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Shading and natural ventilation, addressing indoor overheating in the present and future through the case study of Bysjöstrand eco-village

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Abstract

Climate change temperatures expected to rise and extreme heat events (HW) can be intensified. The influence of climate change on the built environment will became more apparent over the coming years. For example, there would be a shift in the risk of overheating in buildings, as well as the cooling and heating needs.

Studies found that design strategies used to optimize buildings for winter like: good thermal insulation, high airtightness, and extra heat gains increase the risk of overheating. Thus, because of climate change, there is a need for checking the buildings for summer conditions even in heating dominated countries.

This study aims to investigate the potential of two main passive design strategies to mitigate indoor overheating: ventilation and shading. The main focus of this study is on single-family homes within the Swedish context. Bysjöstrand Ekoby Association's Bysjöstrand eco-village project is used as case study. 30 single-family homes are simulated using Honeybee to run EnergyPlus for calculating indoor mean air temperature values, extracting the number of hour and percentages of overheating for each building.

Six alternative scenarios were used to evaluate the eco-village. The first structures were assessed to determine the hours and percentage of time spent overheating in the present and future situations. The second scenarios, which involved utilizing natural ventilation, was tested to determine if and to what extent it can help to reduce the overheating risk in present and future.

A combination of natural ventilation and shading was used for the last scenarios both for current and future climate.

According to the findings, natural ventilation has the greatest influence in reducing overheating. Combining these two strategies in 2020 and 2070 can lower the average percentages of overheating from 17.5 % to 0.6 % and 52.8 % to 12.4%, respectively.

The majority of the overheating risk may be addressed using passive strategies, based on the results. More detailed building design is likely be able to eliminate overheating in single family homes, however, as this study showed it is important to consider passive strategies from the early stage on the design process.

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Abbreviations

Abbreviation	Description
GHG	Greenhouse gases
IPCC	the intergovernmental panel on climate change
SMHI	Swedish Meteorological and Hydrological Institute
UK	United Kingdom
WWR	Windows-to-wall ratio
CIBSE	Chartered Institution of Building Services Engineers

Nomenclature

Symbol	Description	Unit
R	Thermal resistance	m^2K/W
R_{se}	External surface thermal resistance	m^2K/W
Rsi	Internal surface thermal resistance	m^2K/W
U	Thermal transmittance	$W/[m_2K]$

1 Introduction

1.1 Background

The buildings and construction sector account for a large share of our overall energy use. The International Energy Agency reported that buildings are responsible for more than one-third of the global energy use. In the context of Sweden, the total energy use of buildings is 39 % [2]. In addition, this sector is also responsible for around 40 % of CO2 emission, directly and indirectly [1]. Thus, by reducing the energy utilization in building sector carbon footprint can be reduced as well.

Owing to rising temperatures and the intensification of extreme climate events (such as heatwaves, drouths and floods), the influence of climate change on the built environment will became more apparent over the coming years [30]. For example, with rising temperatures, the share of cooling and heating energy use is expected to change over the coming decades. In heating dominated countries, such as Sweden, buildings are optimized for winter-time performance. Some of the most common strategies to reduce the heating demand are the reduction of shading by adjacent buildings, and the increase of airtightness and thermal insultation of the building envelope. However, several studies found that retrofits aiming to improve building energy-efficiency over the cold season often led to increased overheating risk during the warm period of the year [3, 31]. Overheating has an impact on the inhabitant's wellbeing, especially if it affects the night-time sleep as it may result in the premature deaths of vulnerable people [3]. As a result of climate change, overheating caused mortality is expected to triple by 2050 in the UK—assuming no interventions [3].

Shade in the urban environment will decrease surface and air temperature [13]. Moreover, shading can also reduce overheating in buildings and decrease their cooling demand [12]. Trees have an undeniable role in cities: from the aesthetical point of view to their impact on the urban microclimate [12]. As discussed by many studies, several factors may influence which tree is most appropriate for a given location, such as land regulation and ownership, how much space is provided for planting, esthetic considerations [12, 15,16]. The location of the tree in relation to the building influences when and how long in a day a building will benefit from the shade [12, 14]. In contrast to summertime benefits, trees around buildings may also increase the heating demand during winter months. In order to overcome this contradiction, planting of deciduous trees is recommended around buildings, especially in front of the facades facing the equator. Deciduous trees will allow solar radiation to reach the building in winter and they provide shade during the summer months [12].

Natural ventilation is another way to address overheating in buildings. Besides removing excess heat, it also delivers fresh air for the occupants. Thus, natural ventilation may serve different goals, which influence the windows' (assumed) time of operation. These goals may include: (1) the provision of fresh air; (2) the removal of excess heat; and (3) the cooling down of the building thermal mass (the process also known as night flushing). Studies have shown that heat-removal via single-sided ventilation is often ineffective and hence, cannot improve indoor thermal comfort. In contrast, cross-ventilation is better at decreasing the need for cooling and reducing indoor air temperature [27].

1.2 Research questions

The aim of this study is to analyze current and future indoor overheating risk within the Swedish context, utilizing Bysjöstrand eco-village as the case study.

The research questions of the study are as follows:

1. How will climate change affect indoor overheating in Swedish single-family homes (comparing the year 2020 and 2070)?

2. To what extent can natural ventilation (opening the windows) reduce the issue of overheating, now and in the future?
3. Can the issue of overheating overcome with the combined use of shading and ventilation?

2 Literature review

This brief literature review focuses on the effect of trees on indoor overheating, solar access and building energy use

The study by Ozarisoy and Elsharkawy [3], analyzed several porotypes houses that were monitored during the summer of 2018 in the UK. Their study revealed the risk of overheating will likely increase in these houses due to climate change. The identified factors that contribute to overheating are: good thermal insulation, high airtightness, the absence of adequate ventilation in living spaces, and extra heat gains due to using composite cladding material. As noted by the authors, most of these factors are the result of design decisions aiming to reduce heating demand.

According to the study of Tsoka et al. [4], up to 54 % saving in energy demand during the summer can be achieved via shading by urban trees in Greece. The authors found that the two most important parameters for reducing energy consumption is the pattern or location of trees and their foliage density.

Several studies [12, 17, 18], found that for reducing cooling demand, the west façade is the best location for trees, while the second-best is the east façade. The authors recommended shading these facades during afternoon and in the morning.

In their study, Balogun et al. [26], measured two similar buildings: one with shading from trees, the other one without. They analyzed the difference by comparing the cooling degree hours of the buildings. As expected, the authors found that the unshaded building warmed up earlier and faster than the shaded one. "Indoor and outdoor cooling degree day" were also higher for unshaded building.

The importance of choosing appropriate tree species for reducing cooling load was discussed by Abdel-Aziz et al. [12]. According to the authors, deciduous trees are most fit to be used as shade trees. They will provide ample shade during hot summer months and will obstruct little during wintertime when access to solar radiation is beneficial. According to this study, the main parameters affecting the tree's shading potential are: tree species, foliar condition, canopy volume, crown shape, foliation period, leaf area, as well as the tree's location with respect to buildings.

In the article on passive solar design principles [24], Littlefair recommends keeping the south-facing façade unobstructed in the ±20–30° range from the south to ensure solar access during wintertime.

According to the reviewed literature, in order to guarantee that solar radiation will reach the building in winter, keeping the unobstructed range (±20–30°) is really important to overcome the contradiction between winter- and summertime solar access requirement in buildings. Besides this, utilizing deciduous trees and shading western façade help to mitigate the overheating for the buildings during summer months.

3 Materials and methods

Bysjöstrand Ekoby Association's Bysjöstrand eco-village project is used as case study. The information necessary for this study (regarding the site and the buildings) were provided by Inobi AB [11, 22].

3.1 Case study site

Bysjöstrand eco-village is situated in the county of Dalarna, Sweden. It is 20 and 45 km away from the nearby towns of Ludvika and Borlänge, respectively (Figure 1). The main goal of this eco-village is to ensure a sustainable lifestyle for its occupants. This eco-village is in the planning stage and the construction is set to begin in 2022.

Grangärdebygdens Interest Association, which is a "non-profit rural association for housing in Grangärde and its surroundings" is in charge of the development of Bysjöstrand eco-village. The architectural company Inobi AB is also responsible for this development [11, 25]. This eco-village is in the planning stage and the construction is set to begin in 2022.

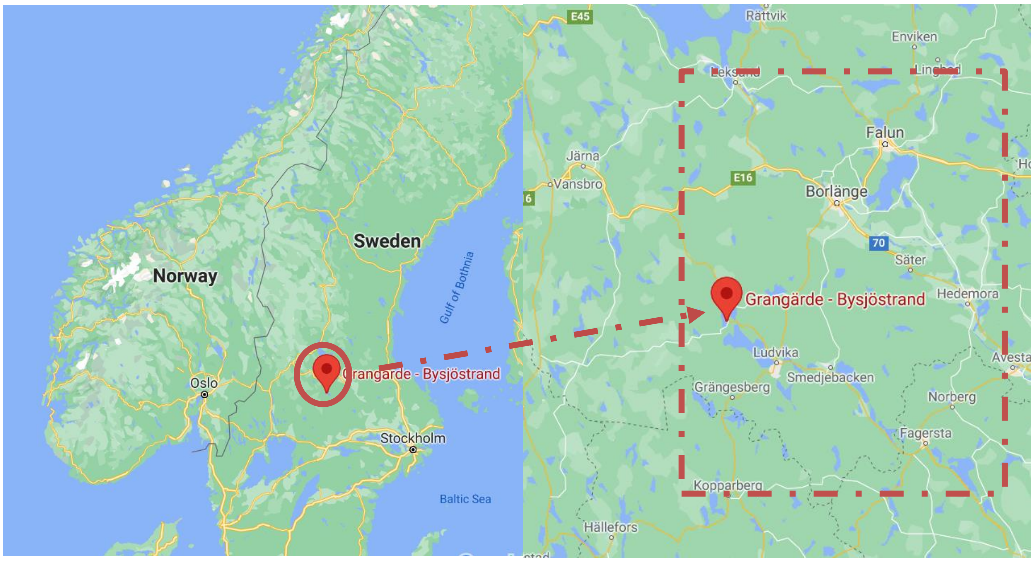

Figure 1. The location of Bysjöstrand eco-village

Site layout and program. The site is bounded by lake Bysjön on the west and is surrounded by Korsnäsberget hill on the east. The layout of the eco-village is organized around a central road that follows the shoreline. The buildings—consisting primarily of detached and semi-detached single-family homes—are arranged along this road. The total area of the site that will be used to build around 40 to 80 residential buildings in it is 31,156 m^2 (Table 1). It is the long-term plan for this eco-village. 30 two-story wooden buildings that are finalized at the moment are the main area of this study to be assessed.

Table 1. Site information [11]

Total land area	31 156 m²
Total buildable surface according to detailed plan	13 800 m²
Approximate number of houses	40–80 pcs
Approximate number of inhabitants	105–210 person
Planned expansion period	2020–2023 year

In addition to residential homes, the eco-village also encompasses a cultural center and a recycling center near the entrance to the village. The cultural center will provide services and amenities to the residents, such as a kindergarten, a restaurant, a grocery store and a gym (Figure 2). The recycling center will be the place of wastewater treatment, waste recycling, composting and local agriculture [11].

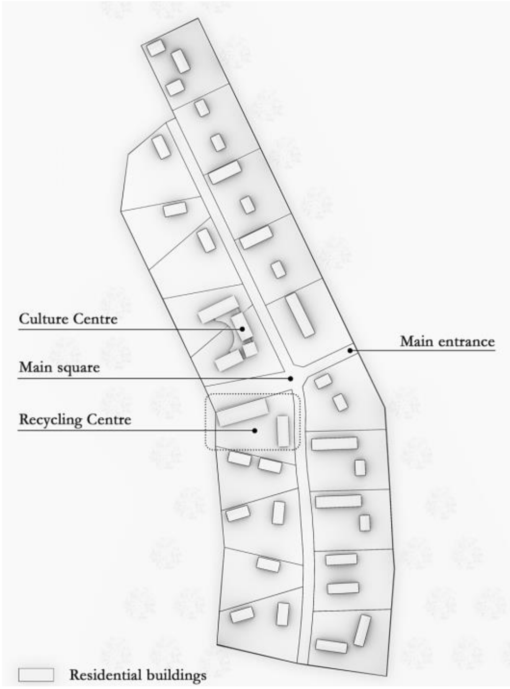

Figure 2. Bysjöstrand Eco-village plan. [11]

3.2 Numerical simulation

The 3-dimensional model of the eco-village was created with the help of Rhino 3D Modeling Software [19]. For the energy and thermal modeling of buildings Honeybee—the extension of Rhino 3D' Grasshopper plugin—was utilized. This extension provides a link and interface to working with building performance models such as Radiance, Daysim, and EnergyPlus [19, 32]. In this study the simulation period was considered during the summer months, June, July and August, when there will be need for cooling in the situation that there are no devices to use for cooling purpose. Winter period was not included in this simulation.

In this study, Honeybee is used to run EnergyPlus for calculating indoor mean air temperature values, extracting the hour and percentages of overheating for each building. Ladybug plugin [20, 32], was another extension of grasshopper utilized to visualize the result with the color coding of each zone and illustrate the graphical parts.

3.2.1 Scenarios

The baseline scenario of this study encompasses the 30 residential buildings with the parameters presented below. In order to answer the research question and thus, to evaluate the impact of climate, natural ventilation and shading on indoor overheating withing the context of the eco-village the following scenarios are devised (Table 2). When the inside temperature hits 22 ºC and the outer temperature is between 15 and 25 ºC, the plan for window opening will be activated. Beside this, it was assumed that all the buildings benefits from cross-ventilation.

1. For evaluating the effect of climate change, the baseline scenario without shadings and natural ventilation for cooling is run for current (B1) and future (B2) climate.
2. The ventilation scenario was run to evaluate the cooling potential of natural ventilation, both in the present (V1) and in the future (V2). Ventilation for cooling was assumed to occur by means of cross-ventilation when indoor air temperature exceeded 22 ºC and outdoor air temperature was within the range of 15-25°C. The ventilation shut off is set to 5 ºC, that is windows are assumed

to be open until outdoor temperature cooler by up to 5 ºC. The assuming a standard tilt and turn window, the operable fraction of windows is set to 10%

3. In order to see if the two key passive design strategies (shading and ventilation) can eliminate overheating in buildings the combined scenario was run with both shading and natural ventilation for the current (C1) and future (C2) climate. For shading two different solutions are assumed. A theoretical louver with a profile angle of 38º (corresponding to the lowest altitude angle during the summer months) is assigned to all south-facing windows. For afternoon solar protection, the two kinds of shade trees are planted in front of the westerly facing facades.

Table 2. six applied scenarios

Building scenarios	***Climate scenarios***	
	2020	2070
Baseline	B1	B2
Ventilation	V1	V2
Combination	C1	C2

3.2.2 Climate

In this study, two weather files are used to describe the climate of the site. The first one refers to present conditions—as understood on the basis of historic, measured data. The second one presents the projected climate of 2070 according to the IPCC RCP8.5 scenario. The weather files were obtained from METEONORM version 8 [9].

Current climate. According to the Köppen-Geiger climate classification [8] Dalarna country's climate is categorized in the Dfc climate category. That means, it has a temperate climate with cold summer and without a dry season [11]. According to the reference weather file, the average annual dry bulb temperature is 5.9 °C. July is the warmest month with +17 °C average monthly temperature and February stands as the coldest month with -3.7 °C average monthly temperature.

In Dalarna, the warm, non-heating season generally lasts for five months: from May to September. The average monthly maximum temperature is around 13.6 °C on these months (May to September). On the other hand, the heating season that lasts for seven months starts in October and last till the end of April. The maximum average monthly temperature for these 7 months is 0.3 °C.

Future climate. IPCC, the Intergovernmental Panel on Climate Change, developed different emission scenarios for the future. The number in the representative concentration pathway (RCP) scenario refers to the possible range of radiative forcing that is expected to occur by the end of this century as a result of different levels of greenhouse gas emissions [34]. The selected scenario with 8.5 W/m^2 forcing is the least optimistic one and assumed continued greenhouse gas emissions through the rest of the 21st century.

In order to understand the trend and magnitude of projected changes, the future climate is presented in reference to the current one (Figure 3). There are several differences between these two climate files, but for building overheating two parameters are important: dry bulb temperature and solar radiation. The mean annual dry bulb temperature will increase from 5.9 to 9.3 °C. As an example, the average dry bulb temperature in July will rise from +17 to +20.6 °C in 2070. Among all the heated months (May to September), July and August will experience greater change in dry bulb temperature.

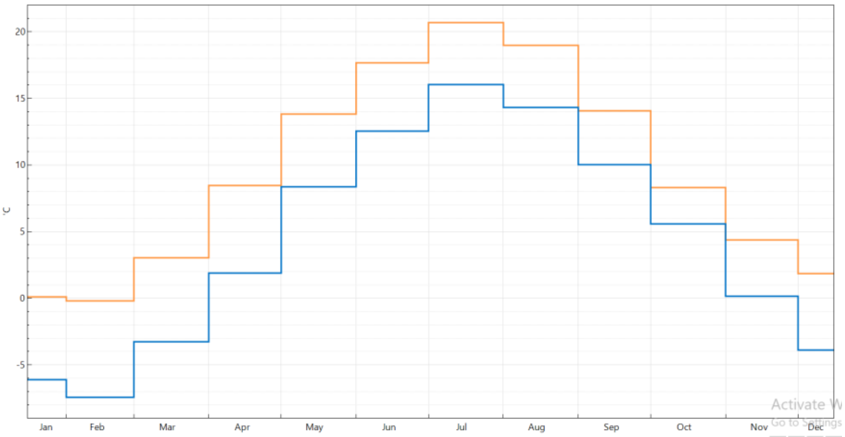

Figure 3. The comparison of the montly average dry bulb temperature in 2020 and 2070 for the whole year. (blue line indicates 2020 and orange line represents 2070.)

Added to comparison of dry bulb temperature, wet bulb temperature of the current situation and future climate were also comprimised. As shown in figure 4, the same scenario will happen and the wet bulb temperature will also rise in the future.

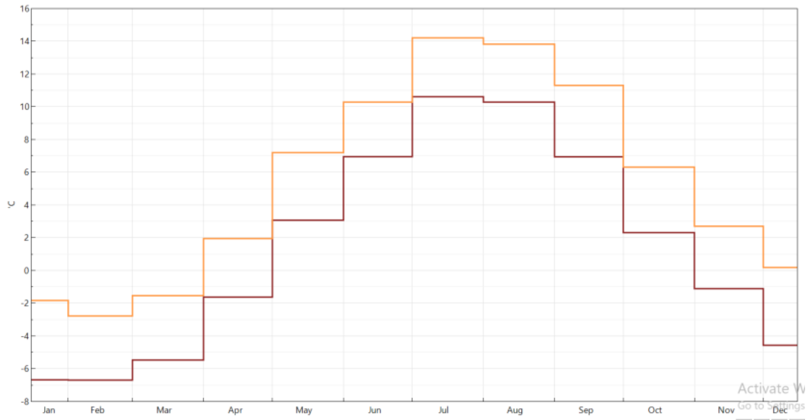

Figure 4. The comparison of the montly average wet bulb temperature in 2020 and 2070 for the whole year. (red line indicates 2020 and orange line represents 2070.)

Figure 5 shows the monthly average direct normal (top) and diffuse radiation (bottom). The blue and green lines refer to the current climate conditions, while the orange and red ones represent the future climate. As can be seen, for the most part of the year the lines overlap and the differences are small. The only exceptions are April, July and August. In the months of April and July direct normal radiation is expected to decrease while diffuse radiation will increase in the future—indicating that the number of days with clear sky will be lower in the future. August, on the other hand, will have more direct normal radiation and less diffuse radiation in the future climate. As a result, there will be more clear sky days.

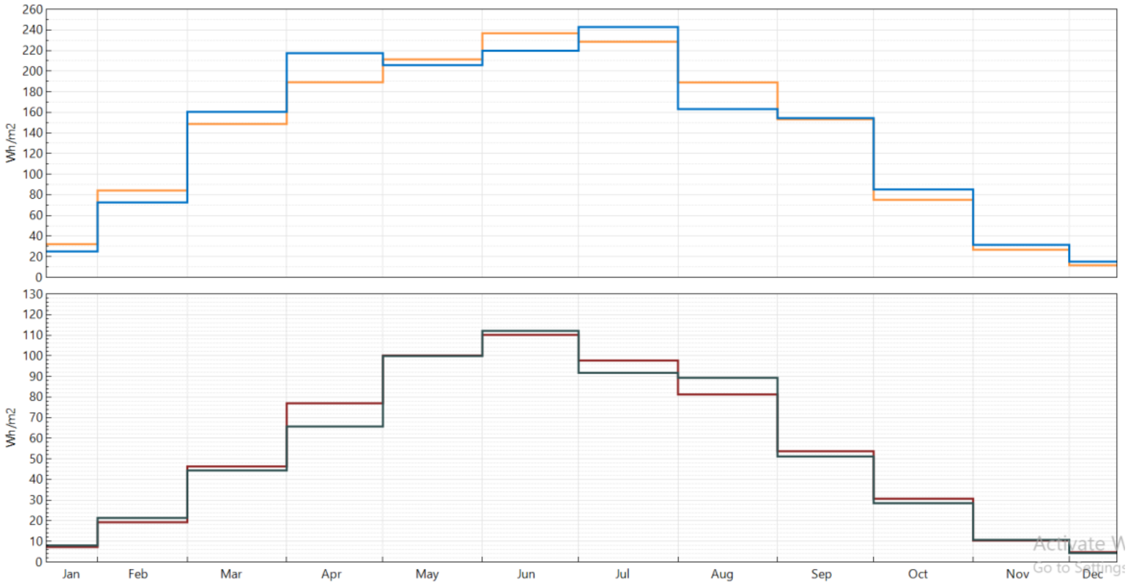

Figure5. Direct normal and diffuse radiation of 2020 and 2070. (Orange and red lines illustrate 2070 while blue and green lines show 2020.)

3.2.3 Buildings

In this study, the orientations and window-to-wall ratios of buildings are adopted from the work of An [11]. The author optimized these parameters for wintertime energy use (see Figure 6).

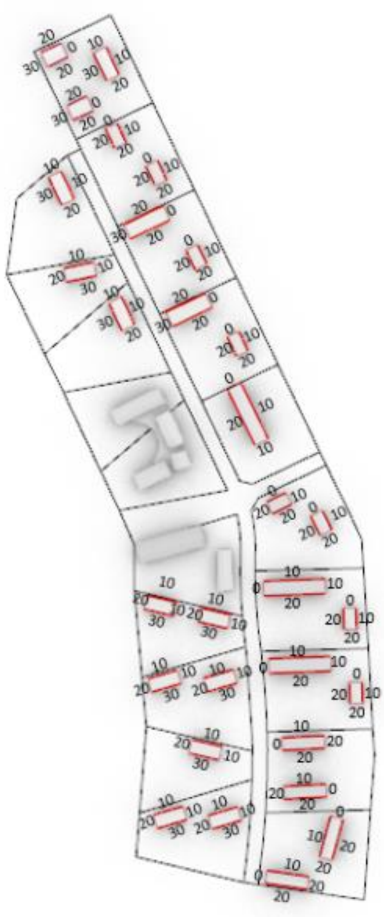

Figure 6. WWR [11]

Construction. All buildings are assumed to be built using timber construction common to Sweden. The construction specification was adopted from the work of An [11]. They were designed to meet Boverket´s building regulations [11, 23]. The adopted construction layers and their basic properties are provided in Table 3. Additional details on the buildings and are included in Appendix A.

Table 3. Façade, ground floor, and roof construction and their thermal transmittance [11].

Building component	Material	Thickness, [m]	R, [m²K/W]
Façade wall	Rse		0.04
	Cover panel	0.022	-
	Bottom panel	0.022	-
	Air gap	0.014	-
	STEICOuniversal board	0.035	0.73
	Loose wood fibre insulation	0.040	1.11
	Wood fibre insulation batt	0.160	4.44
	Vapour barrier	0.002	-
	Air gap	0.034	0.18
	Gypsum board (2 layers)	0.025	0.16
	Rsi		0.13
	Total U-value = 0.15 [W/m²K] Required U-value = 0.18 [W/m²K]		
Ground floor	Rse		0.04
	OSB board	0.02	0.15
	Wood fibre insulation batt	0.22	6.11
	OSB board	0.02	0.15
	Wood floor	0.02	0.14
	Rsi		0.17
	Total U-value = 0.15 [W/m²K] Required U-value = 0.15 [W/m²K]		
Roof	Rse		0.04
	Roof tiles	0.040	-
	Air gap + Tiles batten	0.025	-
	Air gap + Counter batten	0.025	-
	Waterproof breathable membrane	0.002	-
	Sarking	0.020	0.15
	Air gap	0.050	0.16
	Wind protection	0.002	-
	Wood fibre insulation batt	0.200	5.56
	Vapour barrier	0.002	-
	Wood fibre insulation	0.050	1.39
	OSB board	0.020	0.15
	Gypsum board	0.013	0.08
	Rsi		0.10
	Total U-value = 0.13 [W/m²K] Required U-value = 0.13 [W/m²K]		
Window	Clear glass, 3 panes, filled with air		0.97
	Total U-value = 1.03 [W/m²K] Required U-value = 1.2 [W/m²K]		

Heating, cooling and ventilation. Regarding the HVAC systems, this study assumed no air-conditioning in the residential buildings, which is customary of Sweden. Rather, the buildings are assumed to be naturally ventilated during the non-heating period (between May and September).

Building models. In this study, each building is modeled as a single zone residential building. Although the buildings are different in size, they all have two-stories. This, the assumed building height is 6 m. orientation, window to wall ratio, adjacent buildings and materials for different parts of the buildings (roofs, walls, floor ad windows) were taken into account in the simulation. Since the buildings are not constructed yet, it is hard to decide on the number of occupants. Therefore, the occupancy density was kept at Honeybee default value [19, 32], which retrieved from ASHARE 2013[37]. Accordingly, the number of the occupant is set to 0.028 people per square meter.

The lighting and equipment schedules are also based on ASHARE 2013 and were 11.5 and 6.66 W/m^2, respectively. For default ventilation, a 0.35 air change per hour (ACH) is assumed, according to ASHARE 2013. The building numbering used in this study is show in Figure 7.

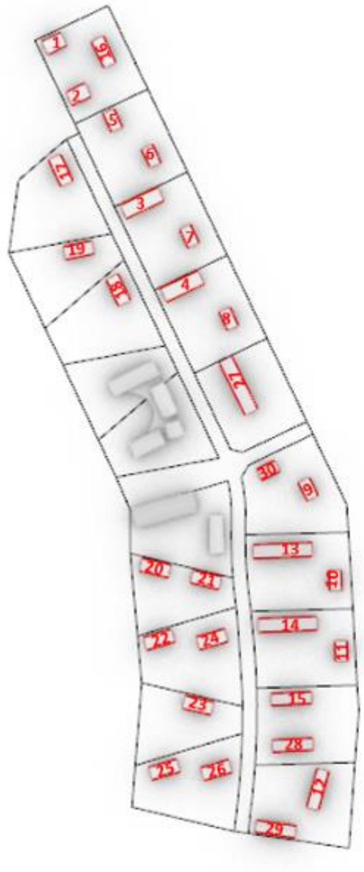

Figure 7. Building numbering

3.2.4 Shade trees

Trees Location. The location and species of the trees should be selected in consideration to both the winter and summer solar needs. In the summer, trees should be arranged in a way to reduce the risk of overheating. However, they should not block the sun in the winter. Thus, for wintertime passive solar utilization, the recommendation is to avoid having obstacles within an angle about 20-30 º south [24]. Due to high solar altitude angles around noon, south-facing windows are best controlled with the aim of horizontal awnings or louvres. On the other hand, the solar protection of westerly facades is best achieved by shade trees. To determine where the trees should be planted the location of the sun and solar radiation angle during the summertime was simulated with the aim of Rhino software from 2 PM to 6 PM. The intersection of these hours creates the optimum location for having the trees.

Tree's characterization. In the below table, the types of trees and their characteristics used in the model are shown. Shortwave radiation transmissivity for these trees were considered based on the average value for these kinds of trees, about 0.05, (5%) [36].

Table 4. Tree's characteristics

Characteristics	Appletree	Birch
Height (m)	12	21
Spread (m)	10	14
Rate of Growth	moderately fast-growing	Fast-growing
Season of Fls	April- May	March – April

Appletree, Hawthorn, Ash, and Birch are common types of trees mostly used in Sweden. All types are considered deciduous trees that will lose their leaves during autumn and winter. This factor is important because using evergreen trees will increase the heating demand during wintertime.

3.3 Analysis

The impact of different scenarios on buildings is analyzed in terms of indoor air temperature. For each building in Bysjöstrand, indoor air temperatures are simulated for the summer months (Jun, July, and August). The comparisons are made on the basis of (a) mean indoor air temperature, calculated for each building over the tree-month period and (b) the number and share of summertime overheating hours. In this study, overheating hours are defined as those hours when the indoor air temperature exceeds 26 °C. No standard for indoor overheating exists yet. This study followed the method adopted by Chartered Institution of Building Services Engineers (CIBSE), with overheating threshold of 26 °C [35].

4 Results and discussion

4.1 Scenarios without natural ventilation and shading (Baseline scenarios)

Table 5 presents the number and share of overheating hours for B1 and B2 scenarios. As the results indicate, buildings without shading and natural ventilation experience overheating both in the present and in the future. Compared to current conditions, the risk of overheating will increase from an average of 17.5 % up to 52.8 % in 2070.

Considering the hours and percentages of overheating for both scenarios, it can be concluded that buildings number 17 and 18 are the most critical ones from overheating point of view. Looking at figure 6, these buildings have one of the longest facades toward west. Besides, most of these buildings suffer from lack of shading.

Table 5. Hours and percentages of overheating in 2020 and 2070.

Building's number	*B1 (2020)* *Hours*	*percentage*	*B2 (2070)* *Hours*	*percentage*	*hour difference*
1	507	22	1272	57	765
2	490	22	1262	57	772
3	380	17	1210	54	830
4	376	17	1205	54	829
5	390	17	1185	53	795
6	397	17	1194	54	797
7	382	17	1179	53	797
8	393	17	1189	53	796
9	372	16	1162	52	790
10	363	16	1143	51	780
11	367	16	1147	51	780
12	334	15	1162	52	828
13	128	5	842	38	714
14	124	5	832	37	708
15	138	6	842	38	706
16	544	24	1331	60	787
17	586	26	1392	63	806
18	574	25	1370	62	796
19	532	24	1305	59	773
20	499	22	1226	57	727
21	428	19	1200	54	772
22	537	24	1317	59	780
23	479	21	1244	56	765
24	488	22	1265	57	777
25	549	24	1303	60	754
26	510	23	1285	58	775
27	589	13	1125	50	536
28	211	9	924	41	713
29	222	10	980	44	758
30	343	15	1125	50	782
Average	407	17.5	1173	52.8	766

According to the statistics in table 5, building 14 has the best performance in both B1 and B2 situations. It can be explained by the fact that this building benefits from the shade provided by its adjacent buildings. Furthermore, building 14 has 0 percent WWR toward west, which can assist manage and minimize the number and percentages of overheating hours.

Building 17 on the other hand, may be considered the worst-performing building in both situations. Figure 7 shows that this building has one of the longest west-facing façades, with

a 30 percent WWR. Furthermore, there is no shade object on the north and west sides of the home, which increases the overheating experience in these types of buildings.
Figure 8 illustrates the average zone mean air temperature for scenario B1 (left) and B2 (right). The red-colored buildings are those that have the highest mean indoor temperature and thus, demand greater care in design to avoid overheating issues both in the present and the future. As it can be seen, the average mean indoor air temperature is expected to rise as a result of climate change. However, this increase is not linear. The maximum mean air temperature will increase more than the minimum mean air temperature: the former will increase by 3.82 °C (from 24.08 up to 27.90 °C), while the latter by only about 3.1°C (from 21.95 °C to 25.12 °C).

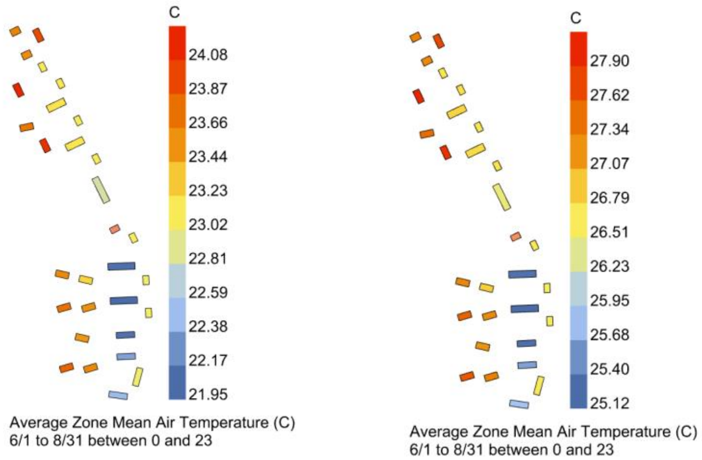

Figure 8. Average zone mean air temperature for 2020 and 2070

4.2 Scenarios with natural ventilation for cooling

Natural ventilation was the first adaptation strategy assessed to see if and to what extent it can help to reduce the overheating risk.

Table 6 presents number and share of overheating hours for V1 and V2 scenarios. As the results indicate, natural ventilation reduces the number of overheating hours. In the case of present climate conditions, (B1 vs V1), this reduction is from 407 to 99 hours on average. In the case of future climate, (B2 vs V2), the reduction is from 1173 to 619 hours on average.

This approach reduced the overheating percentage for 2020 from an average of 17.5 % to an average of 4.1 %. The same reduction happened for the year 2070 and the overheating percentage from an average of 52.8 % to the average of 27.6 %. As we can see from the results, additional interventions will be needed in the future to avoid overheating in buildings.

Table 6. Hours and percentages of overheating in 2020 and 2070

Building's number	V1 (2020) Hours	percentage	V2 (2070) Hours	percentage	hour difference
1	108	4.8	638	28	530
2	108	4.8	636	28	528
3	97	4	631	28	534
4	95	4	632	28	537
5	101	4	620	28	519
6	102	4	622	28	520
7	102	4	617	27	515
8	102	4	625	28	523
9	103	4	615	27	512
10	97	4	608	27	511
11	98	4	611	27	513
12	81	3	587	26	506
13	65	2.9	536	24	471
14	64	2	530	24	466
15	70	3	543	24	473
16	106	4.8	641	29	535
17	110	4.9	653	29	543
18	109	4.9	649	29	540
19	122	5	660	29	538
20	112	5	644	29	532
21	110	4.9	645	29	535
22	119	5	663	30	544
23	114	5	643	29	529
24	117	5	663	30	546
25	120	5	664	30	544
26	119	5	664	30	546
27	74	3	581	26	507
28	78	3	572	25	494
29	80	3	589	26	509
30	94	4	614	27	520
Average	99	4.1	619	27.6	520

Figure 9 shows the average zone mean air temperature for scenario V1 and V2. As it can be seen, natural ventilation is able to reduce indoor temperatures considerably. Referring to current climate conditions (B1 vs V1), the range of average mean air temperature decreased from 21.95–24.08 °C to 21.27–21.65 °C with natural ventilation. With regards to future climate (B2 vs V2), the range of average mean air temperature dropped from 25.12–27.90 °C to 23.71–24.41 °C. Using nature ventilation helped to reduce average mean air temperature by around 3 °C.

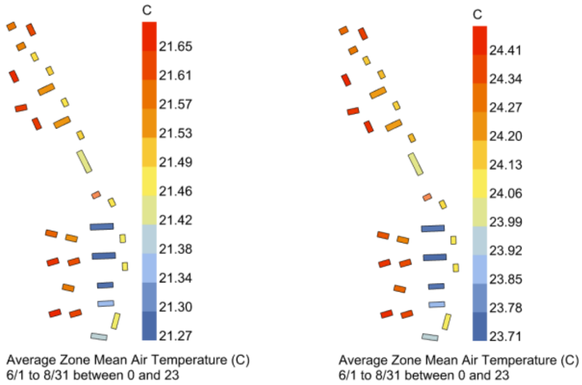

Figure 9. Average zone mean air temperature for 2020 and 2070

4.3 Scenarios with shading

Table 7 presents the number and share of overheating hours for C1 and C2 scenarios which are combination of natural ventilation with shading.

Shading when combined with natural ventilation contributed to minimizing the average percentages of overheating from 4.1 % in 2020 to 0.6 % and in 2070 from an average percentage of 27.6 % to 12.4 %.

Table 7. Hours and percentages of overheating in 2020 and 2070, combination of natural ventilation and shading

Building's number	*C1 (2020) Hours*	*percentage*	*C2 (2070) Hours*	*percentage*	*hour difference*
1	23	1	349	15	326
2	16	0.7	307	13	291
3	14	0.6	256	11	242
4	14	0.6	276	12	262
5	14	0.6	278	12	264
6	14	0.6	268	12	254
7	15	0.6	285	12	270
8	15	0.6	296	15	281
9	14	0.6	278	12	264
10	17	0.7	310	14	293
11	17	0.7	313	14	296
12	52	2	503	22	451
13	4	0.1	207	9	203
14	4	0.1	201	9	197
15	5	0.2	223	10	218
16	18	0.8	328	14	310
17	18	0.8	340	15	322
18	12	0.5	258	13	246
19	16	0.7	296	13	280
20	14	0.6	261	11	247
21	15	0.6	274	12	259
22	16	0.7	269	12	253
23	16	0.7	303	13	287
24	12	0.5	259	11	247
25	16	0.7	283	12	267
26	16	0.7	279	12	263
27	15	0.6	281	12	266
28	4	0.1	194	8	190
29	14	0.6	296	13	282
30	11	0.5	247	11	236
Average	15	0.6	283	12.4	268

Figure 10 indicates how the combination of natural ventilation and shading influence the average mean air temperature. Utilizing two strategies have impact on decreasing the indoor temperature. It could reduce the range of average mean air temperature in 2020 (V1 vs C1), from 21.27–21.65 °C to 20.44–21.12 °C and in 2070 (V2 vs C2), from the range of 23.71–24.41 °C to 22.22–23.54 °C.

Table 8 shows how the hours of overheating for each building has changed after applying the combination of strategies; natural ventilation and shading in comparison to the situation when only natural ventilation was used.

Table 8. Hours of overheating in 2020 and 2070, comparing V1 vs C1 and V2 vs C2

Building's number	*(2020) V1*	*C1*	*hour difference*	*(2070) V2*	*C2*	*hour difference*
1	108	23	85	638	349	289
2	108	16	92	636	307	329
3	97	14	83	631	256	375
4	95	14	81	632	276	356
5	101	14	87	620	278	342
6	102	14	88	622	268	354
7	102	15	87	617	285	332
8	102	15	87	625	296	329
9	103	14	89	615	278	337
10	97	17	80	608	310	298
11	98	17	81	611	313	298
12	81	52	29	587	503	84
13	65	4	61	536	207	329
14	64	4	60	530	201	329
15	70	5	65	543	223	320
16	106	18	88	641	328	313
17	110	18	92	653	340	313
18	109	12	97	649	258	391
19	122	16	106	660	296	364
20	112	14	98	644	261	383
21	110	15	95	645	274	371
22	119	16	103	663	269	394
23	114	16	98	643	303	340
24	117	12	105	663	259	404
25	120	16	104	664	283	381
26	119	16	103	664	279	385
27	74	15	59	581	281	300
28	78	4	74	572	194	378
29	80	14	66	589	296	293
30	94	11	83	614	247	367

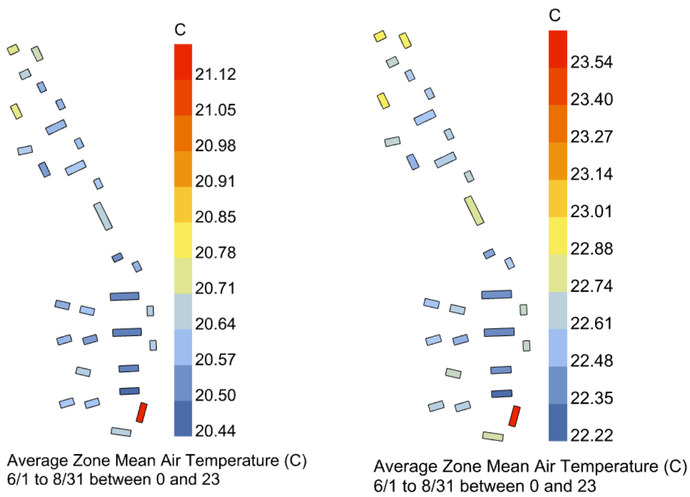

Figure 10. Average zone mean air temperature for 2020 and 2070

4.4 Cross comparison and discussion

Based on the aforementioned data and a comparison of several scenarios, it can be concluded that climate change effects are not linear, and that each one building would have the same outcome. Buildings that are deemed to be the worst in scenario B1 are not entirely the same in scenario B2. These distinctions are shown in Table 9. For example, building number 27 is one of the buildings experiencing high hours of overheating in the B1 scenario, (it has the highest numbers of overheating in B1), however this building cannot be considered one of the worst cases in the B2 scenario. This is possible because, in addition to changes in mean dry bulb temperature, variances in wind pattern and solar radiation may impact the outcome. Other buildings in scenario B1 that were ranked as best or worst buildings, followed the same trend in scenario B2. In both instances, buildings 13, 14, and 15 belonged to the best-case scenario, whereas building 17 and 18 remained the worst-case in both.

Table 9. Comparing number of overheating hours for B1 and B2 scenarios

	B1	***B2***
Building's number	***Hours***	***Hours***
1	507	1272
2	490	1262
3	380	1210
4	376	1205
5	390	1185
6	397	1194
7	382	1179
8	393	1189
9	372	1162
10	363	1143
11	367	1147
12	334	1162
13	128	842
14	124	832
15	138	842
16	544	1331
17	586	1392
18	574	1370
19	532	1305
20	499	1226
21	428	1200
22	537	1317
23	479	1244
24	488	1265
25	549	1303
26	510	1285
27	589	1125
28	211	924
29	222	980
30	343	1125

In the comparison between scenarios B1, V1 and C1, in table 10, virtually all of the buildings had the same pattern after implementing natural ventilation, with the exception of Building 12, which was not among the worst instances in previous scenarios, is nonetheless the worst-case building in C1. The hours of overheating in this building decreased, although not to the same extent as in other buildings once the combined techniques were implemented. As aforementioned it could be due to change in wind pattern and solar radiation in the future climate.

Table 10. Comparing B1, V1 and C1 scenarios

	B1	***V1 (2020)***	***C1 (2020)***
Building's number	***Hours***	***Hours***	***Hours***
1	507	108	23
2	490	108	16
3	380	97	14
4	376	95	14
5	390	101	14
6	397	102	14
7	382	102	15
8	393	102	15
9	372	103	14
10	363	97	17
11	367	98	17
12	334	81	52
13	128	65	4
14	124	64	4
15	138	70	5
16	544	106	18
17	586	110	18
18	574	109	12
19	532	122	16
20	499	112	14
21	428	110	15
22	537	119	16
23	479	114	16
24	488	117	12
25	549	120	16
26	510	119	16
27	589	74	15
28	211	78	4
29	222	80	14
30	343	94	11

In compared to scenarios B2, V2 and C2 all of the buildings had less hours of overheating, as seen in table 11. The discrepancies were in the fact that not all of the structures adhered to the same set of regulations. Building 12 was rated as one of the good-performed buildings in scenario V2, while it was rated as the worst in scenario C2. To put it another way, natural ventilation and shading help the building number 12 to cool down, but not as much as they help other buildings lose heat, just same as it happened with the previous analyzed, (comparison between B1, V1 and C1). Building 28 comes out to be the best building in scenario C2 with 194 hours of overheating, while not being the best building in situations B1 and V1.

Table 11. Comparing B2, V2, and C2 scenarios

Building's number	B2 Hours	V2 (2070) Hours	C2 (2070) Hours
1	1272	638	349
2	1262	636	307
3	1210	631	256
4	1205	632	276
5	1185	620	278
6	1194	622	268
7	1179	617	285
8	1189	625	296
9	1162	615	278
10	1143	608	310
11	1147	611	313
12	1162	587	503
13	842	536	207
14	832	530	201
15	842	543	223
16	1331	641	328
17	1392	653	340
18	1370	649	258
19	1305	660	296
20	1226	644	261
21	1200	645	274
22	1317	663	269
23	1244	643	303
24	1265	663	259
25	1303	664	283
26	1285	664	279
27	1125	581	281
28	924	572	194
29	980	589	296
30	1125	614	247

A brief overview of the baseline model and how it changes with the aim of different approaches are listed below in table 12.

Table 12. Impact of strategies on average hours and percentages of overheating in 2020 and 2070

scenarios	*2020* *Hours*	*percentage*	*2070* *Hours*	*percentage*
No window ventilation No tree shading	407	17.5	1173	52.8
Window ventilation only	99	4.1	619	27.6
Window ventilation + shading	15	0.6	283	12.4

The most critical buildings were buildings number 17 and 18 in both B1 and B2 scenarios, regarding the hours and percentage they experience overheating issue. Table 13 and 14 show the condition of them and the way they improved with the aim of applied strategies.

Table 13 hours and percentages of overheating in 2020 and 2070 for building 17

Building number 17	*2020* *Hours*	*percentage*	*2070* *Hours*	*percentage*
No window ventilation No tree shading	586	26	1392	63
Window ventilation only	110	4.9	653	29
Window ventilation + shading	18	0.8	340	15

Table 14 hours and percentages of overheating in 2020 and 2070 for building 18

Building number 18	*2020* *Hours*	*percentage*	*2070* *Hours*	*percentage*
No window ventilation No tree shading	574	25	1370	62
Window ventilation only	109	4.9	649	29
Window ventilation + shading	12	0.5	258	13

5 Conclusions

This study analyzed the effect of climate change on the overheating of Swedish single-family homes through the case study of Bysjöstrand eco-village and evaluated the effect potential of two passive design strategies: natural ventilation and shading.

In baseline scenario (B1, current climate with no passive strategies), average overheating without shading and natural ventilation was 407 hours (17.5 %) for current situation. This numbers increased in the future climate (B2, future climate with no passive strategies), and reached an average of 1173 hours (52.8 %) of overheating. This change is due to the effect of rise in temperature especially in July and August that seem to face greater rise in dry bulb temperature.

Besides, there will also be differences in direct normal radiation and diffuse radiation which can influence the overheating. In the future climate, August will have more clear sky due to rise in direct normal radiation while in July diffuse radiation will increase.

This study found that natural ventilation is able to reducing overheating considerably, both in the present and the future. In this case, the number of overheating hours decreased from an average of 407 hours to an average of 99 hours (comparing scenarios B1 and V1, baseline vs using natural ventilation for current climate). Regarding the future climate, natural ventilation strategy decreases the average of 1173 hours to 619 hours (comparing scenarios B2 vs V2).

The indoor mean air temperature was improved even further by adding shade. Scenarios C1 and C2, which include natural ventilation and shade, assist to reduce overheating from 99 to 15 in current climate and from 619 to 283 for the future climate in comparison to situations V1 and V2. The efficiency of the combined scenario may be appreciated by comparing B1 and B2 to C1 and C2. In 2020, it dropped the average number of overheating hours from 407 to 15 (B1 vs C1), and in 2070, it lowered the average number of overheating hours from 1173 to 283 (B2 vs C2).

5.1 Limitations

The limitations of this study are as follows:

- Cooling effect of the lake was not considered.
- The buildings were modeled as single zones with a uniform 26 ºC threshold adopted for overheating. However, CIBSE method has different temperature threshold for living rooms (28 ºC) and for bedrooms (26 ºC).
- The single-zone approach also ignored effect multiple stories in the buildings. However, different stories can have different solar exposures and ventilation potential.

5.2 Future work

Works in the future could extend the scope of the study as follows:

- Assess the effect of vegetation on the heating demand.
- Assess the effect of trees on wind and how this influences the heating demand in the winter and ventilation potential in the summer.
- Assess the effect of trees on the microclimate, in general and its ability to reduce outdoor air temperature, in particular.

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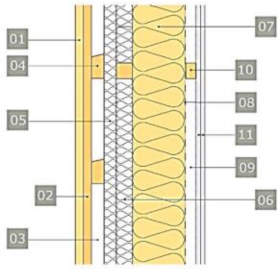
Appendix A

Building's construction [11]

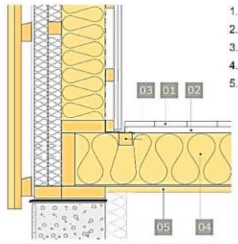
Facade wall

#	Material	λ, W/mK	δ, m	R, m2K/W	U-value, W/m2K
	Rse			0,04	
1	Cover panel	-	0,022	-	
2	Bottom panel	-	0,022	-	
3,4	Air gap + Horizontal nailed battens	-	0,014	-	
5	STEICOniversal board	0,048	0,035	0,73	
6	STEICOflex 036 + Horizontal laths	0,036	0,040	1,11	
7	STEICOflex 036 + Wooden studs	0,036	0,160	4,44	
8	Vapor barrier	-	0,002	-	
9, 10	Air gap + Horizontal nailed battens	0,189	0,034	0,18	
11	Gypsum board (2 layers)	0,16	0,025	0,16	
	Rsi			0,13	
	Total		0,354	6,79	0,15
	Required U-value				0,18



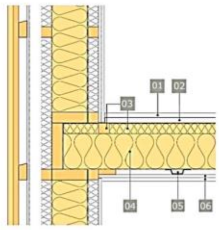
Ground floor

#	Material	λ, W/mK	δ, m	R, m2K/W	U-value, W/m2K
	Rsi			0,17	
1	Wood_Floor	0,14	0,02	0,14	
2	OSB board	0,13	0,02	0,15	
3	STEICOflex 036 + Beams	0,036	0,22	6,11	
4	OSB board	0,13	0,02	0,15	
	Rse			0,04	
	Total		0,28	6,77	0,15
	Required U-value				0,15



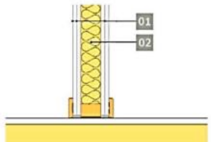
Interior floor

#	Material	λ, W/mK	δ, m	R, m2K/W	U-value, W/m2K
	Rsi			0,17	
1	Wood_Floor	0,14	0,02	0,14	
2	OSB board	0,13	0,02	0,15	
3	STEICOflex 036	0,036	0,04	1,11	
4	STEICOflex 036	0,036	0,16	4,44	
5	Air gap + Acoustic profile	0,214	0,045	0,21	
6	Gypsum board (2 layers)	0,16	0,025	0,16	
	Rse			0,04	
	Total		0,310	6,43	0,16



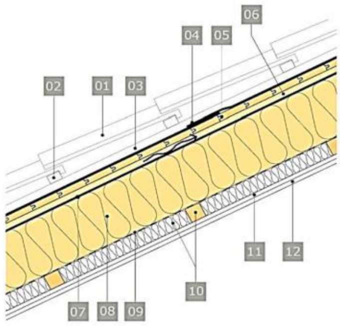
Partition

#	Material	λ, W/mK	δ, m	R, m2K/W	U-value, W/m2K
1	Gypsum board (2 layers)	0,16	0,025	0,16	
2	STEICOflex 036	0,036	0,07	1,94	
3	Gypsum board (2 layers)	0,16	0,025	0,16	
	Total		0,12	2,26	0,44



Roof

#	Material	λ, W/mK	δ, m	R, m2K/W	U-value, W/m2K
	Rse			0,04	
1	Roof tiles	-	0,04	-	
2	Air gap + Tiles batten	-	0,025	-	
3	Air gap + Counter batten	-	0,025	-	
4	Water proof breathble membrane	-	0,002	-	
5	Sarking	0,13	0,02	0,15	
6	Air gap	0,31	0,05	0,16	
7	Wind protection	-	0,002	-	
8	STEICOflex 036	0,036	0,20	5,56	
9	Vapor barrier	-	0,002	-	
10	STEICOflex 036	0,036	0,050	1,39	
11	OSB board	0,13	0,02	0,15	
12	Gypsum board	0,16	0,013	0,08	
	Rsi			0,10	
	Total		0,449	7,63	0,13
	Required U-value				0,13



Windows

#	Material	λ, W/mK	δ, m	R, m2K/W	U-value, W/m2K
1	B_Glass_Clear_3	0,9	0,004	0,004	
2	Air	0,0250	0,012	0,48	
3	B_Glass_Clear_3	0,9	0,004	0,004	
4	Air	0,0250	0,012	0,48	
5	B_Glass_Clear_3	0,9	0,004	0,004	
	Total		0,04	0,97	1,03
	Required U-value				1,2