Sensitivity analysis on Demand shifting capability based on the TwinHouse model

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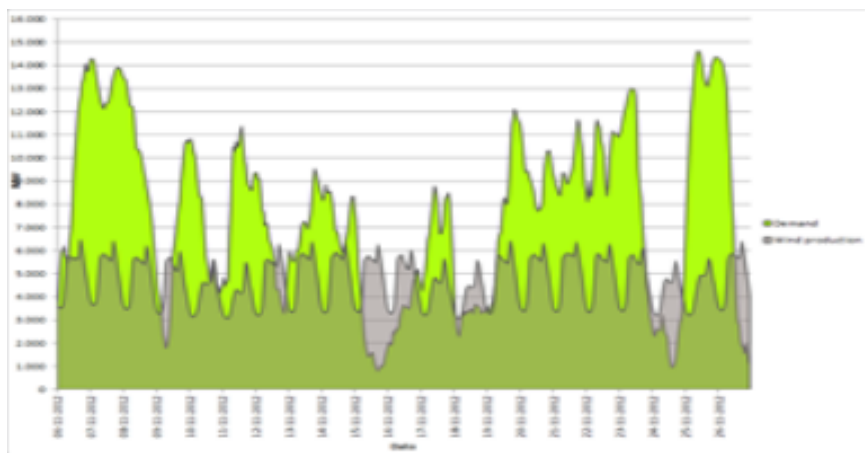
Purpose of this study

- 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 ther e is excess power generation in the grid



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

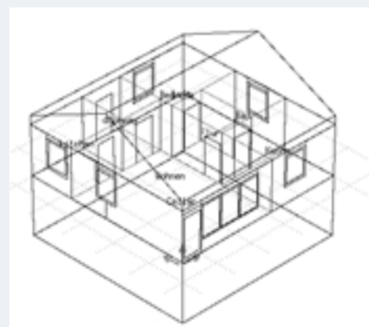
- Comprehensive sensitivity analysis is required to understand which factors a re most important for the demand flexibility
  - There were a few sensitivity analysis on demand shifting but the number of par ameters were very limited

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

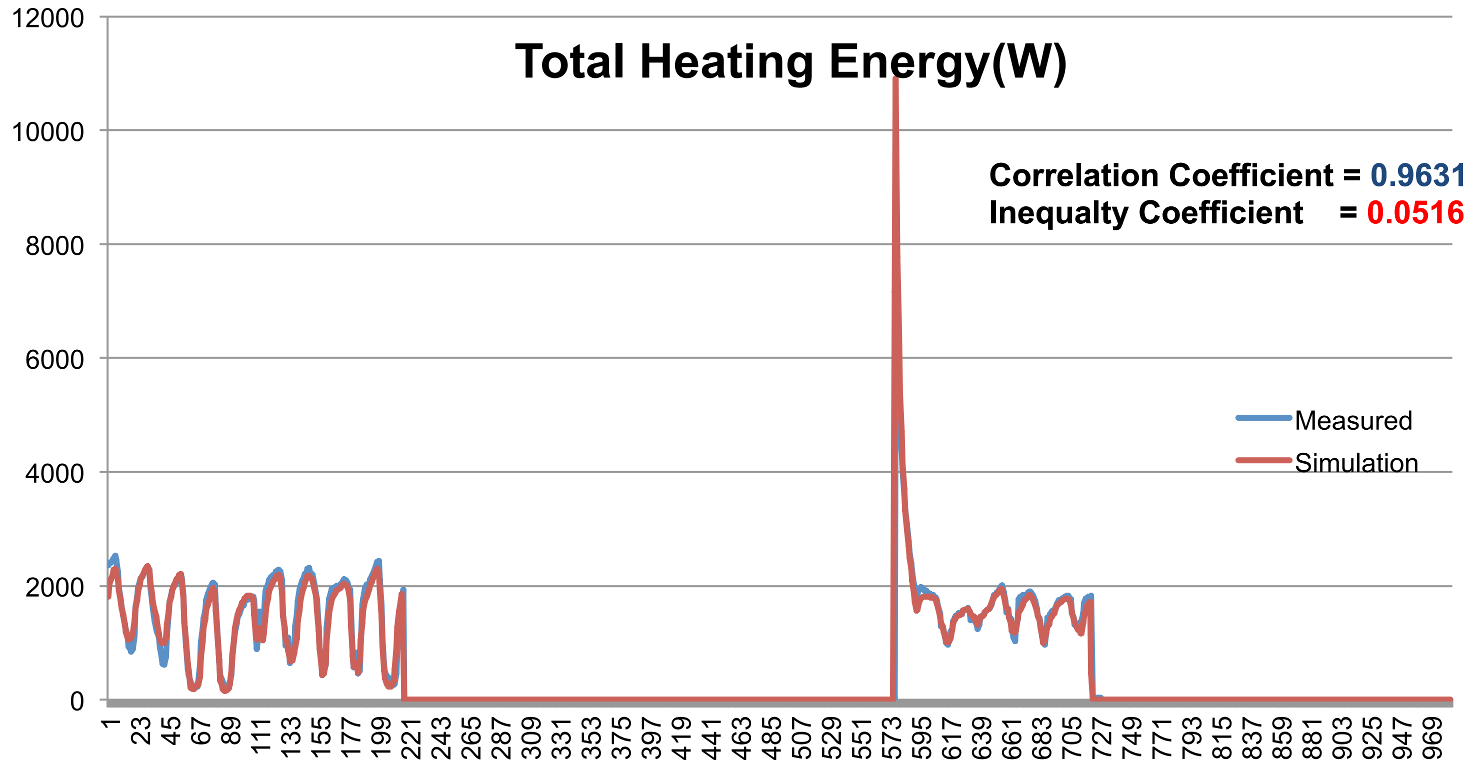
The TwinHouse Model

- 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
Geometry, Calculation detail	Same as TwinHouse calibrated Model 
Construction Infiltration, Overheating duration time	Input Parameter of each cases
Climate Data	Copenhagen, Denmark
Simulation day and Time step	1st of January, 2 minutes

The TwinHouse Model

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



Definition of parameter range

- Construction data is extracted from TABULA database

<Images from TABULA web tool>

Definition of parameter range

- Input for sensitivity analysis

Category	Item	Unit	Data Type	max	min	mode		
insulation	wall	W/㎡k	Triangular	2.8	0.12	1.6		
	floor	W/㎡k	Triangular	1.21	0.12	0.6		
	ceiling	W/㎡k	Triangular	1.9	0.11	1.03		
	window	W/㎡k	Discrete	0.8	1.7	2.7	4.2	5.1
g-value	window		Discrete	0.5	0.63	0.76	0.85	
Thermal mass	wall	(J/℃)	Triangular	816000	9576	510000		
	floor	(J/℃)	Triangular	585000	49875	96787.5		
	ceiling	(J/℃)	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 sam ple cases
- Simlab 2.2 is used to generate 25 LHS samples which exceeds the minimum n umber of 3/2*11(perameter number) = 16.5 which is recommended for LHS method

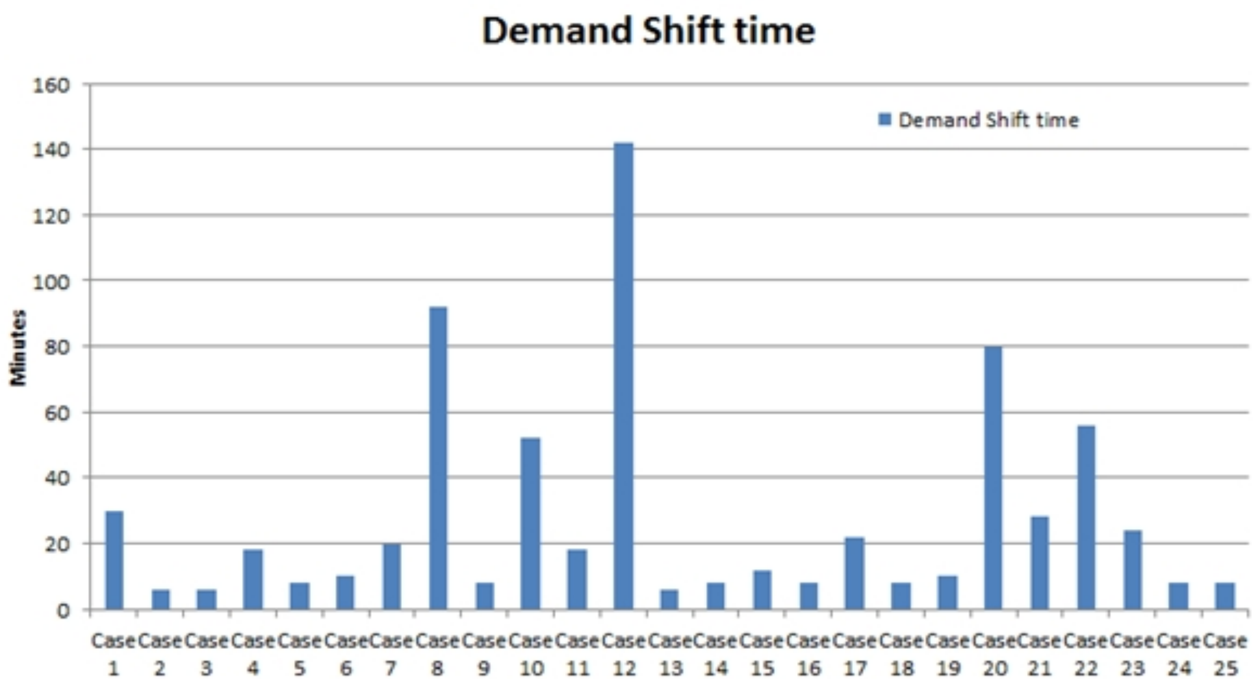
Table. 25 samples from SimLab

Nr.◦	Wallins◦	Floorins◦	Ceilins◦	WinUvalue◦	gvalue◦	WallTherma	FloorTMass	CeilTMass◦	Infiltration◦	PositionofIr	DurationTir
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

Simulation result and analysis of LHS 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 a nalyze the impact of each parameters because all the other parameter chang es at the same time

-> Morris Method is used adapted to generate new sample cases



Morris Case sample cases

- Morris method is similar to LHS in that it uses even number of divided interv al for each parameter. But in Morris method there is only 1 parameter chang e 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

	Wallins	Floorins	Ceilins	Win Uvalue	gvalue	Wall Thermalmass	Floor TMass	Ceil TMass	Infiltration	Insulation Type	Overheating Time	**Demand shifting time**
1	1.64242	0.802293	1.09447	0.8	0.85	419634	95613.7	56113.2	0.224406	1	2	**74**
2	1.64242	0.802293	0.48045	0.8	0.85	419634	95613.7	56113.2	0.224406	1	2	**86**
3	1.64242	0.481663	0.48045	0.8	0.85	419634	95613.7	56113.2	0.224406	1	2	**106**
4	1.64242	0.481663	0.48045	0.8	0.85	419634	95613.7	56113.2	0.224406	3	2	**96**
5	1.64242	0.481663	0.48045	2.7	0.85	419634	95613.7	56113.2	0.224406	3	2	**56**
6	1.64242	0.481663	0.48045	2.7	0.63	419634	95613.7	56113.2	0.224406	3	2	**54**
7	0.69492	0.481663	0.48045	2.7	0.63	419634	95613.7	56113.2	0.224406	3	2	**98**
8	0.69492	0.481663	0.48045	2.7	0.63	419634	255067	56113.2	0.224406	3	2	**98**
9	0.69492	0.481663	0.48045	2.7	0.63	419634	255067	101363	0.224406	3	2	**90**
10	0.69492	0.481663	0.48045	2.7	0.63	419634	255067	101363	0.102399	3	2	**98**
11	0.69492	0.481663	0.48045	2.7	0.63	672599	255067	101363	0.102399	3	2	**98**
12	0.69492	0.481663	0.48045	2.7	0.63	672599	255067	101363	0.102399	3	4	**42**
13	1.11579	0.97461	1.09447	2.7	0.5	419634	437449	69372.2	0.19189	2	1	**12**
14	1.11579	0.97461	1.09447	5.1	0.5	419634	437449	69372.2	0.19189	2	1	**6**

Morris Case sample cases

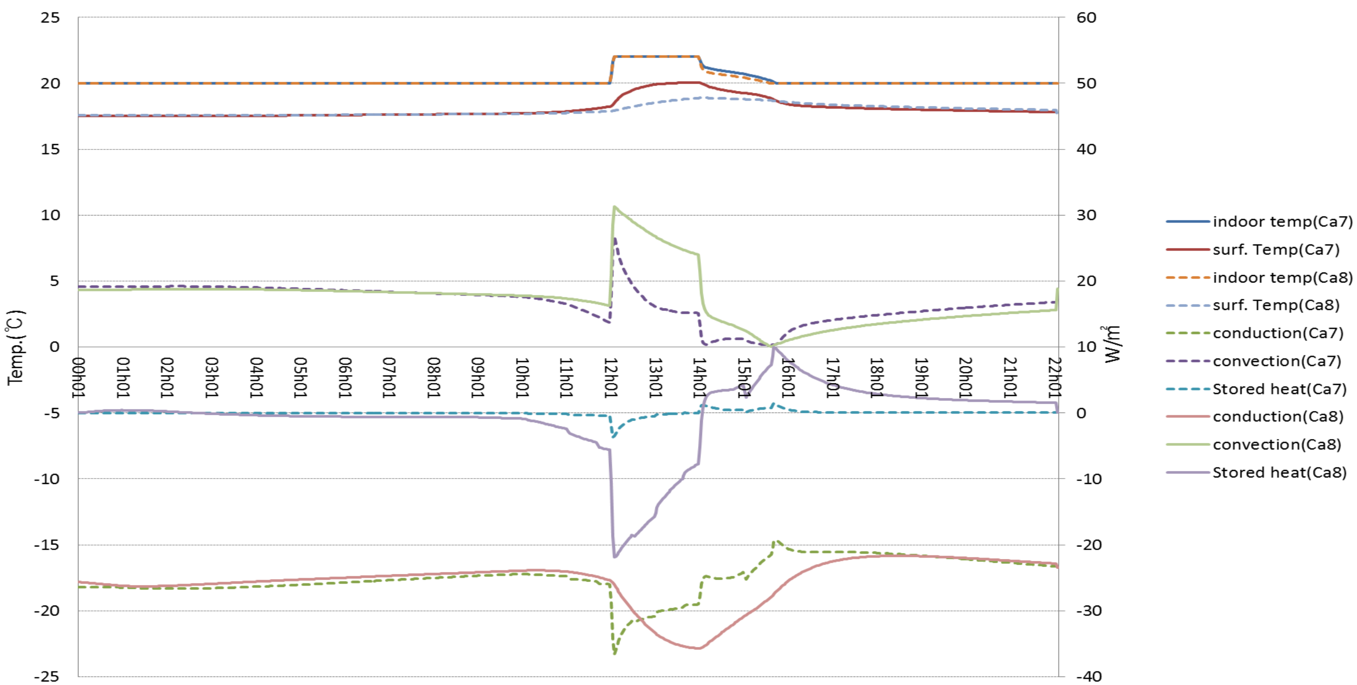
- Small values for μ to factors with negligible effect; σ measures the strength o f the interaction effects
- Insulation level of construction and overheating time are ranked as the most important factor with overheating time
  - As seen in μ value the other factors do not have significant impact on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

Category	Item	Unit	μ	σ	Rank
insulation	wall	W/㎡k	49.33330	40.8444	2
	floor	W/㎡k	24.66670	24.1882	4
	ceiling	W/㎡k	9.33330	10.0133	5
	window	W/㎡k	52.00000	27.9428	1
g-value	window		1.33330	2.0656	10
Thermal mass	wall	(J/℃)	7.33330	14.4037	7
	floor	(J/℃)	0.00000	0	11
	ceiling	(J/℃)	8.66670	9.2664	6
infiltration		ac/h	5.33330	6.0222	9
Overheating time		hour	42.00000	39.5778	3
Position of Insulation			7.33330	7.7632	7

Findings through Morris case study

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

Case	Wallins	Floorins	Ceilins	Win Uvalue	gvalue	Wall Thermalmass	Floor TMass	Ceil TMass	Infiltration	Insulation Type	Overheating Time	Demand shifting time
3	1.64242	0.481663	0.48045	0.8	0.85	419634	95613.7	56113.2	0.224406	1	2	106
4	1.64242	0.481663	0.48045	0.8	0.85	419634	95613.7	56113.2	0.224406	3	2	96



Findings through Morris case study

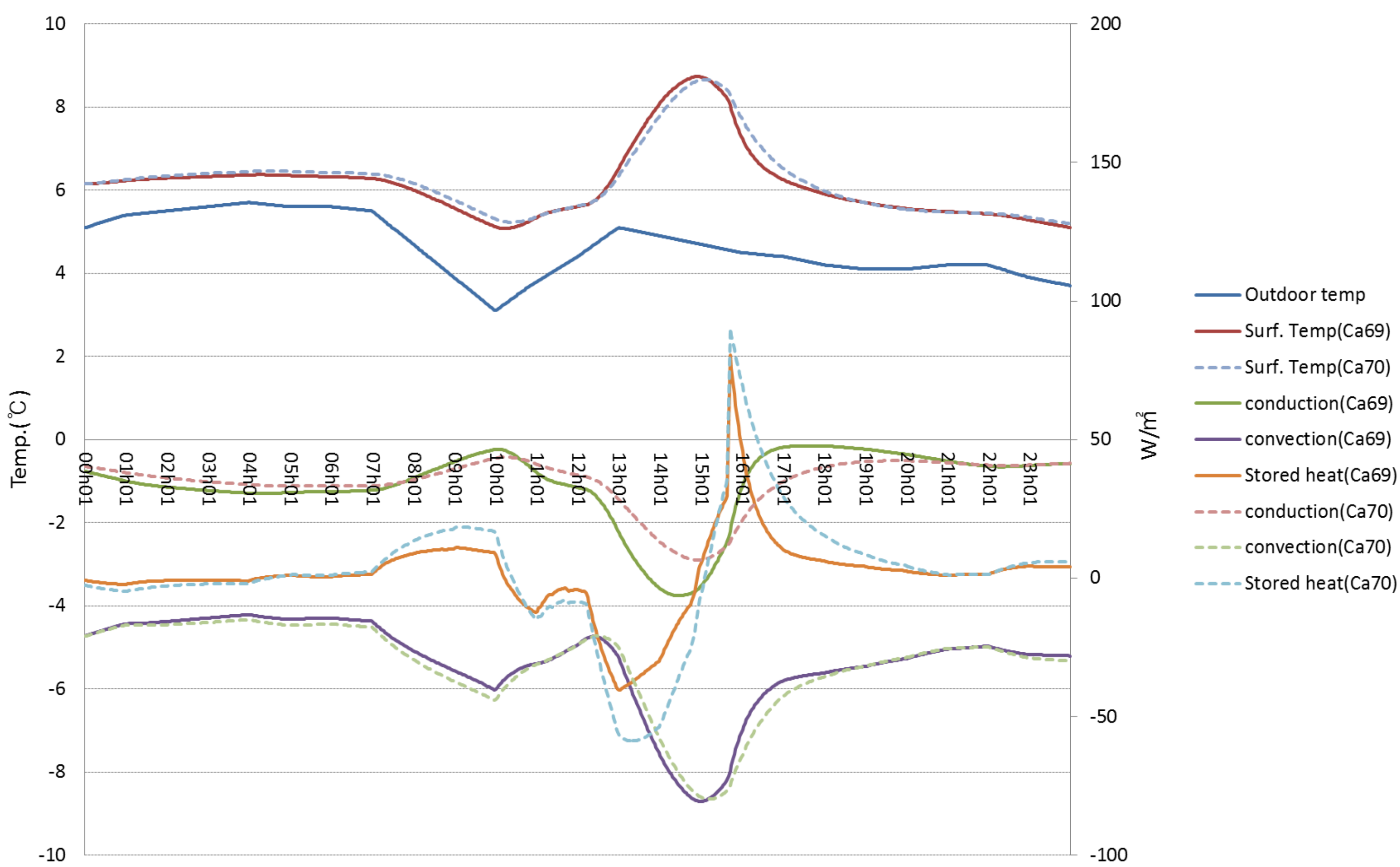
- Same U-value and different Thermal Mass
  - in case 70 which has interior insulation there is a decrease in demand shifting tim e by 18min when the wall thermal mass is increased by 73%

Case	Wallins	Floorins	Ceilins	Win Uvalue	gvalue	Wall Thermalmass	Floor TMass	Ceil TMass	Infiltration	Insulation Type	Overheating Time	Demand shifting time
69	1.90334	0.683653	0.751639	0.8	0.63	327205	437449	122469	0.155399	1	2	62
70	1.90334	0.683653	0.751639	0.8	0.63	567622	437449	122469	0.155399	1	2	44

  - During daytime when the ambient temperature rise, surface temperature of Case 69 which has less thermal mass rise faster than case70, which cause more conduc tion 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

Findings through Morris case study

- Same U-value and different Thermal Mass



Findings through Morris case study

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

Case	Wallins	Floorins	Ceilins	Win Uvalue	gvalue	Wall Thermalmas s	Floor TMass	Ceil TMass	Infiltration	Insulation Type	Overheating Time	Demand shifting time
11	0.69492	0.481663	0.48045	2.7	0.63	672599	255067	101363	0.102399	3	2	98
12	0.69492	0.481663	0.48045	2.7	0.63	672599	255067	101363	0.102399	3	4	42

  - It is sure that thermal mass absorb more heat as the overheating time gets longer.
  - But as in these cases if the end of overheating time goes over outdoor pea k 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 capa bility 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 const ruction, 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 sat uration time
- To get best demand shifting capability, detailed analysis on various building s tock within the grid needs to be carried out

Thank you for your attention

For more questions please contact me at
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