



Sensitivity analysis on Demand shifting capabilit y based on the TwinHouse model

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Purpose of this study

- In the future heating demand shifting can do an important role in increasing the efficiency of the energy grid
 - Due to increasing portion of renewable energy and its fluctuating nature
 - Heating demand can be shifted for a while by intentional over heating when there is excess power generation in the grid



<Predicted Electricity demand and wind power generation in Denmark 2020>

- Comprehensive sensitivity analysis is required to understand which factors are most important for the demand flexibility
 - There were a few sensitivity analysis on demand shifting but the number of parameters were very limited

Parameters which affect on demand shifting

- 1. Insulation level of building fabric (Wall, Floor, Ceiling, Window)
- 2. Amount of Thermal mass (All the part in a building)
- 3. Ventilation and Infiltration rate
- 4. Overheating duration time
- 5. Position of insulation (Exterior or interior insulation)
- 6. Solar radiation absorbed inside face of a building fabric (G-value)
- 7. Types of heater
- 8. outside boundary condition of ceiling and floor of a floor

The TwinHouse Model

- Energy simulation model of the TwinHouse at the Fraunhofer test site in Holzkirchen, Germany is used for sensitivity analysis
 - The model is calibrated with real detailed measured data as an IEA Annex 58 activity

Item	Contents							
Simulation tool	ESP-r							
	Same as TwinHouse calibrated Model							
Geometry, Calculation detail	Image: state of the state o							
Construction Infiltration, Overheating duration time	Input Parameter of each cases							
Climate Data	Copenhagen, Denmark							
Simulation day and Time step	1 st of January, 2 minutes							

The TwinHouse Model

- Calibration to the simulation model include detailed thermal bridge analysis, change surface convection coefficient and ventilation heat losses adjustment
 - Calibrated model shows CC : 0.9611 and IC : 0.0516



Definition of parameter range

• Construction data is extracted from TABULA database

7				Tabula	WebTool - Chrome					- 🗆 🗙
🗈 webtool.building-ty	polog	y.eu/webtool	/tabula.html							Ę.
			Existing state		Refurbishment Packa	ge 1	Refurbishment Package 2		Sele	cted Building:
TARVILA	TAPULLA				Usual Measures		Advanced Measures		00.0	dia bonany.
IN PACT		surface area	180.0 ^{m2}		180.0 ^{m2}	180.0 ^{m2}			100	
WebTool		type of construction	Boards / Rafter, 150 mm in Træ / bjælker- 150 mm is	sulation	Add 150 mm insulati Efterisoleret med 150 r	Add 250 mm insulation Efterisoleret med 250 mm				
∧ Types		refurbishment measure							Buildir	ng Size Class: SFH
∧ Variants	Roof or								Const	ruction Period:
∧ Comparison	top				$\Box \cap \cap \cap$		$\Box \cap \cap C$		19	9611972
✓ Data	- coming	picture							Refere	nce Floor Area:
Building Data		piotare				\sim				153 m ²
Building Data						\sim			Heat S	Supply System:
System Data								central heat	ing, natural ventilation	
		U-value	0.3 W/(m ² K)		0.13 W/(m ² K)	0.1 W/(m ² K)			
		surface area	121.0 ^{m2}		121.0 ^{m2}		121.0 ^{m2}		Dis	splay chart
		type of construction / refurbishment	30 cm brick (cavity wall) insulation (at erection 30 cm hul isoleret	, 7,5 cm on).	Add 125 mm Efterisoleret med 125 r	Add 225 mm Efterisoleret med 225 mm		energy need for heating energy need for heating [kWh/(m²a)]		
Calculation Details	Wall 1	picture						HANNA -	200 - 191. 190 - 191. 180 - 191.	94.0
		U-value	0.6 W/(m ² K)		0.19 W/(m ² K)		0.13 W/(m ² k	0	90 - 80 -	79.4
DK.N.SFH.05.Gen.ReEx 001		surface area	160.0 ^{m2}		160.0 ^{m2}		160.0 ^{m2}		70 60	
Heating System: DK.Gas.B_NC_CT.SUH.01	-	type of construction / refurbishment measure	Linoleum / Concrete / 20 cm tiled concrete Linoleum / Beton / 20 cm Leca		New floor with 250 mm isolation Udgravning og etablering af nyt gulv med 250 mm isolering		New floor with 300 mm isolation Udgravning og etablering af nyt gulv med 300 mm isolering		50 - 40 - 20 - 20 - 20 - 20 - 20 - 20 - 2	
Hot Water System: DK.Gas.B_NC_CT.SUH.01 Ventilation System: DKGen.01	Floor 1	picture							▲ Existing State	usual Usual Refurbishment Refurbishment Refurbishment
Co-funded by the	Country	in charge:	Charts - Display	Display Prin	mary Energy on pages 'Variants':	Assessmen	t of Energy Bui	lding:		Automatic
Intelligent Energy Europe Programme of the European Union	Denmar	k SBi	standard calculation not		ible primary energy Carriers:		exemplary existing		+	
			adapted		European s		ean standard values building			

<Images from TABULA web tool>

Definition of parameter range

• Input for sensitivity analysis

Category	Item	Unit	Data Type	max	min	mode		
	wall	W/m²k	Triangular	2.8	0.12	1.6		
inculation	floor	W/m²k	Triangular	1.21	0.12	0.6		
Insulation	ceiling	W/m²k	Triangular	1.9	0.11	1.03		
	window	W/m²k	Discrete	0.8	1.7	2.7	4.2	5.1
g-value	window		Discrete	0.5	0.63	0.76	0.85	
	wall	(J/°C)	Triangular	816000	9576	510000		
Thermal mass	floor	(J/°C)	Triangular	585000	49875	96787.5		
	ceiling	(J/°C)	Triangular	195000	49875	49875		
infiltration		ac/h	Triangular	0.4	0.03	0.2		
Overheating time		hour	Discrete	1	2	3	4	5
Position of Insulation			Discrete	internal	middle	exterior		

Latin Hyper cubic sampling cases

- To reduce sampling cases while maintaining acceptable accuracy of statistical characteristics, Latin Hyper Cubic Sampling Method is used to generate sample cases
- Simlab 2.2 is used to generate 25 LHS samples which exceeds the minimum number of 3/2*11(perameter number) = 16.5 which is recommended for LHS method

Nr.	Wallins	Floorins	Ceilins	WinUvalue	gvalue	WallTherma	Fino ass Mass	CeilTM ass	Infiltration	Positionofl	BuurationTir
1	0.586091	0.624	1.41098	4.2	0.5	387260	206101	145896	0.246559	1	1
2	2.33022	0.544	1.47926	5.1	0.5	666290	194432	113703	0.140626	3	2
3	2.28081	0.224	0.841427	5.1	0.5	432032	144705	59864.2	0.20608	1	4
4	1.02406	0.519	0.480777	2.7	0.76	456619	105776	125633	0.220022	2	5
5	2.47173	0.391	1.63347	5.1	0.85	325641	376911	109975	0.171937	1	3
6	1.50666	0.839	0.90881	1.7	0.5	274790	434948	72100.4	0.183303	3	5
7	0.320243	0.988	1.78152	1.7	0.85	259562	350350	144143	0.295067	1	5
8	0.789103	0.314	0.464685	1.7	0.76	417698	390704	88079.2	0.153459	2	4
9	2.01582	0.466	0.276093	4.2	0.63	595518	293027	55529.1	0.120152	1	5
10	1.74477	0.436	1.15243	0.8	0.76	294203	306579	91691.5	0.0921583	3	3
11	1.84005	1.054	1.33157	1.7	0.63	544326	474798	95604.4	0.0388807	1	2
12	1.6893	0.695	1.05971	0.8	0.76	70579.7	152641	50838	0.103822	1	1
13	2.10246	0.804	0.794021	5.1	0.63	587795	128273	71634.6	0.195219	2	4
14	1.64594	0.774	1.03326	4.2	0.85	568773	165484	83786.5	0.322375	1	1
15	1.29764	0.493	0.678382	4.2	0.85	402201	127142	64451.5	0.340304	2	1
16	1.39552	0.906	1.28079	0.8	0.85	503771	327984	163544	0.269404	3	5
17	0.838778	0.605	0.608408	5.1	0.63	153788	258979	66683.5	0.218067	3	2
18	1.2388	0.664	0.932472	2.7	0.85	758326	507531	79041.2	0.385946	2	4
19	1.87154	0.559	1.20512	2.7	0.5	500439	262182	132110	0.199969	3	3
20	1.09984	0.729	1.11373	0.8	0.63	212405	101027	119335	0.241533	3	2
21	1.37675	0.863	0.779923	1.7	0.63	528937	221978	58104.4	0.289053	2	3
22	0.982768	0.589	1.342	0.8	0.63	351335	59547.5	98854.4	0.145899	2	4
23	1.44403	0.368	1.07451	2.7	0.5	675519	239730	75988.7	0.260035	3	1
24	1.56681	0.948	0.981134	4.2	0.76	473232	176740	105463	0.235809	2	3
25	1.98858	0.670	0.685886	2.7	0.85	631986	89093.2	169897	0.165621	2	2

Table. 25 samples from SimLab

Simulation result and analysis of LHS cases

cases

- Demand shifting time ranges from 6 to 142 minutes in each cases
- Shortcoming of LHS method is that it is not easy to compare each cases and analyze the impact of each parameters because all the other parameter changes at the same time

-> Morris Method is used adapted to generate new sample



Demand Shift time

Morris Case sample cases

- Morris method is similar to LHS in that it uses even number of divided interval for each parameter. But in Morris method there is only 1 parameter change in each cases
 - Because of this characteristic it is easier to compare each results than LHS
- In Morris the number of model executions is computed as r*(k+1) where r is the level of sampling and k the number of model input factor
 - In total 72 simulation models were made

ą	<u>Wallins</u> ⊷	<u>Floorins</u> + ²	<u>Ceilins</u> #	Win↓ Uvalue₄ [,]	gvalue⊷	Wall↓ Thermalmass*	Floor↓ TMass+ ²	Ceil↓ TMass≁	Infiltration	Insulation↓ Type↔	Overheating↓ Time≁	Demand↓ shifting↓ time≁	*
1₽	1.64242₽	0.802293₽	1.09447	0.8₽	0.85₽	4 19634₽	95613.7₽	56113.2	0.224406	1 ₽	2₽	74₽	1
2₽	1.64242*	0.802293₽	<mark>0.48045</mark> ₽	0.8↩	<mark>0.85</mark> ₽	4 19634₽	95613.7₽	56113.2 <i>₽</i>	0.224406	1₽	2₽	<mark>86</mark> ⊷	
3₽	1.64242*	<mark>0.481663</mark> ₽	<mark>0.48045</mark> ₽	0.8↩	<mark>0.85</mark> ₽	419634↩	95613.7₽	56113.2 <i>₽</i>	0.224406	1 ₽	2₽	106 ⊷	
4↩	1.64242&	0.481663₽	<mark>0.48045</mark> ₽	0.8↩	<mark>0.85</mark> ₽	4 19634₽	95613.7₽	56113.2 <i>₽</i>	0.224406	3₽	2₽	96⊷	
5₽	1.64242&	<mark>0.481663</mark> ₽	<mark>0.48045</mark> ₽	2.7₽	0.85₽	419634₽	95613.7@	56113.2 <i>₽</i>	0.224406	3₽	2₽	56 ₽	
6 ₽	1.64242&	0.481663₽	<mark>0.48045</mark> ₽	2.7₽	<mark>0.63</mark> ₽	4 19634₽	95613.7₽	56113.2 <i>₽</i>	0.224406	3₽	2₽	54 @]
7₽	<mark>0.69492</mark> ₽	<mark>0.481663</mark> ₽	<mark>0.48045</mark> ₽	2.7₽	<mark>0.63</mark> ₽	4 19634₽	95613.7₽	56113.2 <i>₽</i>	0.224406	3₽	2₽	98 ₽	
8₽	<mark>0.69492</mark> ₽	<mark>0.481663</mark> ₽	<mark>0.48045</mark> ₽	2.7₽	<mark>0.63</mark> ₽	419634↩	255067₽	56113.2 <i>₽</i>	0.224406	3₽	2₽	98 ₽	
9 ₽	<mark>0.69492</mark> ₽	<mark>0.4816</mark> 63₽	<mark>0.48045</mark> ₽	2.7₽	<mark>0.63</mark> ₽	419634₽	255067₽	101 363₽	0.224406	3₽	2₽	90 €]
10₽	0.69492	<mark>0.481663</mark> ₽	<mark>0.48045</mark> ₽	2.7₽	<mark>0.63</mark> ₽	4 19634₽	255067₽	101363₽	0.102399₽	3₽	2₽	98 ₽	
11₽	0.69492	<mark>0.481663</mark> ₽	<mark>0.48045</mark> ₽	2.7₽	<mark>0.63</mark> ₽	<mark>672599</mark> ₽	255067₽	101363₽	0.102399₽	3₽	2₽	98 ⊷	
12₽	0.69492	<mark>0.481663</mark> ₽	<mark>0.48045</mark> ₽	2.7₽	<mark>0.63</mark> ₽	<mark>672599</mark> ₽	255067₽	101363₽	0.102399₽	3₽	4₽	42 ¢	
13₽	1.11579₽	<mark>0.97461</mark> ₽	1.09447₽	2.7₽	0.5₽	419634₽	437449₽	<mark>69372.2</mark> ₽	0.19189₽	2₽	1.0	12 ¢	
14₽	1.11579₽	0.97461₽	1.09447↩	5.1₽	0.5₽	419634₽	437449₽	69372.2₽	0.19189₽	2₽	1 <i>e</i>	6↩	

Morris Case sample cases

- Small values for μ to factors with negligible effect; σ measures the strength of the interaction effects
- Insulation level of construction and overheating time are ranked as the most important factor with overheating time
 - As seen in μ value the other factors do not have significant impact on the demand shifting time

Category	Item	Unit	μ	σ	Rank
	wall	W/m²k	49.33330	40.8444	2
inculation	floor	W/m²k	24.66670	24.1882	4
Insulation	ceiling	W/m²k	9.33330	10.0133	5
	window	W/m²k	52.00000	27.9428	1
g-value	window		1.33330	2.0656	10
	wall	(J/°C)	7.33330	14.4037	7
Thermal mass	floor	(J/°C)	0.00000	0	11
	ceiling	(J/°C)	8.66670	9.2664	6
infiltration		ac/h	5.33330	6.0222	9
Overheating ti	me	hour	42.00000	39.5778	3
Position of Ins	ulation		7.33330	7.7632	7

- Same thermal mass and different insulation type
 - Due to slow response of exterior insulated wall to the change in the indoor temperature, at the end of the overheating time there is more heat loss through convection to surface
 - So the saturation time is reduced



- Same U-value and different Thermal Mass
 - in case 70 which has interior insulation there is a decrease in demand shifting time by 18min when the wall thermal mass is increased by 73%

Case	Wallins	Floorins	Ceilins	Win Uvalue	gvalue	Wall Thermalma ss	Floor TMass	Ceil TMass	Infiltration	Insulatio n Type	Overheatin g Time	Demand shifting time
69	1.90334	0.68365 3	0.751639	0.8	0.63	327205	437449	122469	0.15539 9	1	2	62
70	1.90334	0.68365 3	0.751639	0.8	0.63	567622	437449	122469	0.15539 9	1	2	44

- During daytime when the ambient temperature rise, surface temperature of Case69 which has less thermal mass rise faster than case70, which cause more conduction heat losses in Case70.
- Even the relatively higher U-value of these two cases promotes conduction heat loss with small differences in outside surface temperature

• Same U-value and different Thermal Mass



- Overheating time
 - In a few cases there was a decrease in demand shifting time when there was an increase in overheating time and vice versa

Case	Wallins	Floorins	Ceilins	Win Uvalue	gvalue	Wall Thermalma ss	Floor TMass	Ceil TMass	Infiltratio n	Insulatio n Type	Overheatin g Time	Demand shifting time
11	0.69492	0.48166 3	0.48045	2.7	0.63	672599	255067	101363	0.10239 9	3	2	98
12	0.69492	0.48166 3	0.48045	2.7	0.63	672599	255067	101363	0.10239 9	3	4	42
time gets longer.												

- But as in these cases if the end of overheating time goes over outdoor peak temperature time, there happens more heat losses through exterior wall which is the most important factors in demand shifting
- So to get the best demand shifting time, ambient environment should also be taken into account

Conclusion

- High Insulation of a building is most important factor in demand shifting capability of the building type
- As long as a building is built within the parameter range in TABULA database, thermal mass is not an important factor in demand shifting
- If overheating time is not enough to heat up the thermal mass of a wall construction, interior insulation is more suitable to get an optimal performance in demand shifting
- The time of a day for overheating also have important factors to increase saturation time
- To get best demand shifting capability, detailed analysis on various building stock within the grid needs to be carried out

Thank you for your attention

For more questions please contact me at archope@samsung.com