
O	65735.2	??	Original	-
L	56247.3	??	14.43	Orig. Lights
1	50982	40.14	22.44	9.36
2	51070.5	28.75	22.31	9.20
3	51162.8	22.05	22.17	9.04
4	51307.8	17.54	21.95	8.78
5	51619.1	11.88	21.47	8.23

(e) Small Commerce

- Original design
- Original + light dimming
- Pareto front:
- #1 most energy efficient
- #5 most cost efficient

- Large Office (13.8 days CPU):

#	Energy (kWh)	Cost (€/m ²)	%gain to O	%gain to L
O	9.28297e+06	??	Original	-
L	8.89258e+06	??	4.21	Orig. Lights
1	7.90823e+06	34.96	14.81	11.07
2	7.91344e+06	27.94	14.75	11.01
3	7.92252e+06	22.84	14.66	10.91
4	7.93044e+06	19.03	14.57	10.82
5	8.17636e+06	11.98	11.92	8.05

(a) Large Office

Experiments: more details

- Small Commerce (different experimental settings) :

#	Angle	Windows	Materials	Energy	% gain
0				57977	0.0
1			X	54972	5.2
2		X		56660	2.3
3	X			56434	2.7
4		X	X	53064	8.5
5	X		X	53599	7.6
6	X	X		55966	3.5
7	X	X	X	52699	9.1

Experiments: The VALUE of the Cloud

Source: US Dept. of Labor, Bureau of Labor Statistics, April 2012

	United States	Chicago area	Percent difference
Electricity (per Kwh)	\$0.127	\$0.153	20.5

Source: Microsoft Azure Medium size, June 2012

CPU hour	\$0.24		
Small Commerce	Design "L" (kWh)	56247.30	
	Design "1" (kWh)	50982.00	
	Savings /year	5265.30	\$805.59
	CPU (days)	3.50	\$20.16
Large Office	Design "L" (kWh)	8892580.00	
	Design "1" (kWh)	7908230.00	
	Savings /year	984350.00	\$150,605.55
	CPU (days)	13.80	\$79.49

Summary

- Buildings worldwide account for 40% of global energy consumption
- Buildings operation represents 80% of energy consumption
- SmartBuildings. **Automatically discover the most efficient variations of a given building design**
- Exploit under specified input
- 5-25% increase in thermal efficiency

Status

- Official *Azure HPC* demo at SuperComputing'11
- Extensions
 - Objective 3: minimize Water Consumption..
 - Objective 4: maximize day lighting...
 - HVAC placements, etc.
 - .. there are more 'don't care' variables for a building designer..
 - Surrogate Optimization
- More details and results:

Álvaro Fialho, Youssef Hamadi, Marc Schoenauer: A Multi-objective Approach to Balance Buildings Construction Cost and Energy Efficiency. ECAI 2012: 961-966