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## **Thermal comfort in residential buildings by the millions**

*Early design support from stochastic simulations*

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# Thermal Comfort in Residential Buildings by the Millions - Early Design Support from Stochastic Simulations

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## Background

New requirements for thermal comfort in residential buildings in Denmark:

Indoor temperature in "critical room":

- Max. 100 hours > 26 °C
- Max. 25 hours > 27 °C

Challenges:

- 10–100 potential "critical" rooms
- Multiplied by 3–4 design proposals
- Time-consuming
- Conservative approach comes at the expense of daylight and outlook
- Design feedback needed early

Simplified hourly method, with roughly 15 inputs, is mandatory to use in Denmark.

## Idea

Idea: extensive stochastic simulations to represent (almost) all design combinations for most common rooms.

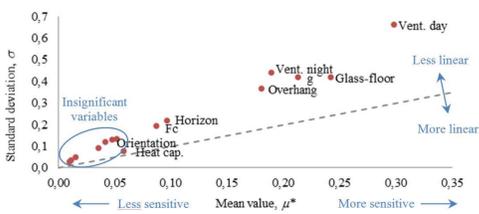
## Sensitivity Analysis

Morris sensitivity analysis used to remove insignificant inputs.

Table 1. Distributions for 15 inputs

Parameter	Unit	Discrete values	Min.	Max.
1 Orientation	-	W SW S SE E		
2 $U_A$ , envelope	W/K (m <sup>2</sup> )		0.1	0.3
3 $U$ , windows	W/m <sup>2</sup> K		0.7	1.1
4 Recess	%		0	15
5 Ventilation, day	l/s m <sup>2</sup>		0.9	5
6 Ventilation, night	l/s m <sup>2</sup>		0	3
7 Ventilation, winter	l/s m <sup>2</sup>		0	3
8 Glass-floor-ratio	%		10	40
9 g-value	-	0.23 0.3 0.35 0.42 0.5		
10 Heat capacity	Wh/K m <sup>2</sup>	60 80 100 120 140		
11 $F_c$ (shading)	-	0.2 0.4 0.6 0.8 1		
12 Overhang	-	0 20 40 60		
13 Horizon	°	10 25 40		
14 Fins, left	°		0	30
15 Fins, right	°		0	30

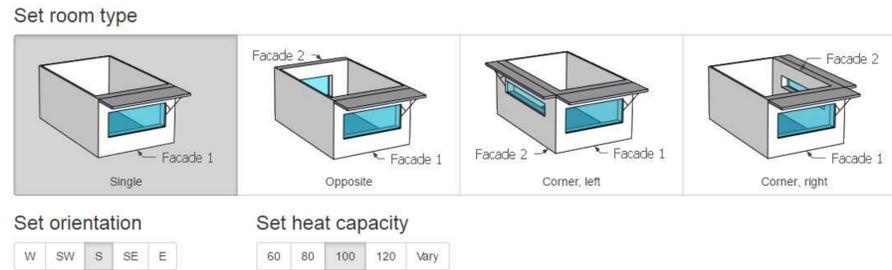
Figure 1. Plot of Morris sensitivity measures



## Rapid exploration of millions of simulations

100.000 simulations have been performed for each combination of common room types, orientation, and building heat capacity.

Figure 2. The design team chooses a combination of room type, orientation, and heat capacity.



Using an interactive parallel coordinate plot, the design team may rapidly test different designs and see how the design affects thermal comfort.

Figure 3. Interactive parallel coordinate plot showing inputs and outputs for 100.000 simulations

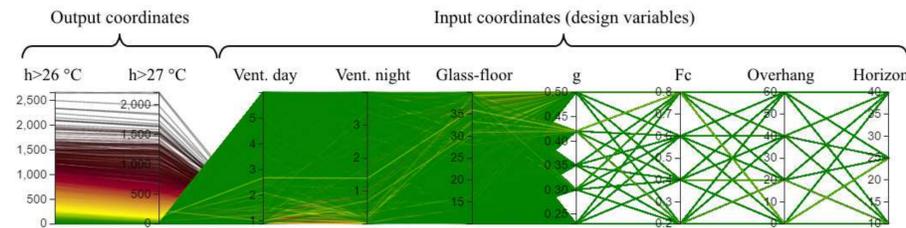


Figure 4. "Forward" approach to seek limits and test different design in early design stages

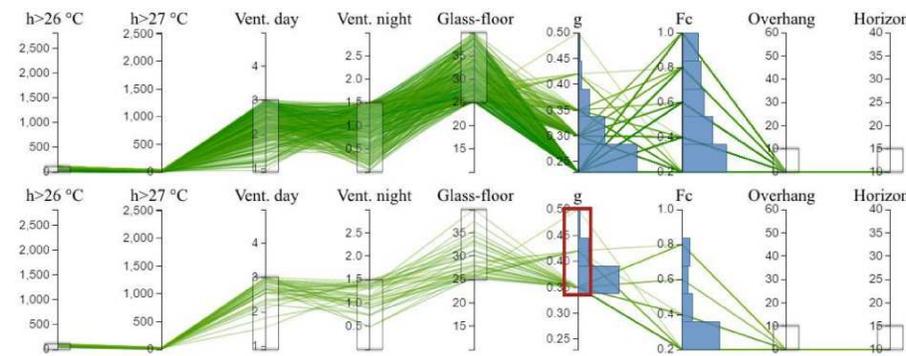
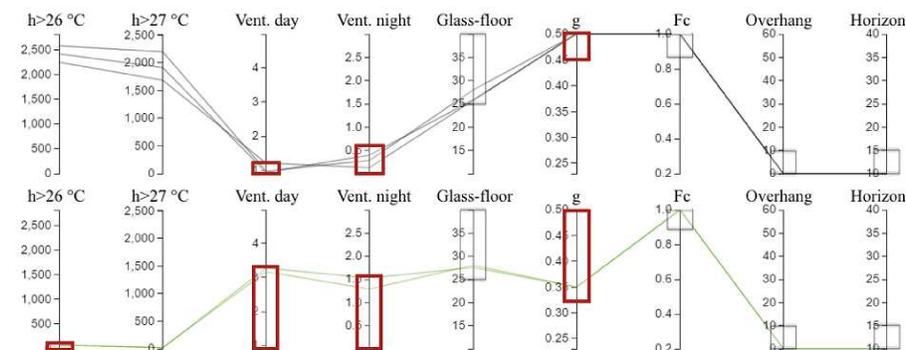


Figure 5. "Backward" approach shows the results for a "bad" design and how to find solutions



## Regulation input values

A table and corresponding interactive figure help translate regulation guidelines into input values. The dark blue area shows how much of the window that must be openable in order to use the desired venting rate.

Figure 6. Supporting input table and figure

Rumdimensioner	Luftskifter	Åbningsareal
Gulvareal	10 m <sup>2</sup> Naturlig vent.	1,0 l/s m <sup>2</sup> Oplukket areal
Vinduesareal	2,5 m <sup>2</sup> Mekanisk vent.	0,3 l/s m <sup>2</sup> Tværvæntilning
Rumhøjde	2,4 m Samlet vent.	1,3 l/s m <sup>2</sup> Ensidig ventilation
Glasandel, $F_g$	0,8 Luftmængde	10,0 l/s Effektiv åbning
Glas-gulv forhold	20,0 %	Luftmængde 36,0 m <sup>3</sup> /h
Bredde, facade 1	4,0 m	Luftskifte 1,4 h <sup>-1</sup>



## Discussion

The proposed method is not intended for final documentation but for rapid identification of limits and for testing of various design paths.

The code compliance software only assess thermal comfort. It may be substituted with detailed building performance software to address energy, illuminance, draught, etc. This increases the level of detail and the number of inputs which requires more simulations. Again, sensitivity analysis can help reduce the number of inputs.

## Try it yourself

Explore millions of simulations on [buildingdesign.moe.dk](http://buildingdesign.moe.dk)

Login: clima\_2016  
Password: clima\_guest

## Authors



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100+ potential critical rooms

4+ design proposals

g-value allowed to vary