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

INDUSTRIAL PHD-PROJECT WITH MOE A/S

PHD STUDENT TORBEN ØSTERGÅRD

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?

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About me

- Name / nimi = Torben Østergård
- Industrial PhD student
  - Enrolled at Aalborg University, Denmark
  - Employed by MOE
    Consulting | Engineering, Denmark & Norway, ~550 employees
- 3 years – June 2014 → May 2017

- Spare time (hopefully)?
  - Sports (climbing), travelling and much more



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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

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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

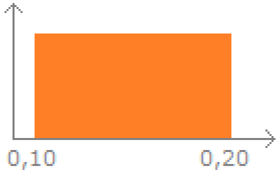
- *e.g.* energy consumption, overheating, daylight factor, embodied energy *etc.*

Generate knowledge-based input databases for quicker modelling

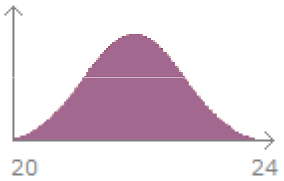
UA / SA – A quickie

1. Determine input distributions

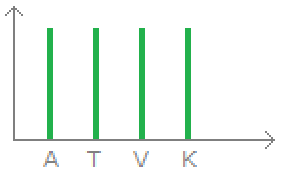
X_1: U-value (uniform)



X_2: Heating SP (normal)



X_3: Pump type (discrete)



⋮

X_n

2. Run building simulations (Monte Carlo)

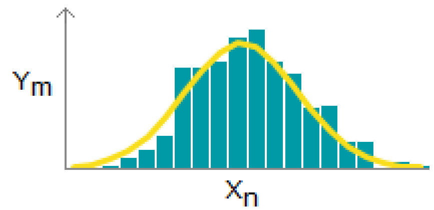
↳ k = 100 + times

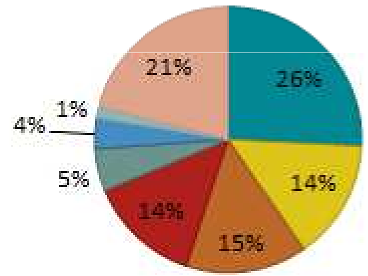
Simulation program(s)
Y_1 (X_1, X_2, …, X_n) = Energy Need Y_2 (X_1, X_2, …, X_n) = Daylight Factor ⋮ Y_m (X_1, X_2, …, X_n)

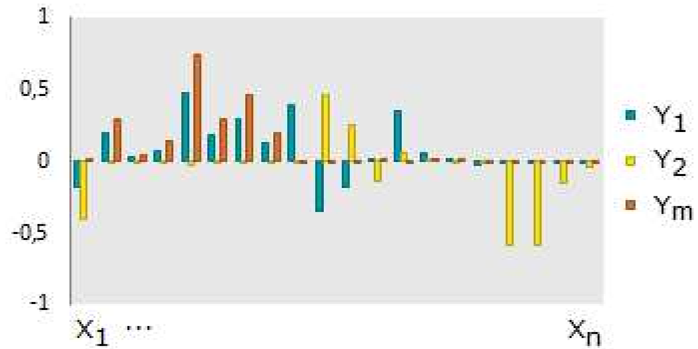
e.g. EnergyPlus, BSim, Be10, IDA-ICE, IES-VE, EcoTect, etc.

3. Perform and present SA + UA

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







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)

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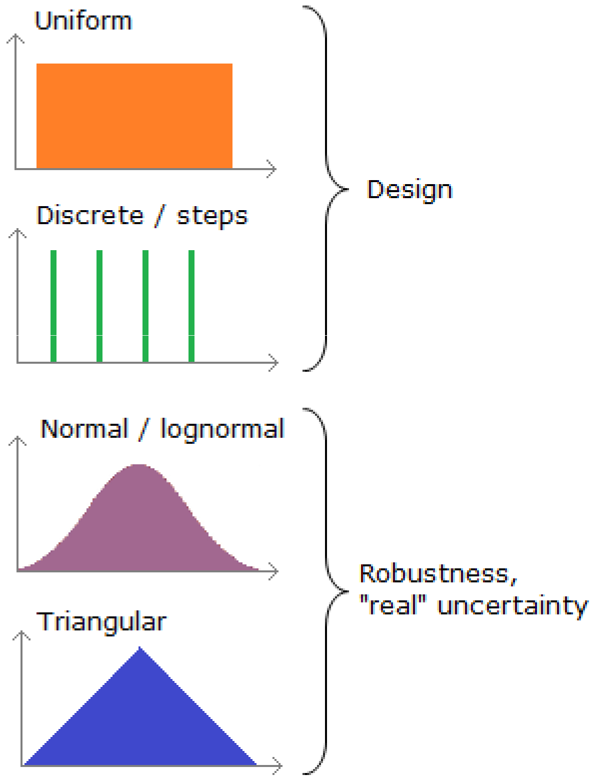
Setting up input

Input til UA/SA						Distributioı	Min	Max	Steps
ID	Inclu	Bun	Parameter	Unit	Category	_dist1	dis	dis	dis
#1	1		Heat capacity	Wh/K m²	Quality	Steps	40	120	8
#4	1		U-value, roof	W/m² K	Quality	Steps	0,08	0,15	10
#5	1		U-value, terrain	W/m² K	Quality	Steps	0,1	0,15	10
#6	1		U-value, floor	W/m² K	Quality	Steps	0,07	0,12	10
#7	1		U-value, wall	W/m² 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, fou	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/m² 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 m²	HVAC	Steps	0,3	0,5	4
#21	1		Ventilation, qvm, d	l/s m²	HVAC	Steps	0,3	0,5	4
#22	1		Venting, day	l/s m²	HVAC	Steps	0,9	3,6	12
#23	1		Venting, night	l/s m²	HVAC	Steps	0	2	8
#28	1	b	People load	W/m²	Robustness	Steps	1	2	2
#29	1	b	Equipment load	W/m²	Robustness	Steps	2	7	5
Total	23								

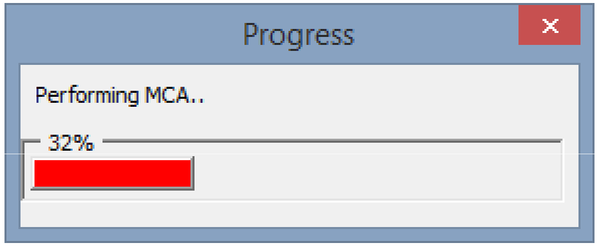


Setting up output

ID	Include	Parameter	Unit	Function
¤1¤	1	Net energy demand	kWh/m²	¤3¤ + ¤4¤ + ¤5¤
¤2¤		Energy demand, DK regislation	kWh/m²	
¤3¤		Heating demand	kWh/m²	
¤4¤		DHW demand	kWh/m²	
¤5¤		Electricity demand	kWh/m²	
¤6¤		Overheating	kWh/m²	
¤7¤		Lighting	kWh/m²	
¤8¤		Ventilation	kWh/m²	
¤9¤		Cooling	kWh/m²	
¤10¤		Minor electricity contributions	kWh/m²	¤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/m²	
¤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)

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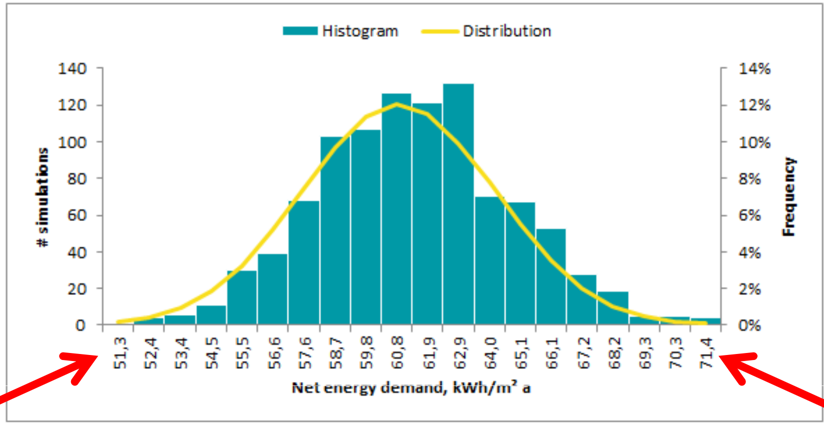
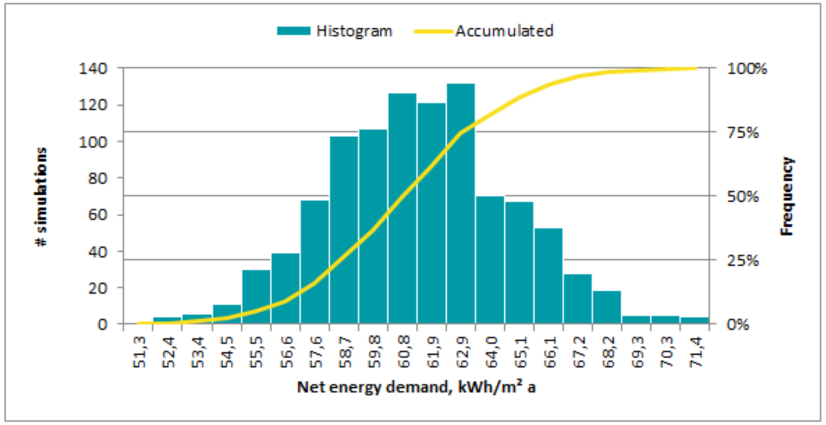
Output distribution (uncertainty)

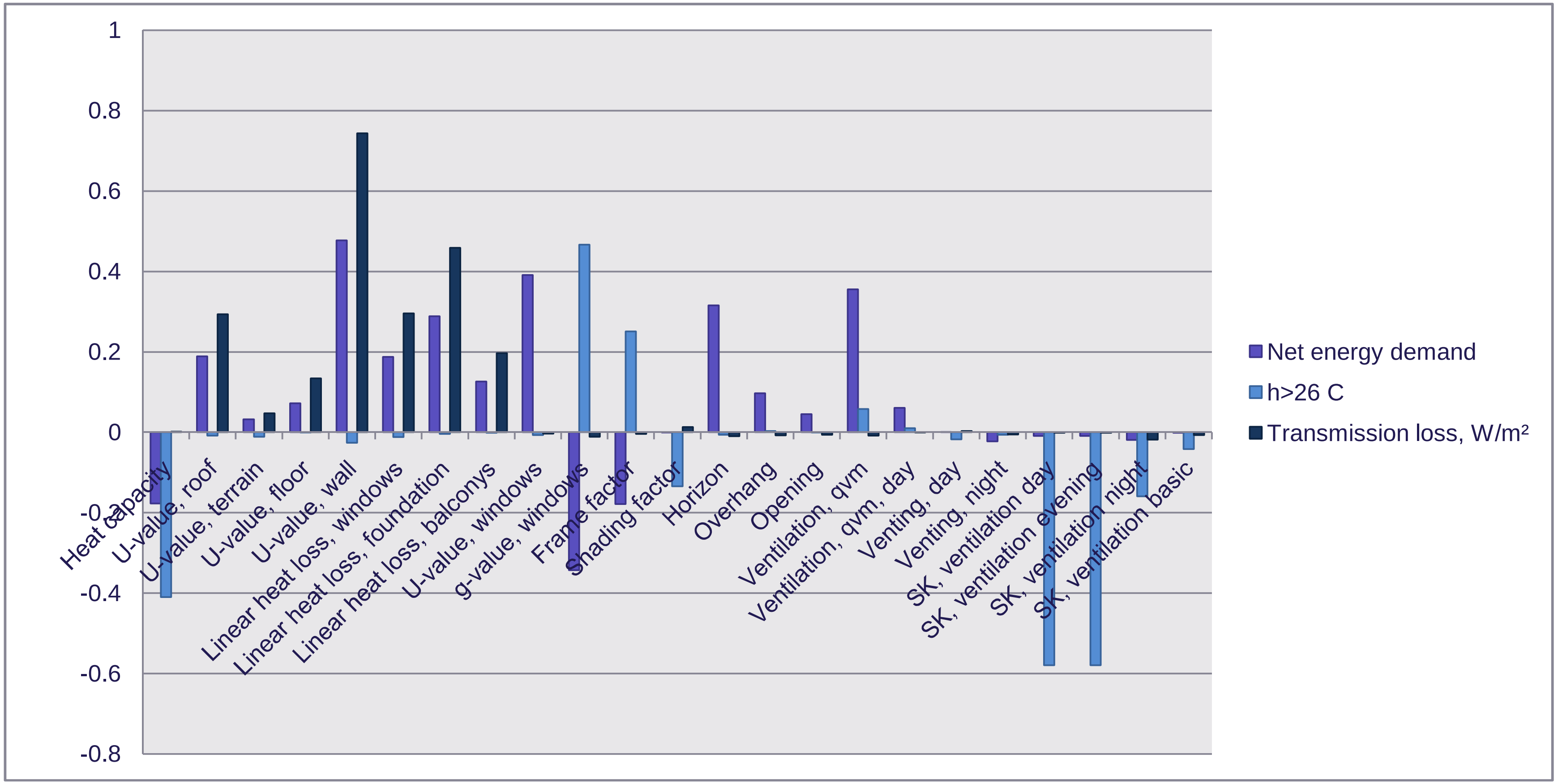


BEST CASE
Choosing the best input

WORST CASE



Sensitivity analysis – 23 input, 3 output



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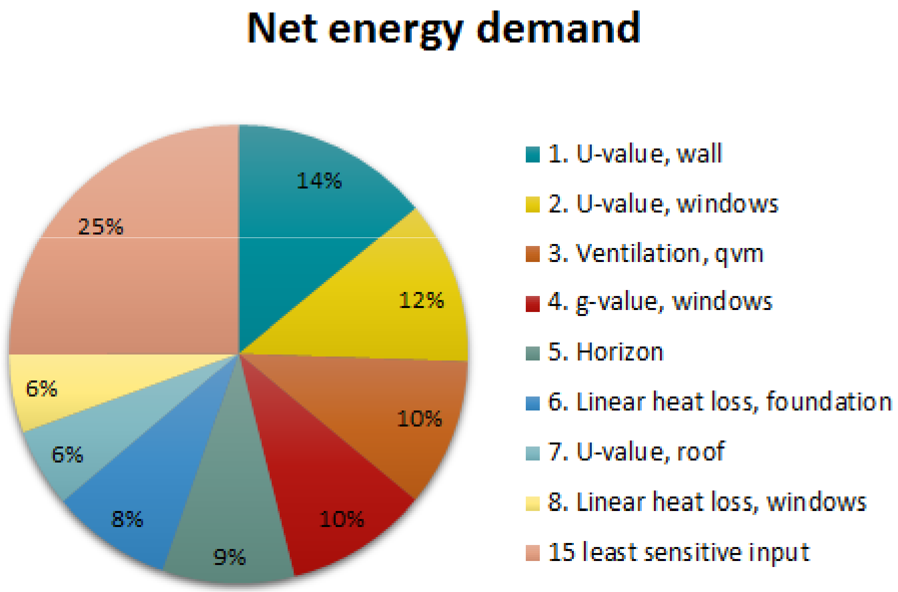
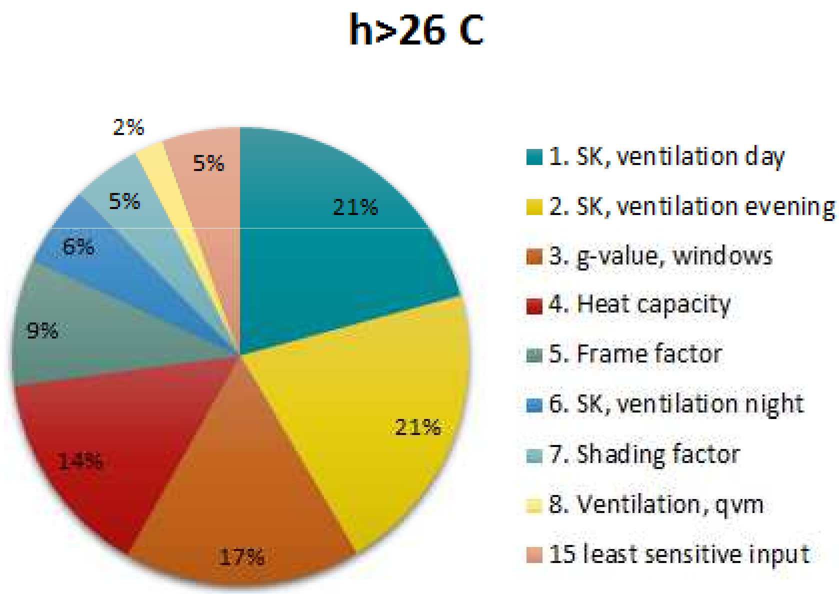
Sensitivity analysis – 23 input, 3 output

Ranking and quantitative sensitivity





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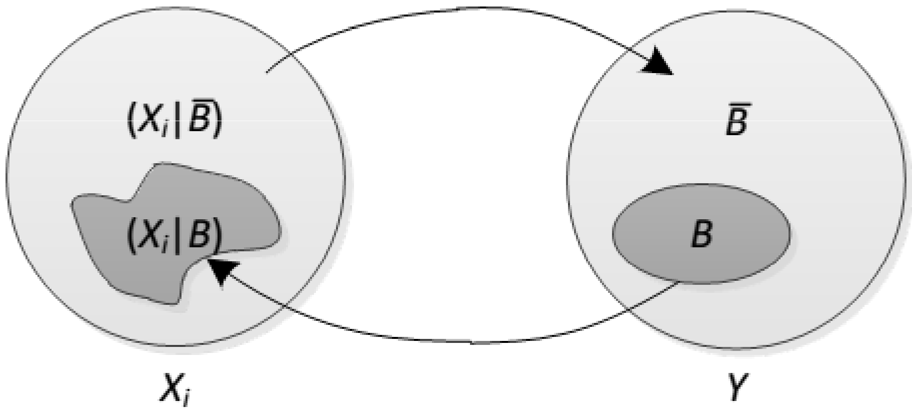
Slide 13

RLJ4 Mærkeligt at solafskærmning kun er #7 - men det må vel ha' noget med inputfordelingerne at gøre
Rasmus Lund Jensen; 22.9.2014

Monte Carlo Filtering

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

Input space Output space

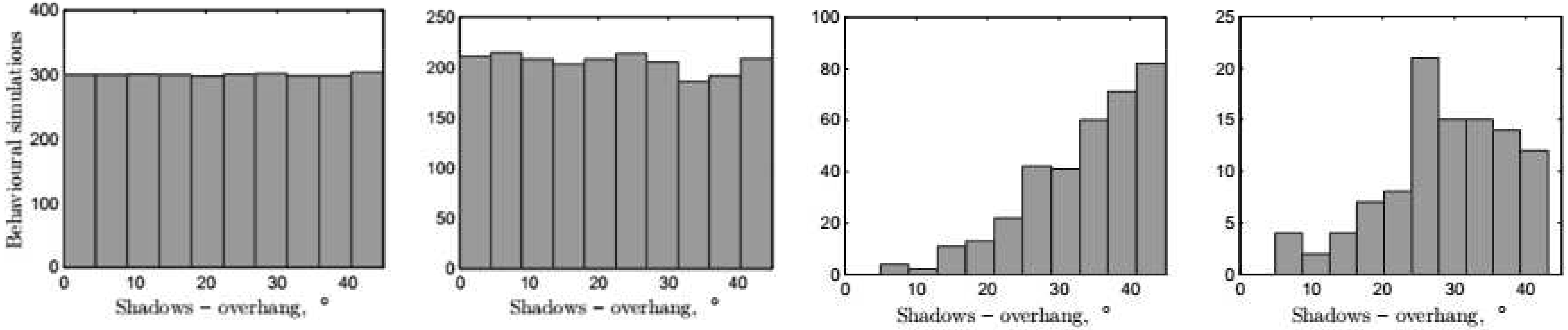


Two subsets for input space , X_i:
(X_i|B) produce behavioural (acceptable) results

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

Monte Carlo Filtering RLJ5

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

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Slide 15

RLJ5 Den her slide forstår jeg ikke - men din forklaring hjælper nok på det

Du har 1-4 i punktopstillingen og a-d i figurerne!?
Rasmus Lund Jensen; 22.9.2014

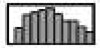
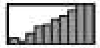
Example: SA + MCF

Ordered by sensitivity

22 parameters (uniform dist.)

Filtered by 10 % best (holistic)

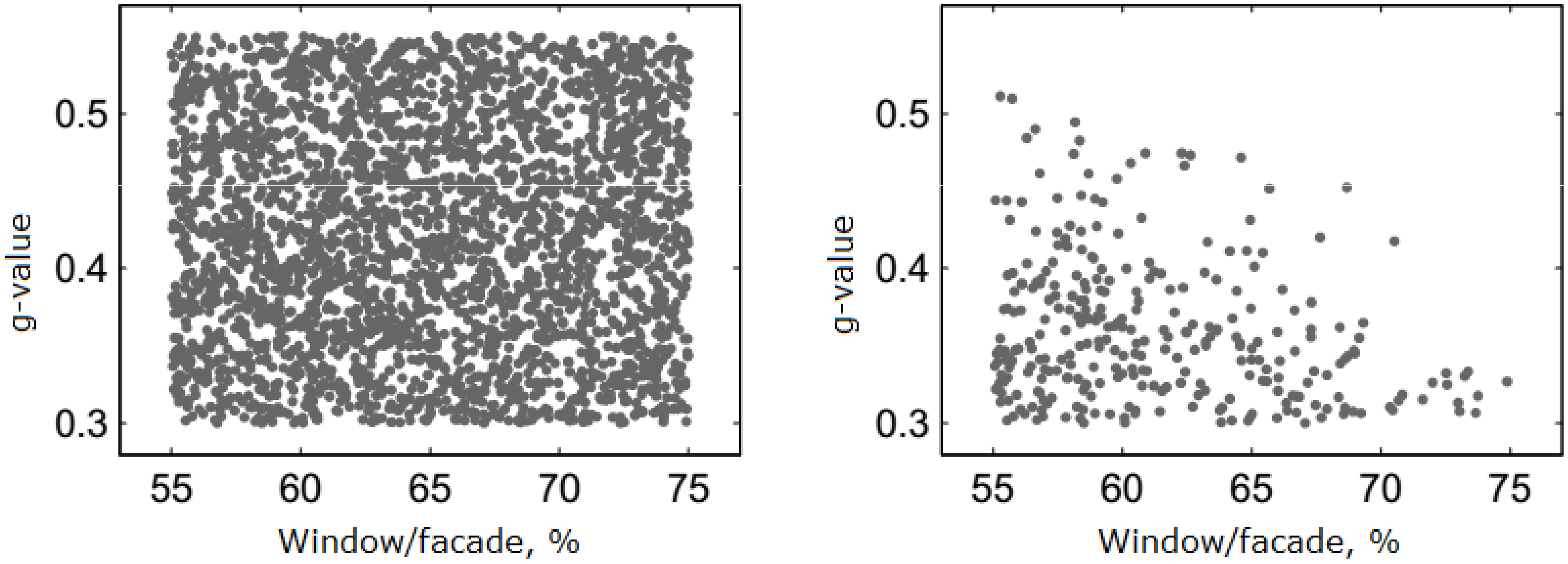
Recommendations based on histograms

	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

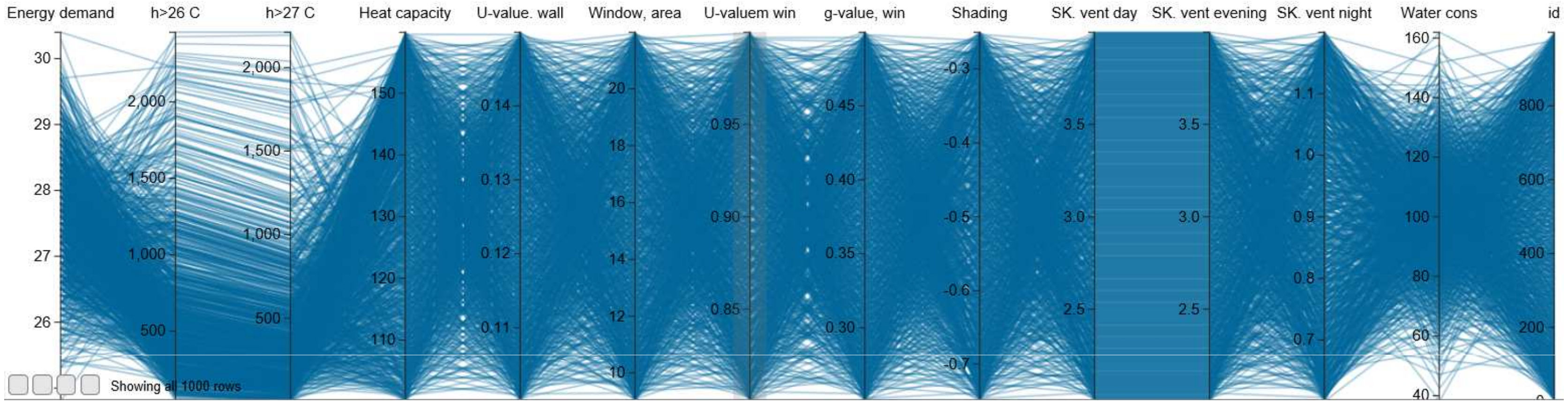
Input-input correlations

- Example: 3000 simulations > sorting top 10 %

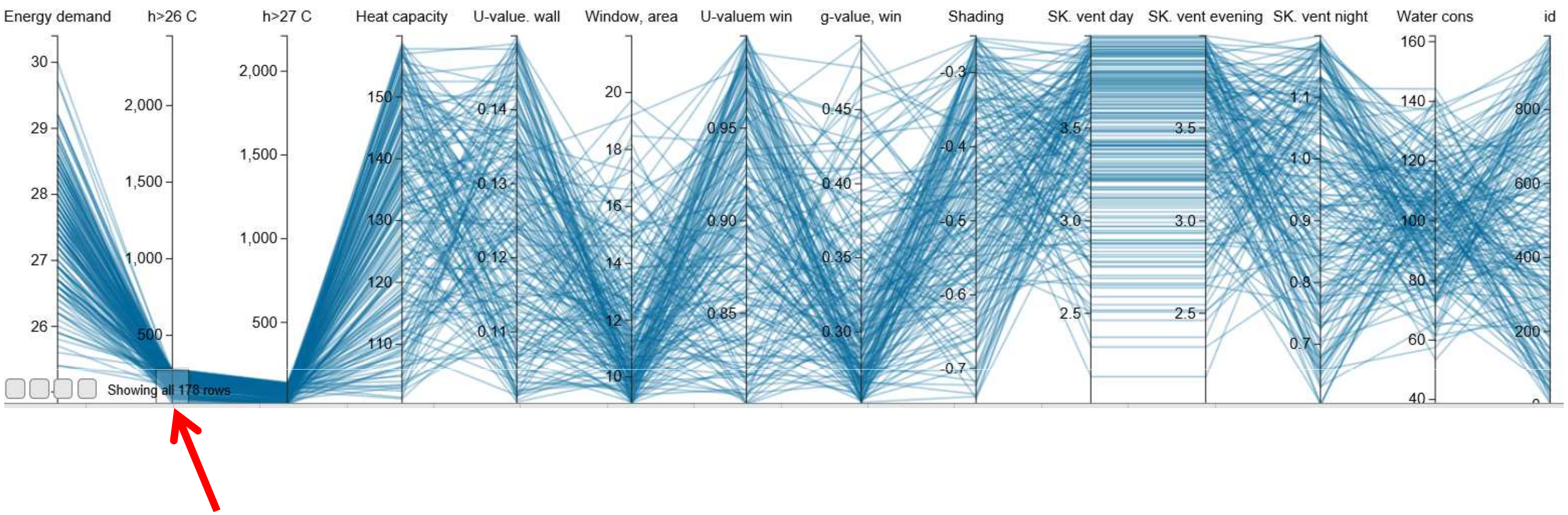


(a) No filtering   (b) MC Filtering, top 10 %

Parallel coordinate plot



Parallel coordinate plot



FILTER
Max 250 h > 26 C

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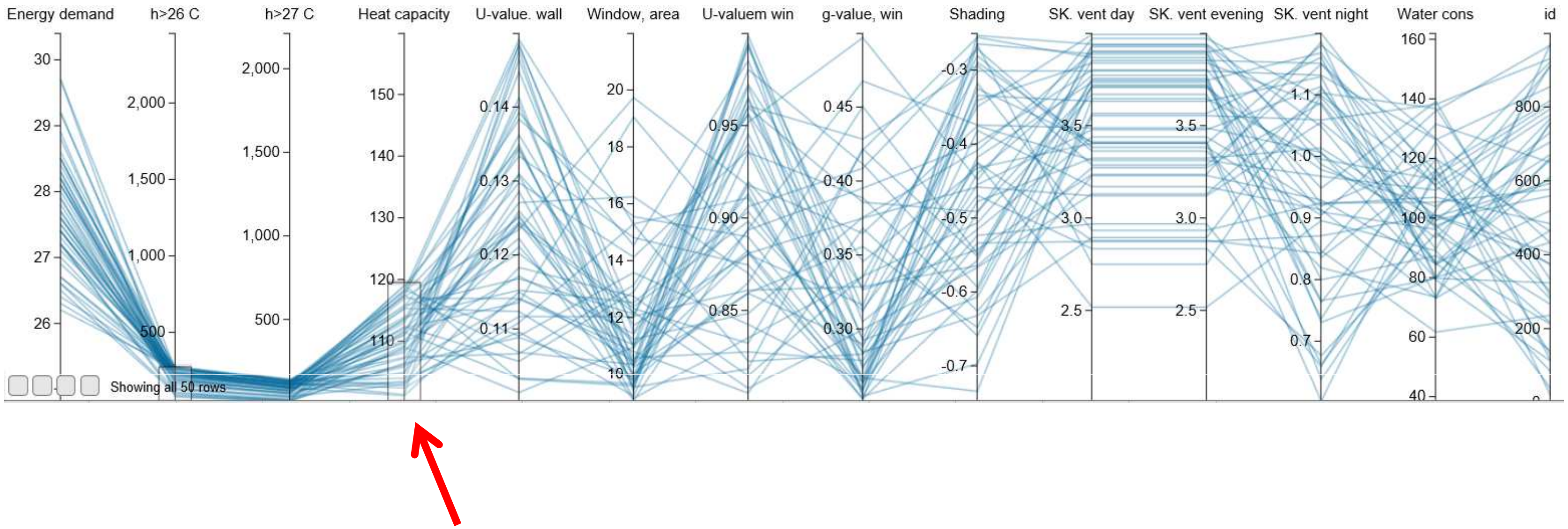
Parallel coordinate plot



FILTER
Heat capacity max 120 Wh/m2 floor area

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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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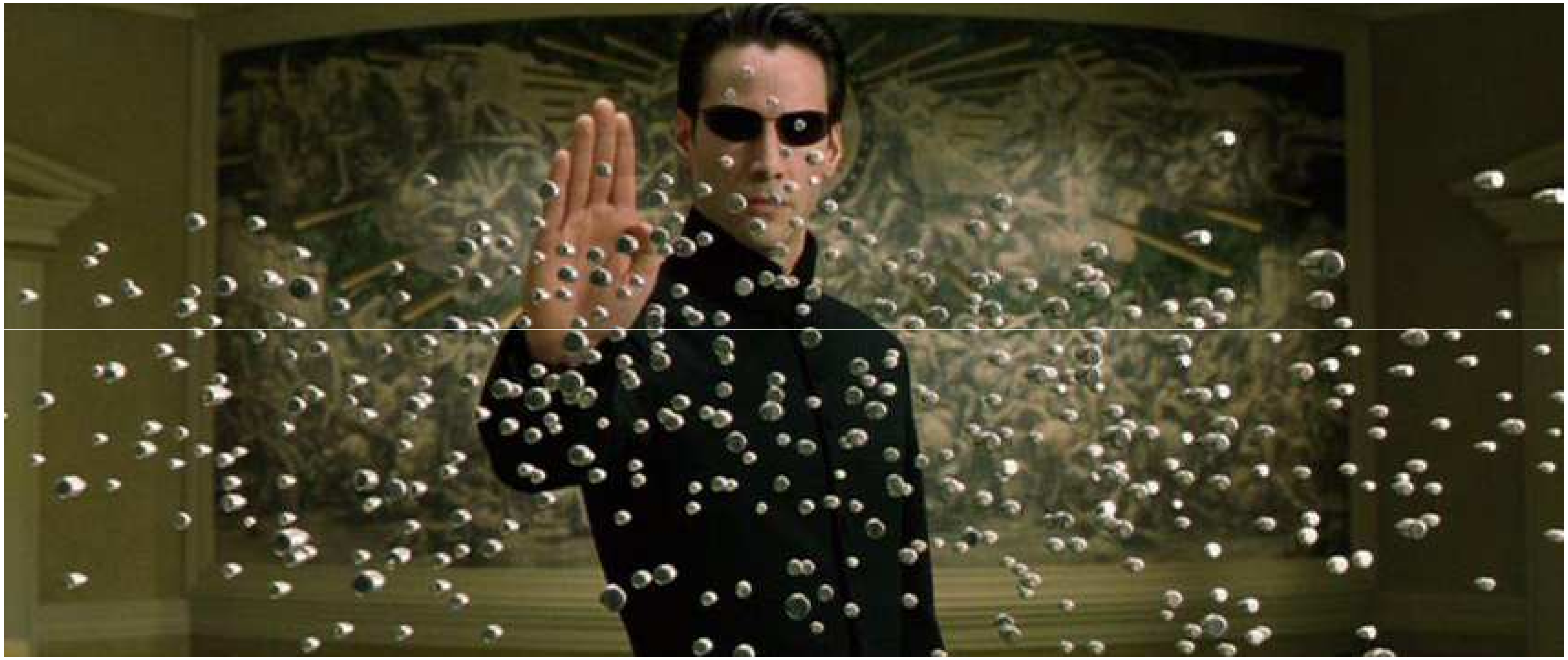
Questions and/or critical remarks?



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Informed decision making, term pre-design DM (adapted from Attia)

Input-input parameters

Example: if PV possible – no need to optimize (SA) on several parameters, but instead focus on challenged areas (SA important parameters for thermal, daylight, etc.)

Monte Carlo Filtering

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