Passivhus Norden 2013

The architects and the residents are in charge of the indoor temperature

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Abstract

Reduced energy consumption is an important strategy for climate change mitigation. Buildings, worldwide, accounts for 40 % of the primary energy use and 24 % of greenhouse gas emissions.

There are studies and publications indicating that problems with high indoor temperature during summer are increasing in residential buildings designed as passive houses and low-energy buildings.

The objective of this study is to investigate and quantify the effect of different measures that may reduce the risk of high indoor temperature for dwellings in summer. The result may serve as guidelines for architects and consultants in early design stages.

This study examined the effect of different measures that may be applied to reduce the indoor temperature in dwellings in summer by simulations using IDA ICE 4.5. Hence, the results should only be used for residential buildings.

The simulations show that for residential buildings the duration of high indoor temperature increases when taking the step from the standard concept to the low-energy concept, regardless of investigated option. However the increase in duration is low compared to decreases of high indoor temperature, possible to reach by different airing strategies or different measures to reduce the solar insolation.

Airing must be presumed in order to achieve and maintain a high thermal comfort during summer without mechanical cooling. High indoor temperatures cannot be solved with only shading and window sizes. Therefore; Always create possibilities for airing, which requires operable windows,

doors or airing panels. Mechanical automated control may be a suitable feature in order to reduce the effort required from the residents. Secondly; consider large external horizontal solar shading. Note that the required size of a horizontal shading in relation to window height usually is higher on facades facing east and west.

Keywords: Thermal comfort, Indoor temperature, Airing, Solar shading, Simluation, IDA ICE

Introduction

Reduced energy consumption is an important strategy for climate change mitigation. Buildings, worldwide, accounts for 40 % of the primary energy use and 24 % of greenhouse gas emissions [International Energy Agency (IEA), 2013]. As the population of the world grows, the need for buildings increases. Hence, reduced energy consumptions in buildings and increased use of renewable energy are important measures to reduce our energy dependency and generation of greenhouse gases.

In a Nordic climate, reduced energy demand for space heating is an important measure to reduce the energy consumption in residential buildings. For new construction this is often achieved by applying the passive house design principle where the first step is to reduce heat losses by constructing a well insulated and air tight building envelope in combination with balanced ventilation with high system heat recovery efficiency [Janson, 2010].

There are studies and publications indicating that problems with high indoor temperature during summer are increasing in residential buildings following the design principles described above [Blomsterberg et al., 2012; Brunsgaard, Larsen, Heiselberg, & Knudstrup, 2010; Gervind & Ruud, 2011; Granmar, 2011; Larsen, 2011; Sikander et al., 2009]. Of these, [Brunsgaard et al., 2010; Granmar, 2011; Larsen, 2011] are describing problems with high indoor temperatures in summer time and [Blomsterberg et al., 2012; Gervind & Ruud, 2011; Sikander et al., 2009] are discussing the problem and giving recommendations of measures who can reduce the risk of high indoor temperature during summer. However, the guidelines given are not describing how big the effect different measures may be in quantified terms.

A questionnaire conducted in 2013 indicates that decisions regarding window sizes and solar shading are often made early in the design process of buildings and that studies and/or simulations of the thermal comfort were often not conducted [Berggren et al., 2012].

Objective

The objective of this study is to investigate and quantify the effect of different measures that may reduce the risk of high indoor temperature for dwellings in summer. The result may serve as guidelines for architects and consultants in early design stages.

Method

This study examined the effect of different measures that may be applied to reduce the indoor temperature in dwellings in summer by simulations using IDA ICE 4.5 [EQUA, 2013]. Hence, the results should only be used for residential buildings.

A similar study was presented in 2012 [Olsson, 2012]. However the study focused on technical systems and included mechanical cooling. Furthermore, the results indicated that solar shading had a larger impact on the indoor thermal comfort compared to mechanical cooling. Hence, there is a need to further study and quantify passive measures.

Two different buildings were simulated for all measures; a standard building, in parity with the Swedish building regulations regarding energy requirements, and a low-energy building, in parity with passive house requirements, see Table 1. The baseline for all simulations is presented in Table 2.

Table 1 Baseline for all simulations.

Option	Abbreviation	Adjusted parameter
Standard concept	Strd	U-value, exterior wall: 0.19 W/m^2K, U-value Windows: 1.20 W/m^2K.
Low-energy concept	LowE	U-value, exterior wall: 0.09 W/m^2K, U-value Windows: 0.70 W/m^2K.

Table 2 Baseline for all simulations.

Parameter	Description/Value
Ventilation system	Balanced ventilation with heat recovery. Heat exchanger efficiency: 85 %, No bypass. Temperature rise over supply air fan: 1°C.
Air exchange rate	0.375 l/s, m^2 (corresponds to 0.52 h^{-1}).
Temperature set point for heating	+21°C.
Climate	Stockholm (59.4N, 18.0E).
Peak heat gains from residents	2.0 W/m^2 (Variation described in Figure 1).
Peak heat gains from plug loads	4.9 W/m^2 (Variation described in Figure 1).
Intermediate floor	200 mm concrete (λ=1.7 W/mK, c=2300 kg/m^3 ρ=880 J/kgK) + flooring (λ=0.18 W/mK, c=1100 kg/m^3 ρ=920 J(kgK).
Internal walls	70 mm insulated stud wall (λ=0.044 W/mK, c=56 kg/m^3 ρ=1720 J/kgK) + 13 gypsum board on each side (λ=0.22 W/mK, c=970 kg/m^3 ρ=1090 J/kgK).
Windows	Two windows in each room (1.2x1.5 m) g_{glass}=0.45. Window-floor-ratio (A_w/A_c) = 20%.
External walls	Light infill walls. 13 mm gypsum board + 170 mm insulated stud wall + 45 mm insulation (λ=0.036 W/mK, c=20 kg/m^3 ρ=750 J/kgK) + 10 mm plaster (λ=0.8 W/mK, c=1800 kg/m^3 ρ=790 J/kgK).

Eight different rooms, in different directions, were studied. Schematic plan and location of rooms together with the variation of heat gains are presented in Figure 1. Variation of heat gains are based on [Bagge, 2011].

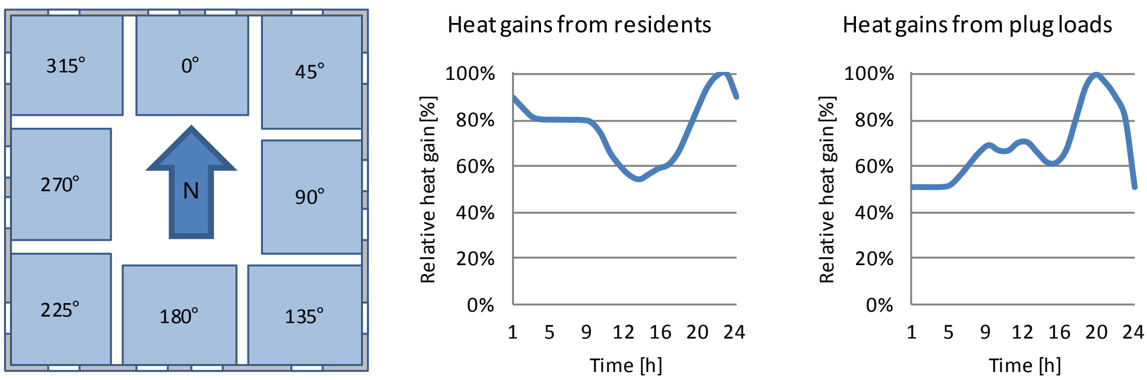


Figure 1 Left: Locations of different rooms. Middle: Relative heat gains from residents Right: Relative heat gains from plug loads. Heat gains are based on [Bagge, 2011]. Peak loads for heat gains are presented in Table 1.

The study focused on different types of solar shading, airing strategies, high/low thermal mass within the building and window sizes. The different options are described in Table 3. Each option was simulated separately and in combination with other options. For fixed exterior horizontal solar shading; both shading lentgh and shading angle is presented, the correlation is presented in Figure 2.

Except for airing; all measures described in Table 3 affects daylighting. These effects are not included in this study. The study is focused on measures which may be considered without increasing the energy consumption of the building. Hence, mechanical cooling was not considered.

Table 3 Description of investigated measures and corresponding abbreviations.

Option	Abbre-viation	Adjusted parameter
Base Case	BC	No adjustments.
Larger windows	W+5	Window size increased, two 1500x1500 mm (A_w/A_c=25%).
Smaller windows	W-5	Window size decreased, two 900x1500 mm (A_w/A_c=15%).
Airing strategy 1	A1	If indoor temperature > 25°C → Windows are open 100 % 1 h starting 6 A.M. and 6 P.M.
Airing strategy 2	A2	If indoor temperature > 25°C → Windows are open 100 % 1 h starting 6 A.M. and 4 h starting at 6 P.M. Rest of the day: 10% open.
Airing strategy 3	A3	If outdoor daily average outdoor temperature > 15°C → Windows are 25% open all day.
Heavy building	H	Exterior wall; 150 mm concrete + exterior insulation (adjusted to achieve U-values according to Strd and LowE) + 10 mm plaster. Intermediate floor: increased to 300 mm concrete.
Light building	L	Intermediate floor: concrete construction replaced with 200 mm insulated wooden frame.
Fixed solar shading 1a	SS1a	Exterior horizontal solar shading (“small balcony”) L=1.0 m, $\alpha_{1.0}$=34°
Fixed solar shading 1b	SS1b	Exterior horizontal solar shading (“medium balcony”) L=1.5 m, $\alpha_{1.5}$=45°
Fixed solar shading 1c	SS1c	Exterior horizontal solar shading (“large balcony”) L=2.0 m, $\alpha_{2.0}$=53°
Interior blinds	SS2a	Interior blinds. Drawn when solar radiation > 100 W/m^2 (interior side of glass, measured without blinds). g_{glass} reduction = 35 %.
Exterior blinds	SS2b	Exterior blinds. Drawn when solar radiation > 100 W/m^2 (interior side of glass, measured without blinds). g_{glass} reduction = 86 %.
Solar control glass	SS3	Solar control glass. g_{glass} reduced by 50% (g_{glass} = 0.225).

There are different ways to define accepted indoor temperature, both in standards [ASHRAE, 2010; Swedish Standard Institute, 2005, 2007] and building rating systems [Swedish green building council, 2012; Sveriges Centrum för Nollenergihus, 2012; US Green Building Council, 2013]. Within the Swedish definition/criterion of/for “mini energy house”, passive house and zero-energy building; calculations must be carried out to investigate the indoor temperature from April to September. It is recommended that the indoor temperature should not exceed 26°C more than 10% of the period. Based on this requirement; the results from the simulations were evaluated by calculating the duration of the period April-September of which the indoor temperature exceeded 25.99°C.

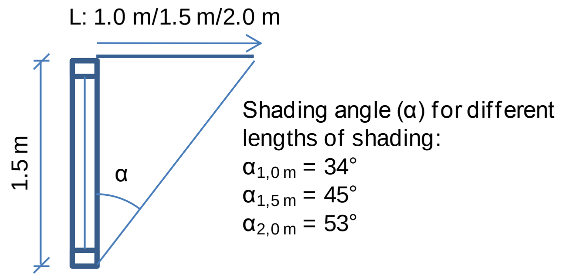


Figure 2 Correlation between different shading lengths and shading angle.

Results and discussion

In Figure 3-5; all results are presented graphically, presenting the energy needed for space heating together with the duration of indoor temperature above 25.99°C during April-September. Each dot/point in the graphs represents a specific result for a room. Thus, there are eight results for each option. To show the large spread and still enable highlighting specific simulations and results; all results are presented in each graph in grey, where specific results are highlighted in each graph. When the expression "too high indoor temperature" is used; it means that indoor temperature is above 25.99 °C. When comparing differences between temperature and energy for different options; average values for all rooms are used. E.g. for the Base case with low-energy concept; the energy demand for space heating varies in between 13 and 29 kWh/m^{2}a. The average energy demand for all eight rooms, which is used to compare energy demand with other options, is 21 kWh/m^{2}a.

Comparing the base case with standard- and low-energy concept (Figure 3, left); the low-energy concepts, in general, has a lower energy demand for space heating and longer duration of too high indoor temperature. When the duration with too high indoor temperature increases from 61% to 75%, the energy demand decreases from 38 kWh/m^{2}a to 21 kWh/m^{2}a. Rooms towards south and west suffers the most from too high indoor temperature. Rooms in the standard energy concept towards south and west has a longer duration of too high indoor temperature compared to rooms towards north and northeast in the low-energy building. Never the less, the duration of too high indoor temperature are far above recommended value of 10% from "Sveriges centrum för nollenergihus".

Comparing different options for reducing the solar insolation (Figure 3, right) for the low-energy concept; the exterior horizontal solar shading is the best option in general. The duration of too high indoor temperature is reduced from 75 % to 44 %. The energy demand increases from 21 kWh/m^{2}a to 28 kWh/m^{2}a. The interior blinds have a very low effect on the indoor temperature and energy demand for heating. The exterior blinds have a rather good effect. The duration of too high indoor temperature is reduced to 47%, combined with a smaller increase of energy demand for space heating, when compared to exterior horizontal solar shading. It should be noted that the exterior blinds show a stable and consistent indoor temperature regardless of direction. Hence they are expected to be used when needed. It should also be noted that towards west; the exterior blinds has a bigger impact on the indoor temperature than the exterior horizontal solar shading, as presented in Figure 3 (medium balcony). However if a large balcony is used; the exterior horizontal solar shading is the best option.

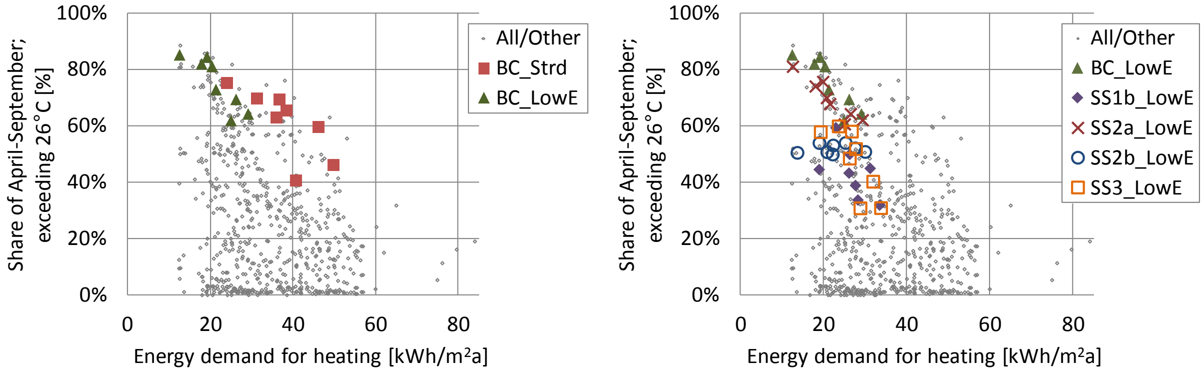
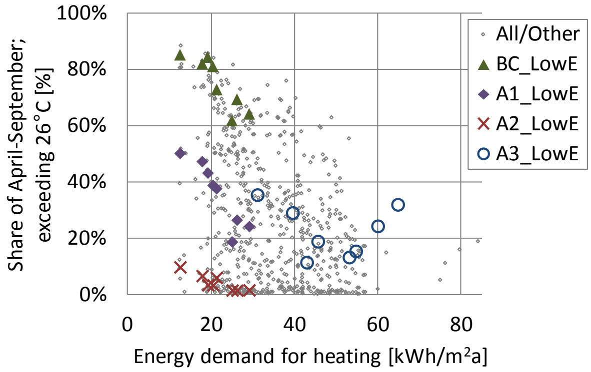


Figure 3 Energy demand for heating and duration of too high indoor temperature. Different options are high-lighted. Left: Base case for standard- and low-energy concept. Right: Low-energy concept with different options for reducing solar insolation.

Different airing strategies have a large impact on indoor temperature (Figure 4, left). Comparing different airing strategies for the low-energy concept; opening the windows one hour in the morning and the afternoon, when indoor temperature is above 25°C, the duration of too high indoor temperature is reduced from 75% to 36%. The energy demand for space heating is not affected by this rather limited airing. If the airing is increased, A2, the duration of too high indoor temperature is reduced to 4% while the energy demand for space heating is increased by only 1 kWh/m^{2}a. If one are keeping the windows ajar during summer, option A3, the duration of high indoor temperature is reduced to 22%. However, the energy demand for space heating is increased from 21 kWh/m^{2}a to 49 kWh/m^{2}a.

The results indicate that an attentive and active resident or an automatic mechanical window opening system combined with a thoughtful airing strategy may improve the indoor thermal comfort during summer significantly with low or no impact on the energy demand for space heating. A less thoughtful airing strategy may improve the thermal comfort but also increase the energy demand for space heating. It shall be noted that a professional facility manager shuts down the space heating during summer. Hence the actual bought energy for space heating may be lower than the simulated demand.

As can be seen in Figure 4, right; increasing the window size always results in a higher energy demand for space heating and a longer duration of too high indoor temperature. However, there is one exception; the room towards the south with low-energy concept. In this case the duration of too high indoor temperature is already very high, and only slightly increased. The energy demand for space heating is not increased, it is slightly reduced.



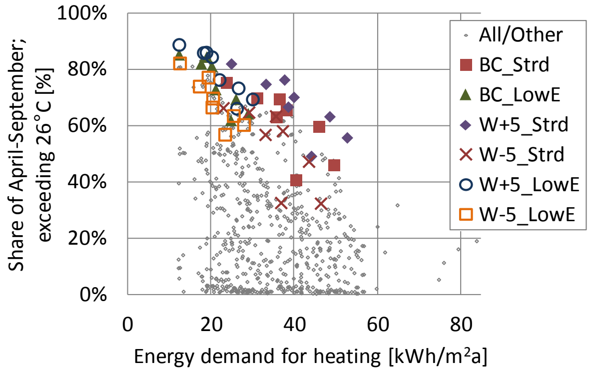


Figure 4 Energy demand for heating and duration of too high indoor temperature. Different options are high-lighted. Left: Low-energy concept with different airing strategies. Right: Standard- and low-energy concept with different window sizes.

In Figure 5, left; the effect of different thermal inertia within the low-energy building is studied with or without airing strategy A1. Only increasing the thermal inertia for the low-energy building has no impact on the indoor temperature or the energy demand for space heating. Hence, the thermal inertia, due to the intermediate floor in concrete, is already high. Reducing the thermal inertia slightly reduces the duration of too high indoor temperature and increases the energy demand for space heating. The duration decreases from 75 % to 71 %, the energy demand increases from 21 kWh/m^2a to 23 kWh/m^2a. Combining different thermal inertia with airing show larger effect on the indoor temperature; the option with low thermal inertia has a more stable indoor temperature regardless of direction and has a lower duration of too high indoor temperature, 34 % compared to 37 % when the building has a high thermal inertia. The largest differences are reached in rooms towards south and west.

However, sorting out the combinations with the lowest energy demand for space heating and lowest duration of too high indoor temperature; high thermal inertia is included in all combinations (Figure 5, right). The best combinations, with both low energy demand for space heating and low duration with too high indoor temperature are low-energy buildings with high thermal inertia, airing strategy 2 and external or internal blinds. If airing strategy 1 is considered to be more reasonable; high thermal inertia in combination with external blinds or exterior horizontal solar shading (medium balcony) is preferred. These results indicate that high thermal inertia is not preferable for dwellings/rooms in residential buildings if they are exposed to direct sunlight and if there are no possibilities for airing. If measures are implemented to reduce solar insolation and airing is assumed; high thermal inertia is preferable. Hence it reduces the energy demand for space heating and contributes to a stable and low indoor temperature.

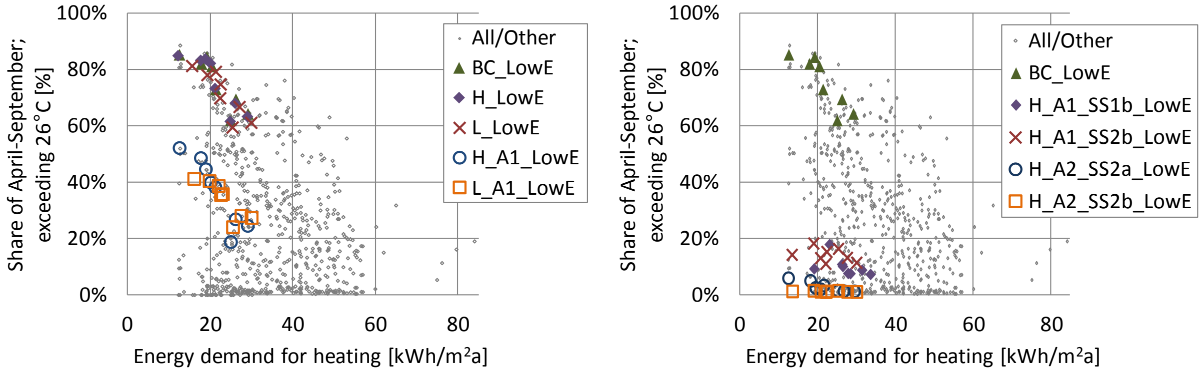


Figure 5 Energy demand for heating and duration of too high indoor temperature. Different options are high-lighted. Left: Low-energy concept with different thermal inertia, with and without airing. Right: Low-energy concept. Combinations with the lowest indoor temperature are displayed. Two combinations including A1, two combinations including A2.

Conclusions

The simulations show that for residential buildings the duration of too high indoor temperature increases when taking the step from the standard concept to the low-energy concept, regardless of investigated option. However the increase in duration is low compared to decreases of too high indoor temperature, possible to reach by different airing strategies or different measures to reduce the solar insolation.

There is a large spread in the results. There are results with low energy demand for spaceheating, less than 15 kWh/m^{2}a, and low duration of too high indoor temperature, below 10%. There are also results with high energy demand for space heating, above 50 kWh/m^{2}a, and long duration of too high indoor temperature, over 50%. This indicates that it is possible to design residential buildings with low energy demand for space heating during winter and high thermal comfort during summer if airing is presumed. Furthermore, the simulations show that some options (e.g. high thermal inertia) are less suitable as a single measure or in combination with other measures, while they may be suitable in specific combinations. The result highlights the complexity of this issue.

It is possible to achieve a high thermal comfort during summer simply by airing (options A2). However, this requires a lot of the residents if there is no mechanical and automated control of opening of windows. Therefore, residential buildings should always be designed with measures to reduce the solar insolation, as this may enable the residents to achieve and maintain a high thermal comfort during summer by airing one hour in the morning and in the afternoon. This airing strategy should be easy for the residents to maintain.

The simulations show that zones towards south, east and west need to be given attention when considering measures to reduce the solar insolation. Enhanced focus needs to be given to facades facing east and west if exterior horizontal solar shading is used since the solar altitude is lower in these directions.

This study shows that airing must be presumed in order to achieve and maintain a high thermal comfort during summer without mechanical cooling. High indoor temperatures cannot be solved with only shading and window sizes.

Decisions regarding window sizes and solar shading are often made early in the design process of buildings. Hence, the thermal comfort during summer should also be investigated and evaluated early in the design process.

Based on this study the following recommendations and ranking of different measures are given for residential buildings:

1. Always create possibilities for airing. This requires operable windows, doors or airing panels. It should be possible to facilitate airing when the residents are not at home. Hence, consider risk of burglary and rainfall. Mechanical automated control may be a suitable feature in order to reduce the effort required from the residents.
2. Always consider large external horizontal solar shading, shading angle >50°. Note that the required shading angle usually is higher on facades facing east and west.
3. If large external horizontal solar shading is not an option; medium large solar shading, ~45°, could be considered towards the south. Towards east and west external blinds may be a suitable option (provided that adequate operation by the residents is presumed).
4. If external horizontal solar shading is not an option. Consider external blinds.
5. Solar control glass almost has the same impact on indoor temperature as external blinds. However they increase the energy demand for space heating due to the constant reduction of solar insolation, also during winter.
6. Interior blinds have a relatively low effect, but it has a large impact compared to adjustment of quantities and sizes of windows.
7. Adjusting the quantities and sizes of windows may have an impact if the window-wall-ratio is changed more than 10%.
8. Analysing the thermal inertia of the building should be the last option considered after all options above have been considered.

As mentioned in the section describing the method for this study; how different measures affect daylighting is not included. Choice of measure to reduce the solar insolation should be made considering both daylighting and indoor temperature.

The effect of external blinds is depending on the assumptions made of when they are drawn. Hence if different use of the blinds would have been assumed, the effect would have been different.

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Appendix A

Table A.1

Energy demand for heating, ED (kWh/m²a), and duration of overheating, OH, (%). Average, min- and max value + values for each direction for different options and energy concept.															
		BC		W+5		W-5		A1		A2		A3		H	
		Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE
Average	ED	38	21	40	22	36	21	38	22	38	22	67	49	38	21
	OH	61%	75%	67%	79%	53%	69%	24%	36%	4%	4%	14%	22%	62%	75%
Min. value	ED	24	13	25	13	23	13	24	13	24	13	44	31	24	12
	OH	41%	62%	49%	66%	32%	57%	11%	19%	1%	1%	2%	11%	42%	61%
Max value	ED	50	29	53	30	47	28	50	29	50	29	84	65	50	29
	OH	75%	85%	82%	89%	66%	82%	38%	50%	8%	10%	25%	35%	76%	85%

Table A.2

Energy demand for heating, ED (kWh/m²a), and duration of overheating, OH, (%). Average, min- and max value + values for each direction for different options and energy concept.															
		L		SS1a		SS1b		SS1c		SS2a		SS2b		SS3	
		Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE
Average	ED	40	23	43	25	45	27	47	28	39	22	40	23	45	27
	OH	54%	71%	31%	54%	21%	43%	17%	35%	53%	69%	31%	52%	25%	47%
Min. value	ED	28	16	30	17	34	19	37	21	25	13	27	14	34	19
	OH	39%	59%	20%	43%	16%	32%	12%	28%	36%	60%	27%	50%	14%	31%
Max value	ED	51	30	54	32	55	34	56	34	50	29	51	30	56	34
	OH	67%	81%	50%	65%	34%	59%	26%	52%	64%	81%	38%	54%	36%	60%

Table A.3

Energy demand for heating, ED (kWh/m^2a), and duration of overheating, OH, (%). Average, min- and max value + values for each direction for different options and energy concept.															
		L_A1		L_A2		L_SS1b		L_SS2a		L_SS2b		L_SS3		L_A1_SS1b	
		Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE
Average	ED	41	23	41	23	47	28	41	23	42	24	47	28	47	28
	OH	25%	34%	5%	6%	24%	40%	48%	66%	30%	49%	28%	43%	9%	15%
Min. value	ED	29	16	30	12	37	21	29	16	31	17	36	22	37	21
	OH	16%	24%	2%	2%	17%	32%	36%	56%	27%	46%	16%	30%	7%	12%
Max value	ED	51	30	51	30	56	34	51	30	52	31	57	35	56	34
	OH	32%	41%	11%	13%	35%	51%	59%	74%	34%	52%	38%	54%	15%	22%

Table A.4

Energy demand for heating, ED (kWh/m^2a), and duration of overheating, OH, (%). Average, min- and max value + values for each direction for different options and energy concept.															
		L_A1_SS2a		L_A1_SS2b		L_VA1_SS3		L_A2_SS1b		L_A2_SS2a		L_A2_SS2b		L_A2_SS3	
		Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE	Strd	LowE
Average	ED	41	24	42	24	47	28	47	28	41	24	43	25	47	29
	OH	21%	29%	11%	18%	11%	16%	2%	2%	4%	4%	2%	2%	2%	2%
Min. value	ED	30	16	32	17	37	22	37	22	31	17	32	18	37	22
	OH	15%	23%	9%	16%	6%	9%	1%	1%	1%	2%	1%	1%	1%	1%
Max value	ED	51	30	52	31	57	35	56	34	51	30	52	31	57	35
	OH	27%	34%	14%	22%	17%	22%	2%	3%	7%	8%	2%	3%	4%	5%

Table A.5

Energy demand for heating, ED (kWh/m^2a), and duration of overheating, OH, (%). Average, min- and max value + values for each direction for different options and energy concept.															
		T_A1		**T_A2**		**T_SS1b**		**T_SS2a**		**T_SS2b**		**T_SS3**		**T_A1_SS1b**	
		Strd	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**
Average	**ED**	38	21	38	21	45	27	38	22	40	22	45	27	45	27
	OH	25%	37%	3%	4%	21%	46%	54%	69%	33%	51%	25%	48%	5%	10%
Min. value	**ED**	24	13	24	12	34	19	24	12	26	13	33	19	34	19
	OH	10%	19%	1%	1%	14%	35%	39%	59%	29%	50%	11%	32%	3%	7%
Max value	**ED**	50	29	50	29	55	33	50	29	51	30	55	34	55	34
	OH	39%	52%	8%	9%	36%	58%	64%	81%	40%	53%	39%	59%	11%	18%

Table A.6

Energy demand for heating, ED (kWh/m^2a), and duration of overheating, OH, (%). Average, min- and max value + values for each direction for different options and energy concept.															
		T_A1_SS2a		**T_A1_SS2b**		**T_A1_SS3**		**T_A2_SS1b**		**T_A2_SS2a**		**T_A2_SS2b**		**T_A2_SS3**	
		Strd	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**	**Strd**	**LowE**
Average	**ED**	38	22	40	23	45	27	45	27	38	22	40	23	45	27
	OH	19%	28%	7%	14%	7%	12%	1%	1%	2%	3%	1%	1%	1%	1%
Min. value	**ED**	24	12	26	13	33	19	34	19	24	12	27	13	33	19
	OH	10%	18%	4%	11%	2%	5%	0%	1%	1%	1%	1%	1%	0%	1%
Max value	**ED**	50	29	51	30	55	34	55	33	50	29	51	30	55	34
	OH	28%	40%	10%	18%	12%	20%	1%	2%	5%	6%	1%	1%	2%	3%