

PRE-DESIGN INFORMATIVE BUILDING SIMULATIONS FOR IMPROVING THE EARLY DESIGN PROCESS

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**AALBORG UNIVERSITY
DENMARK**

Agenda

About me

Challenges – perspective of the architectural engineer

Proposed methods

- Uncertainty analysis (UA) and sensitivity analysis (SA)

Status on the project

Examples on “pre-design information”

- Output distribution (UA)
- Sensitivity analysis
- Monte Carlo Filtering

What's next

Questions and comments?

About me

- Name / nimi = Torben Østergård
- Industrial PhD student
 - Enrolled at Aalborg University, Denmark
 - Employed by **MØE**
Consulting | Engineering, Denmark & Norway, ~550 employees
- 3 years – June 2014 → May 2017
- Spare time (hopefully)?
 - Sports (climbing), travelling and much more



PRE-DESIGN INFORMATIVE SIMULATIONS – PAGE 3 - 27/09/2014

DEPARTMENT OF CIVIL ENGINEERING / ARCHITECTURAL ENGINEERING
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Challenges (some of them)

Increasing regulatory demands

- Many objectives and increasing use of LEED, BREEAM, DGNB
→ Need for holistic approach
- Multiple software packages and time-consuming model generation

Cooperation with architects

- Keep up with the pace of change in *early design* phase
- Provide *prompt* and relevant decision support
- Foresee challenges and/or consequences
- Foresee favorable design input *regions*

Deviations from expected and measured building performance

Methods of interest

Global sensitivity analysis (SA) and uncertainty analysis (UA)

- Stochastic modelling with input *distributions* → more information
- Demonstrate worst-case / best-case scenarios
- Highlight *most important* input (concurrently changing)
- Indicate favorable and unfavorable regions of input domain
- Indicate design robustness

Evaluate separate (relevant) objectives simultaneously

- e.g. energy consumption, overheating, daylight factor, embodied energy etc.

Generate knowledge-based input databases for quicker modelling

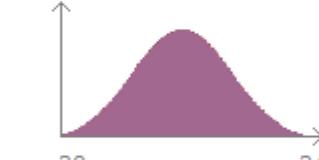
UA / SA – A quickie

1. Determine input distributions

X_1 : U-value (uniform)



X_2 : Heating SP (normal)



X_3 : Pump type (discrete)



⋮

X_n

2. Run building simulations (Monte Carlo)

→ $k = 100 + \text{times}$

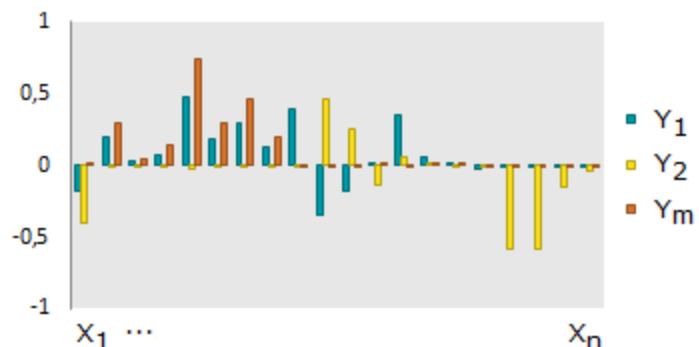
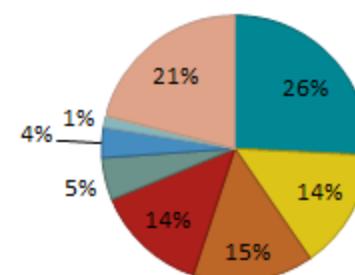
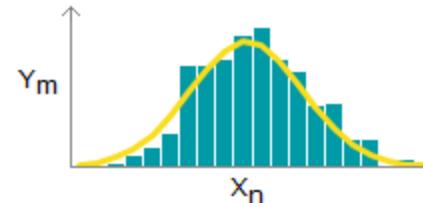
Simulation program(s)

$Y_1(X_1, X_2, \dots, X_n) = \text{Energy Need}$
 $Y_2(X_1, X_2, \dots, X_n) = \text{Daylight Factor}$
⋮
 $Y_m(X_1, X_2, \dots, X_n)$

e.g. EnergyPlus, BSim, Be10,
IDA-ICE, IES-VE, EcoTect, etc.

3. Perform and present SA + UA

↳ e.g. SRC, SRRC, FAST, Sobol,
Anova, Monte Carlo Filtering



PRE-DESIGN INFORMATIVE SIMULATION

Status on the project

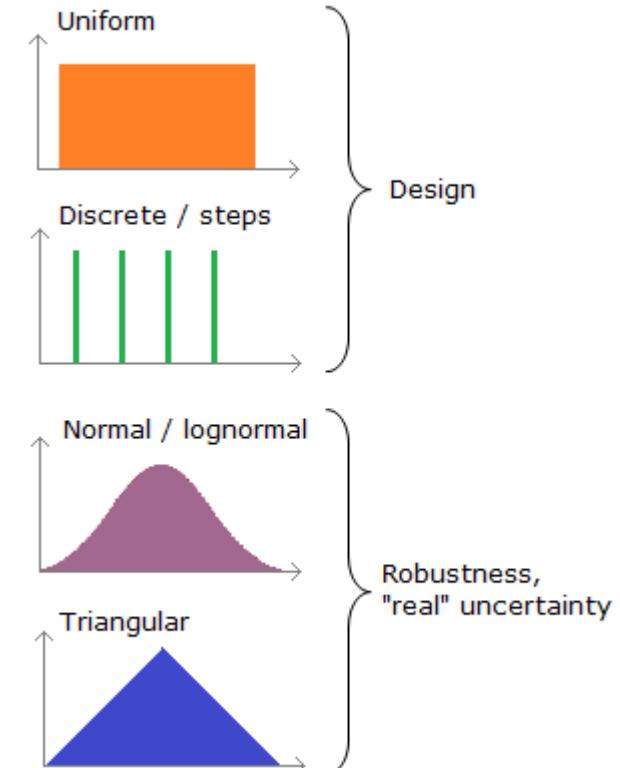
Prototype using Excel VBA and simple “engines”
(used for building compliance in Denmark)

- Energy model – Be10 (EN 13790, DK)
- Thermal module – “Summer comfort” (EN 13790, DK)
- Glass/floor ratios (domestic buildings, DK)

Setting up input

Input til UA/SA

ID	Incl.	Bun.	Parameter	Unit	Category	Distribution	Min	Max	Steps
							dist1	dis	dis
#1	1		Heat capacity	Wh/K m ²	Quality	Steps	40	120	8
#4	1		U-value, roof	W/m ² K	Quality	Steps	0,08	0,15	10
#5	1		U-value, terrain	W/m ² K	Quality	Steps	0,1	0,15	10
#6	1		U-value, floor	W/m ² K	Quality	Steps	0,07	0,12	10
#7	1		U-value, wall	W/m ² K	Quality	Steps	0,1	0,2	10
#8	1		Linear heat loss, wi	W/m K	Quality	Steps	0	0,03	6
#9	1		Linear heat loss, fo	W/m K	Quality	Steps	0,2	0,6	8
#10	1		Linear heat loss, ba	W/m K	Quality	Steps	0,1	0,4	6
#11	1		U-value, windows	W/m ² K	Quality	Steps	0,6	1,2	12
#12	1		g-value, windows	-	Quality	Steps	0,4	0,65	10
#13	1		Frame factor	-	Form and function	Steps	0,7	0,9	8
#14	1		Shading factor	-	Form and function	Steps	-0,6	-0,95	10
#15	1		Horizon	%	Robustness	Steps	0	20	4
#16	1	a	Fins, left	%	Form and function	Uniform	0	15	8
#17	1	a	Fins, right	%	Form and function	Uniform	0	15	8
#18	1		Overhang	%	Form and function	Steps	0	40	8
#19	1		Opening	%	Form and function	Steps	0	15	6
#20	1		Ventilation, qvm	l/s m ²	HVAC	Steps	0,3	0,5	4
#21	1		Ventilation, qvm, d	l/s m ²	HVAC	Steps	0,3	0,5	4
#22	1		Venting, day	l/s m ²	HVAC	Steps	0,9	3,6	12
#23	1		Venting, night	l/s m ²	HVAC	Steps	0	2	8
#28	1	b	People load	W/m ²	Robustness	Steps	1	2	2
#29	1	b	Equipment load	W/m ²	Robustness	Steps	2	7	5
Total	23								

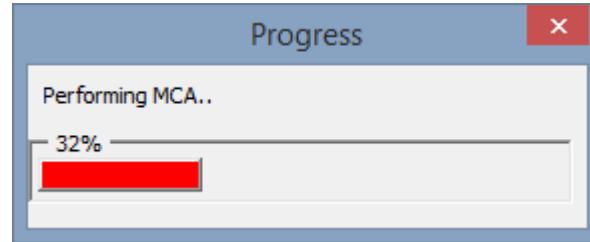


Setting up output

ID	Include	Parameter	Unit	Function
#1#	1	Net energy demand	kWh/m ²	#3# + #4# + #5#
#2#		Energy demand, DK regislation	kWh/m ²	
#3#		Heating demand	kWh/m ²	
#4#		DHW demand	kWh/m ²	
#5#		Electricity demand	kWh/m ²	
#6#		Overheating	kWh/m ²	
#7#		Lighting	kWh/m ²	
#8#		Ventilation	kWh/m ²	
#9#		Cooling	kWh/m ²	
#10#		Minor electricity contributions	kWh/m ²	#5# - #7# - #8# - #9#
#11#	1	Thermal comfort, h>26 C	h	
#12#		Thermal comfort, h>27 C	h	
#13#		Glass/floor-ratio	%	
#14#	1	Transmission loss (envelope)	W/m ²	
#15#		Holistic score	%	

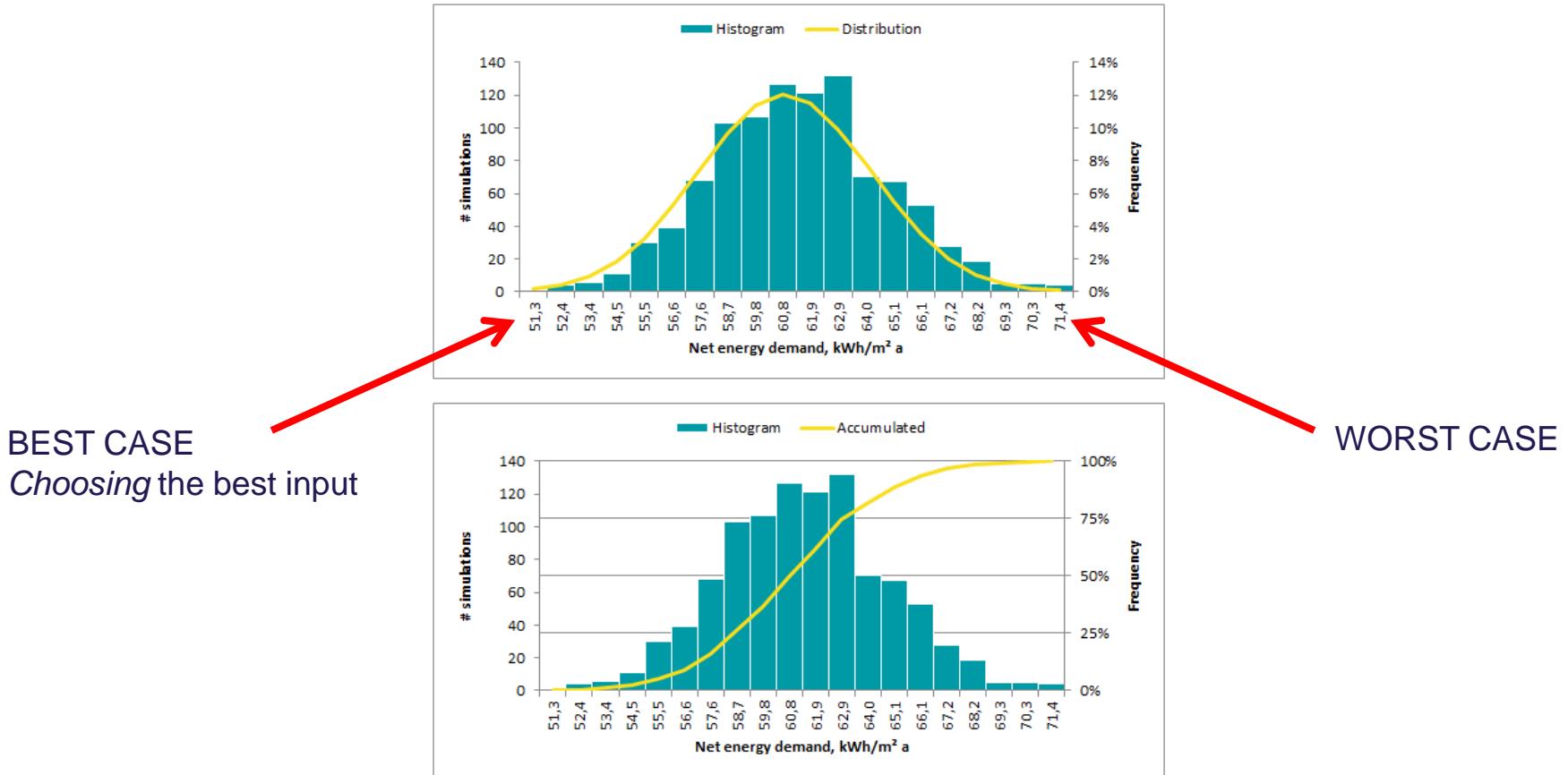
Run simulations

- 1) Choose sampling strategy (random, LHS, Sobol)
- 2) Choose number of simulations – the more, the merrier ☺
- 3) Run simulations

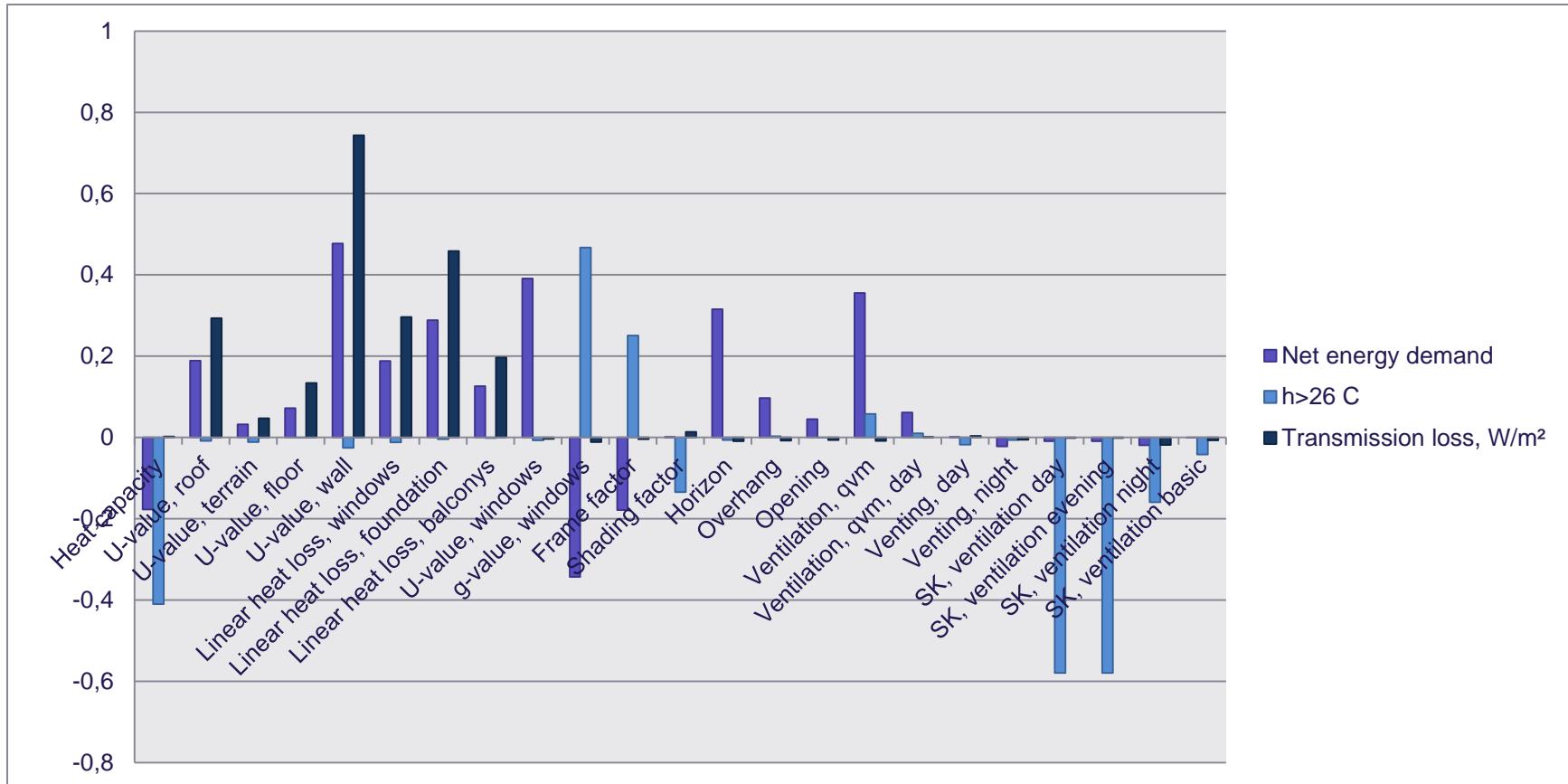


1000 simulations ~ 1-2 minutes (on laptop)

Output distribution (uncertainty)



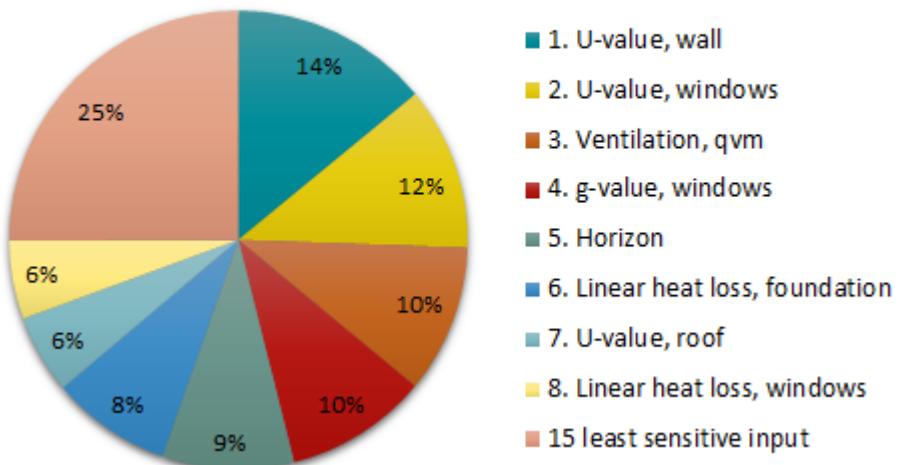
Sensitivity analysis – 23 input, 3 output



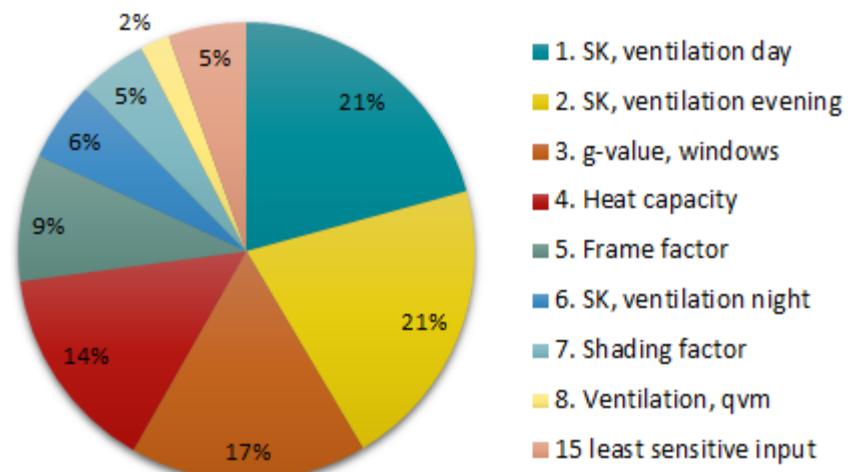
Sensitivity analysis – 23 input, 3 output

Ranking and quantitative sensitivity

Net energy demand

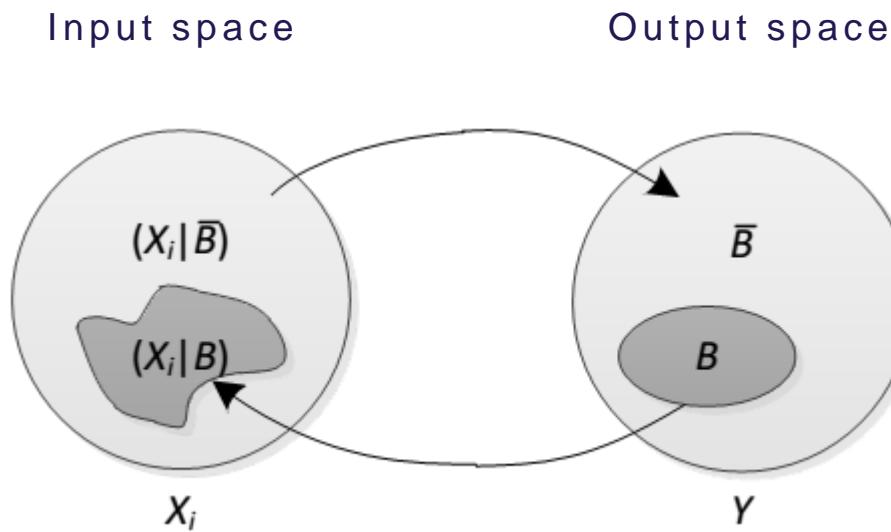


h>26 C



Monte Carlo Filtering

"Which factor or group of factors are most responsible for producing model outputs within or outside specified bounds" (Saltelli et al., 2008)

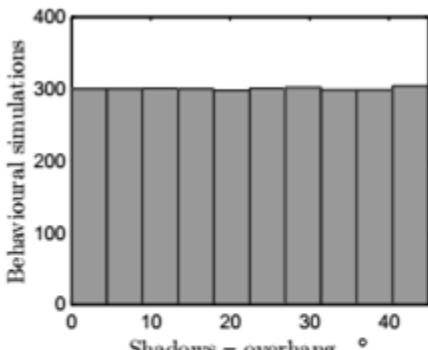


Two subsets for input space , X_i :
 $(X_i | B)$ produce behavioural (acceptable) results

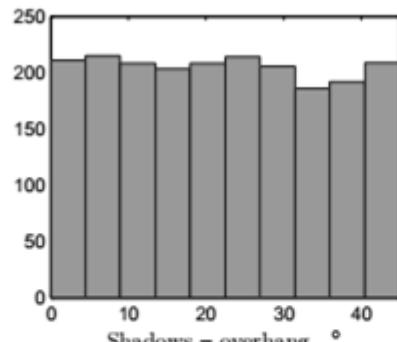
Two subsets for output space , Y :
 B represent behavioural results

Monte Carlo Filtering

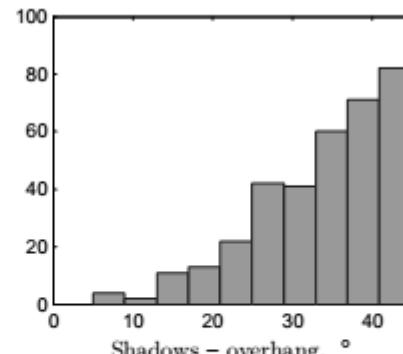
1. Setup *uniform* input distributions
2. Perform simulations representing a large option space
3. Filter results using constraints/requirements
4. Observe which input are most likely to produce acceptable results



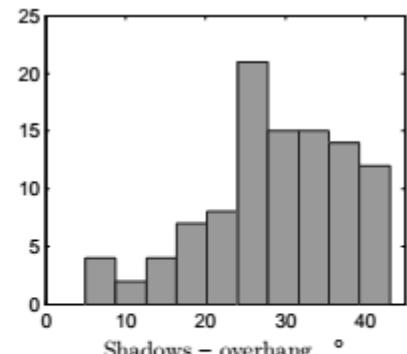
(a) No filtering



(b) One filter:
- Energy



(c) Two filters:
- Energy
- Thermal



(d) Tree filters:
- Energy
- Thermal
- Daylighting

Example: SA + MCF

Ordered by sensitivity

22 parameters (uniform dist.)

Filtered by 10 % best (holistic)

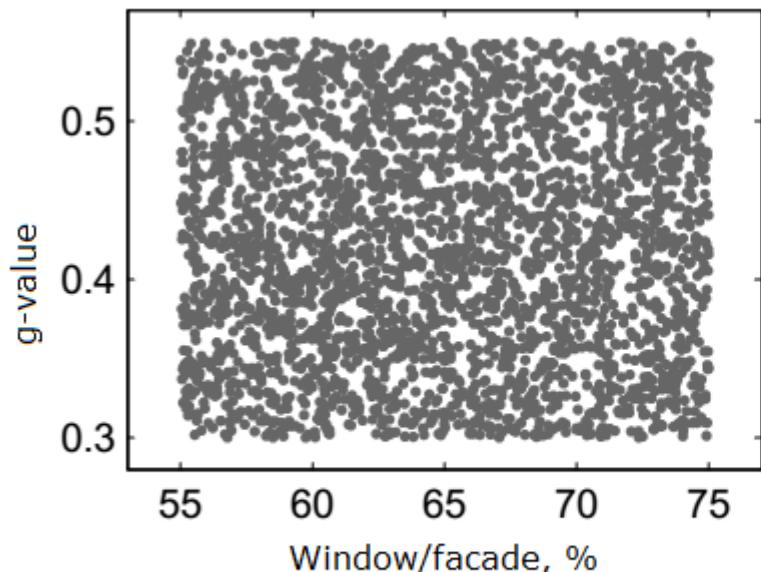
Recommendations based on histograms

Parameter	Span		Histogram	Recom.	
	min	max		min	max
23 g-value	0.3	0.7		-	-
18 Window/facade-%, S	25	75		33	60
6 Mean reflectance	0.4	0.6		0.5	0.6
14 Window/facade-%, N	25	75		30	65
26 Shadows, overhang, %	0	45		-	-
8 Heat capacity, Wh/m2	60	140		85	140
40 Lighting, installed, W/m2	4	10		-	-
22 U-value, windows	1.0	1.6		-	-
24 Shading factor	0.2	1		0.2	0.6
28 Side fins, angle	0	30		-	-
39 Lighting, general	0	1		-	-
34 SPF-factor	1.5	2.1		-	-
31 Heat recovery	0.7	0.95		-	-
5 Wall thickness	0.4	0.6		-	-
2 Vent., day, summer	0.9	3.6		-	-
29 Recess shadows, %	0	10		-	-
3 Vent., night, summer	0.9	1.2		-	-
11 U-value, roof	0.08	0.18		-	-
13 Linear loss, windows	0.02	0.06		-	-
12 Linear loss, foundation	0.1	0.4		-	-
9 U-value, walls	0.1	1.5		-	-
10 U-value, ground slab	0.08	0.13		-	-

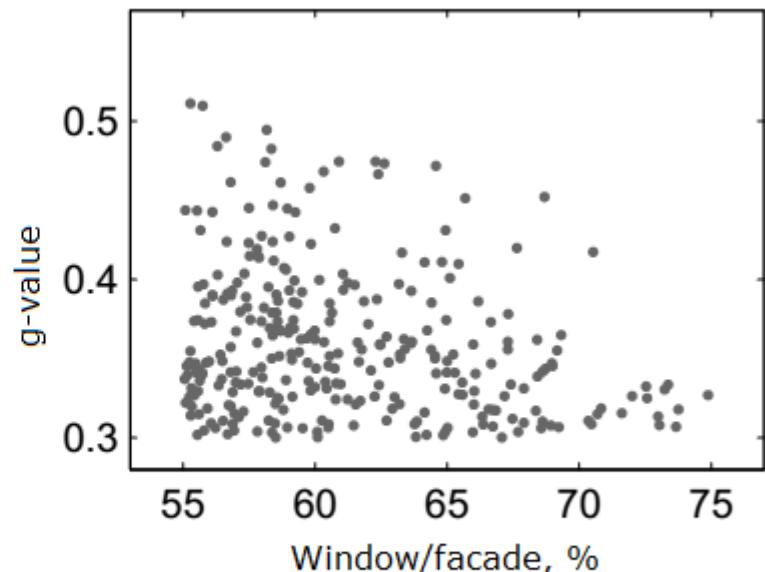
Monte Carlo Filtering

Input-input correlations

- Example: 3000 simulations > sorting top 10 %

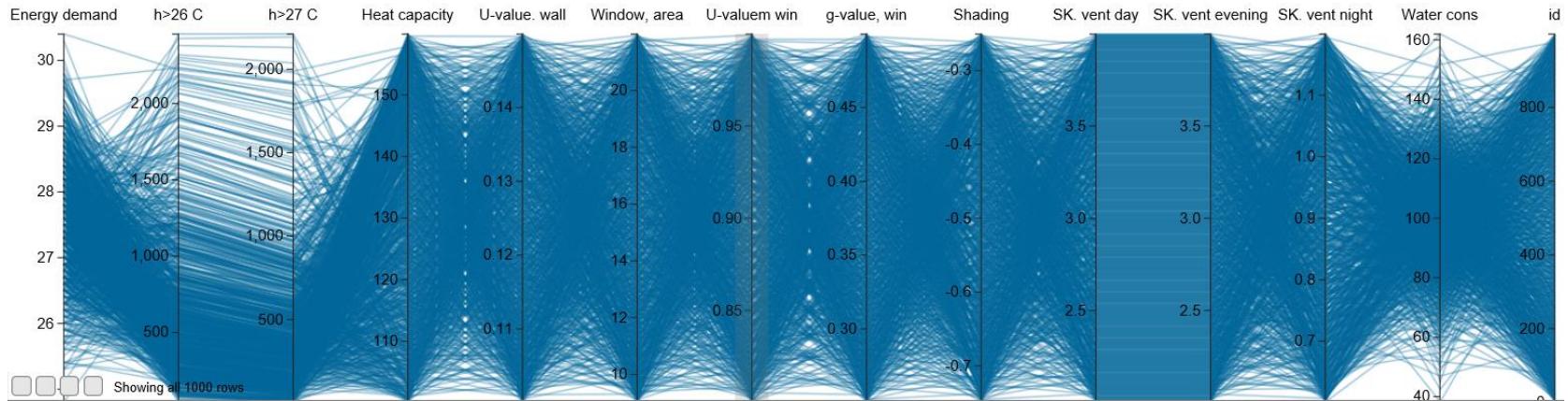


(a) No filtering

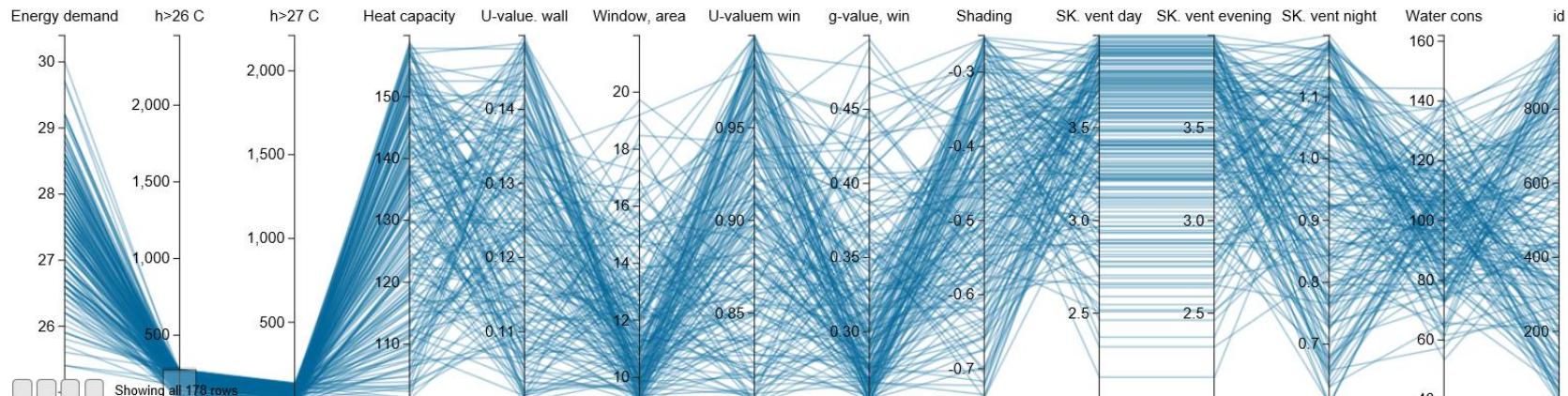


(b) MC Filtering, top 10 %

Parallel coordinate plot

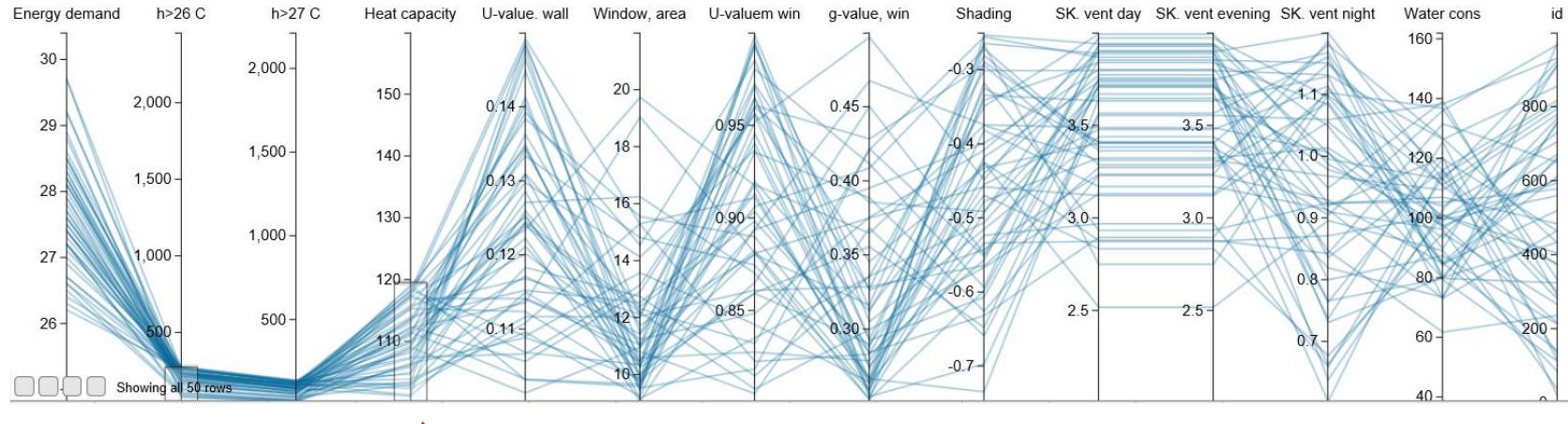


Parallel coordinate plot



FILTER
Max 250 h > 26 C

Parallel coordinate plot



FILTER
Heat capacity max 120 Wh/m² floor area

What's next?

- Continue literature review
- Test prototype on domestic buildings
- Find appropriate simulation software (hourly based)
- Create knowledge based input databases for quick modelling
- Programming platform? Python, C#, VB, web, java...?
- Integrate optimization techniques?
- Unknown/known challenges
 - Multiple zones – how to calculate and evaluate?
 - BIM compatibility?
 - Speed of simulation – clustering or cloud computing?
 - Architects' needs, communication form, visualization, etc.?
 - ...



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