
OLYMPUS

SUMMARY OF HOUT BAY HOUSE RESEARCH PROJECT

Progress in Hout Bay House research project: Thermal properties and wood degradation

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Hout Bay House research project is focused on exploring an unique type of timber construction in South Africa. It is an international research project which uses ecological and sustainable materials. The aim of the project is to find an optimal form of timber construction in South Africa and to awaken the interest and trust in these modern type of buildings.

Hout Bay House is located in Western Cape which is known for coastal and windy conditions. The design of house uses the newest technologies in the wood industry with the respect to basic construction solution increasing the durability of wood and whole service life of a building. The construction of the house is made of the lower brick and mortar part and upper wooden part (Figure 1). For the load bearing wall construction the 84 mm thick NOVATOP solid wood panels based on cross laminated spruce timber were used. The walls were insulated by wood fibre insulation Pavatex (bulk density 145 kg/m3) with the thickness of 80 mm (west façade) and 120 mm. The external layer is created by the wooden facade (Siberian larch and thermally modified pine) held by the spruce grid with ventilated air gap with the thickness of 60 and 100 mm, respectively. In some parts of the interior the Novatop layer is covered by Fermacell gypsumfibre boards. The roof consists of open NOVATOP elements filled with thermal insulation with roof overhangs and covered by metal sheets.

Figure 1: Hout Bay House and its construction

Bedrooms are located on north side while the kitchen and living room are on south side. There is no heating or air-conditioning in the house. Windows are double-glazed with high quality which ensures the whole air tightness of the house – together with complex NOVATOP structure.

The research part is dealing with different topics.

- Evaluation of thermal properties and to determine the ideal thickness of insulation and thermal comfort of the house.
- Surface degradation of treated and untreated wood in the specific conditions of South Africa.

1st RESEARCH PART: THERMAL PROPERTIES OF THE HOUSE

Thermal properties are affected by several factors as building geometry, used materials, type of construction, ventilation, layout, size and orientation of windows and use of a building as well. Generally, ensuring thermal comfort in accordance with energy savings are among the most important parameters of a building. Proper solution protect the house against overheating in the summer and heat loss in the winter. In this research we aim to evaluate the effect of thickness of thermal insulation (8 vs. 12 cm) and the effect of ventilation.

The research can be divided in the theoretical and practical part. Theoretical part is dealing with the calculated data based on the material properties and the practical part is focused on the data measured from sensors and evaluation of thermal properties for the specific climate of South Africa.

a) Theoretical part

The following thermal properties are used in the calculations:

λ Thermal conductivity (W/mK)

- material property to conduct heat
- depends on the moisture content. It increases with the increasing moisture. In the direction perpendicular to fibres wood has higher insulating properties than in the direction of fibres (1,4 - 3 x)

R – value: Thermal resistance (m^2K/W) $R = d/\lambda$

- property of material or construction
- provides that the flow of heat is impeded

U - value: Thermal transmittance (W/m^2K) $U = 1/R$

- reciprocal of R-value
- lower U-values indicate better thermal insulation
- describes the ability of building element to transfer heat through one unit area of a structure divided by the difference in temperature across the structure

The calculations for the different external wall construction with 8 cm and 12 cm of insulation are given below (Figure 2). Both construction types suit the requirements given by South African National Standard SANS 0400-XA:2010:

External walls requirements are:

- min. R-value – 1.9 m^2K/W which corresponds to
- max. U-value – 0.53 W/m^2K.

The calculated values for the walls construction are as follows:

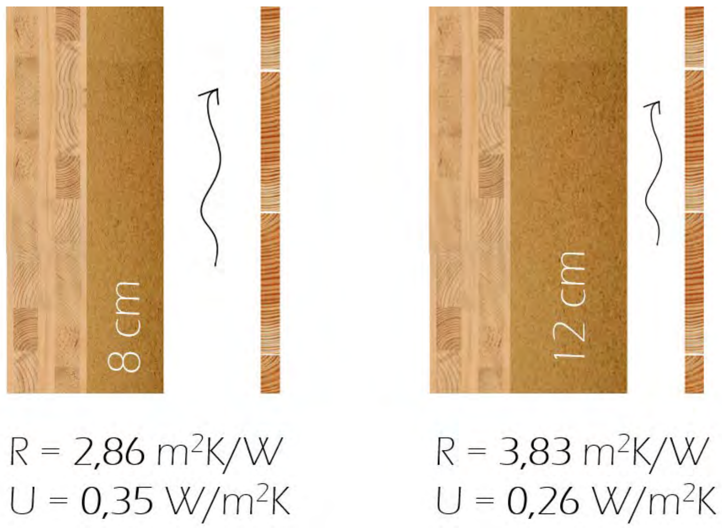


Figure 2: Calculations of thermal properties of different wall structures at Hout Bay House

We aim to prove and further analyse these findings by the measurements in practical part.

b) Practical part

The house has 9 measuring points reflecting the different wall construction and orientation (Figure 3).

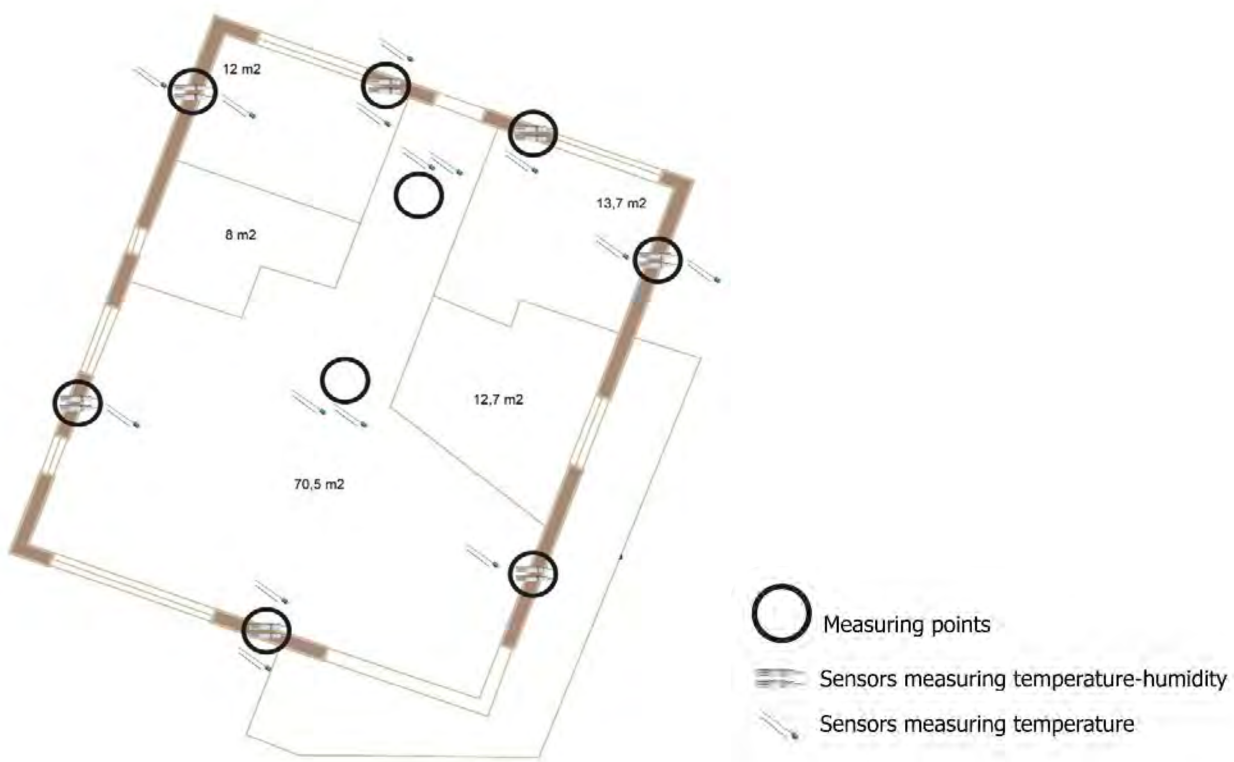


Figure 3: Measuring points

At these measuring points we have installed 32 sensors measuring temperature and relative humidity. At this picture, you can see the location of sensors (Figure 4). We measure the temperatures on both sides of insulation and surface temperature in interior and exterior.

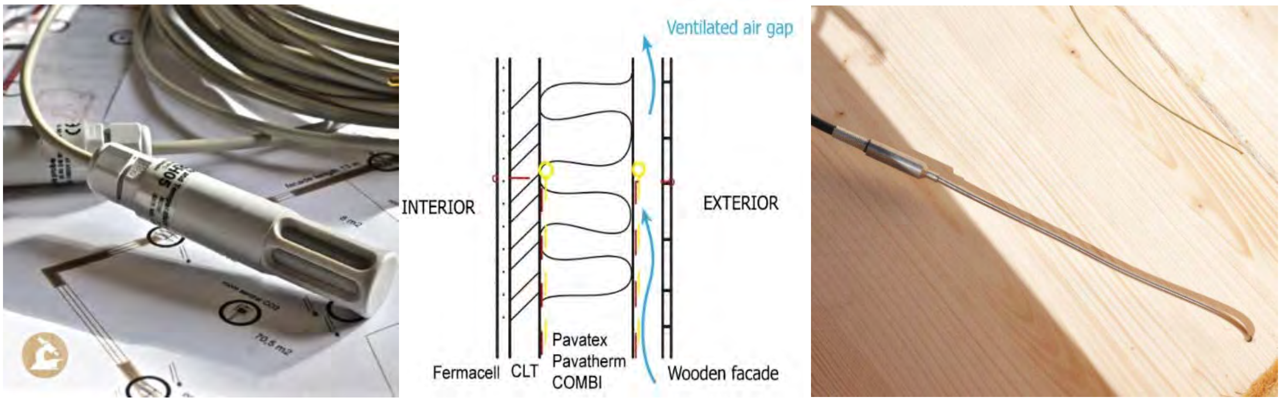


Figure 4: Measuring sensors and their location in the structure

The data are collected in regular intervals and are available online (Figure 5).

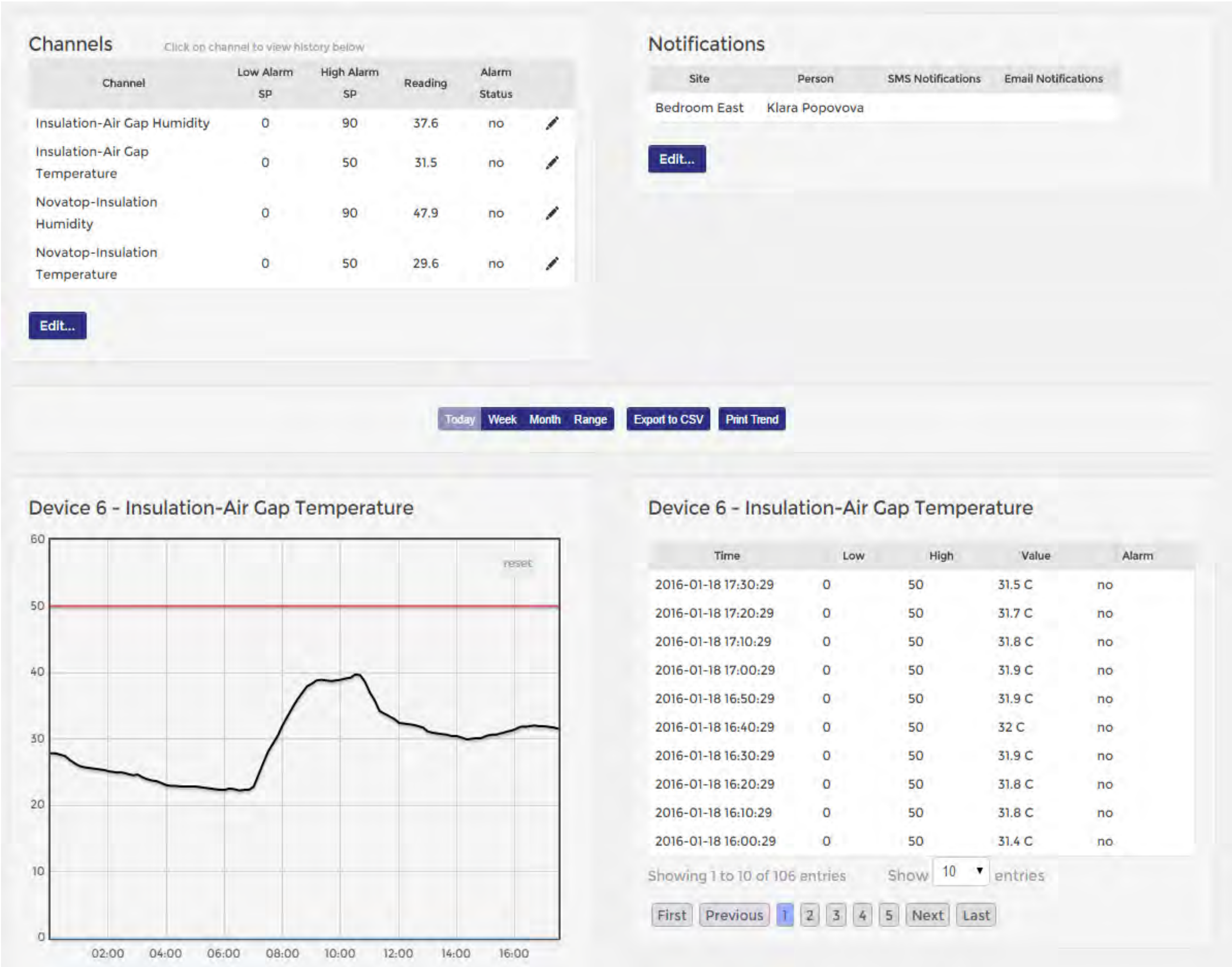


Figure 5: Data are available online

Based on real temperatures from weather station we chose the hottest and coldest day of the year 2016 (Figure 6 and Figure 7). It was the 12th of January and 3rd of July. We had further evaluated the thermal performance of the house during these extreme days.

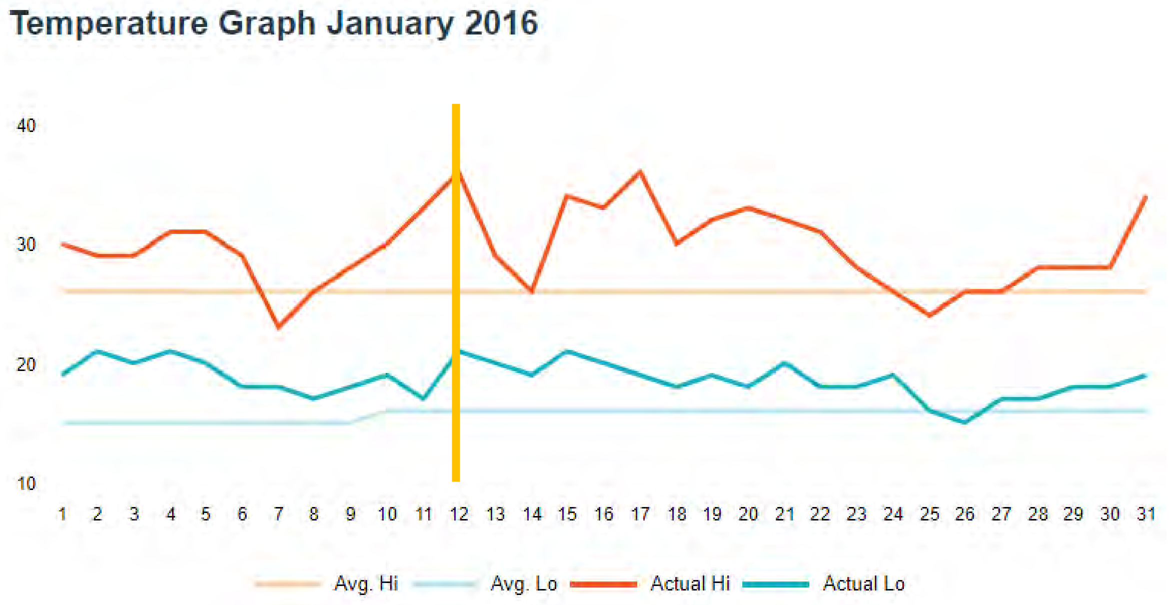


Figure 6: The temperatures during January 2016 - the hottest day 12.1.2016 – 36/21°C

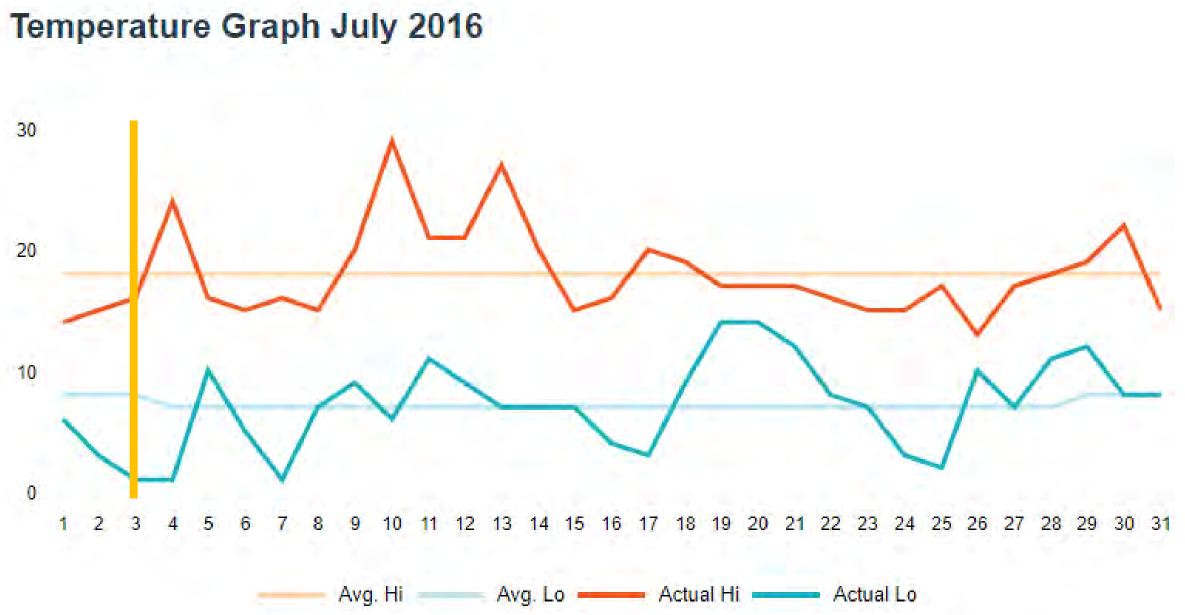
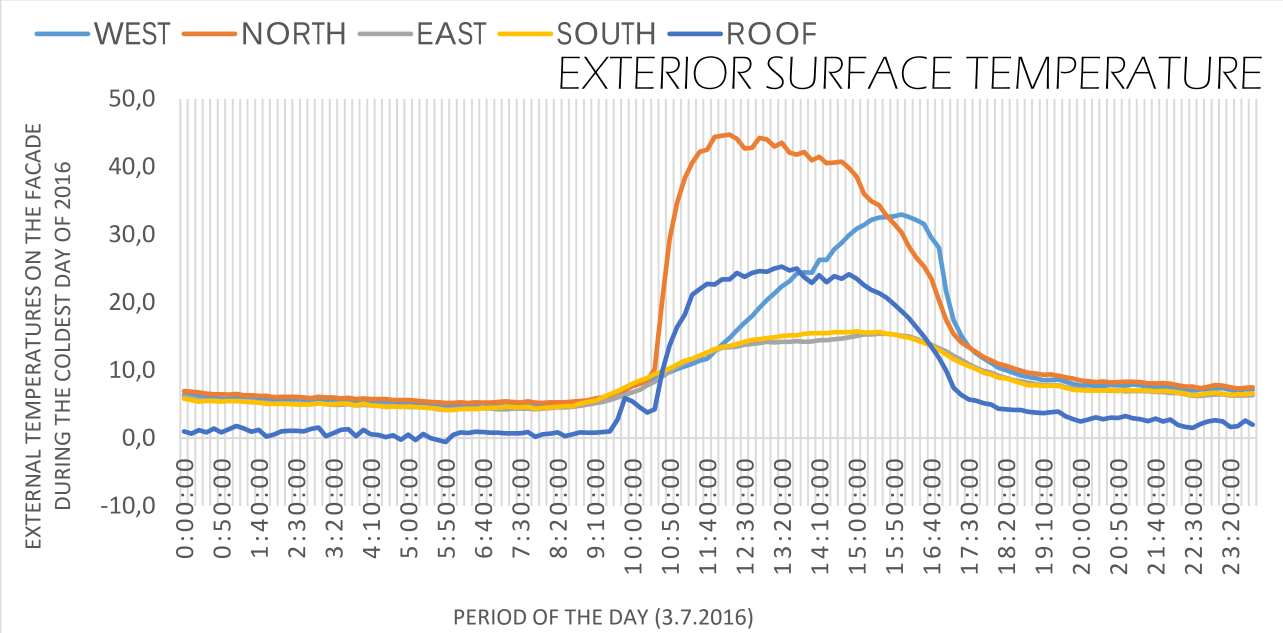


Figure 7: The temperatures during July 2016 - the coldest day – 3.7.2016 – 16/1°C

The graphs show exterior surface temperatures of house according to different orientation (Figure 8). The obvious fluctuations which did not reflect into the interior surface temperatures – which show the graphs bellow not even in the case of west side with 8 cm of insulation. The wall construction is able to resist a heat flow which goes always from the place with higher temperature to place with lower temperature.



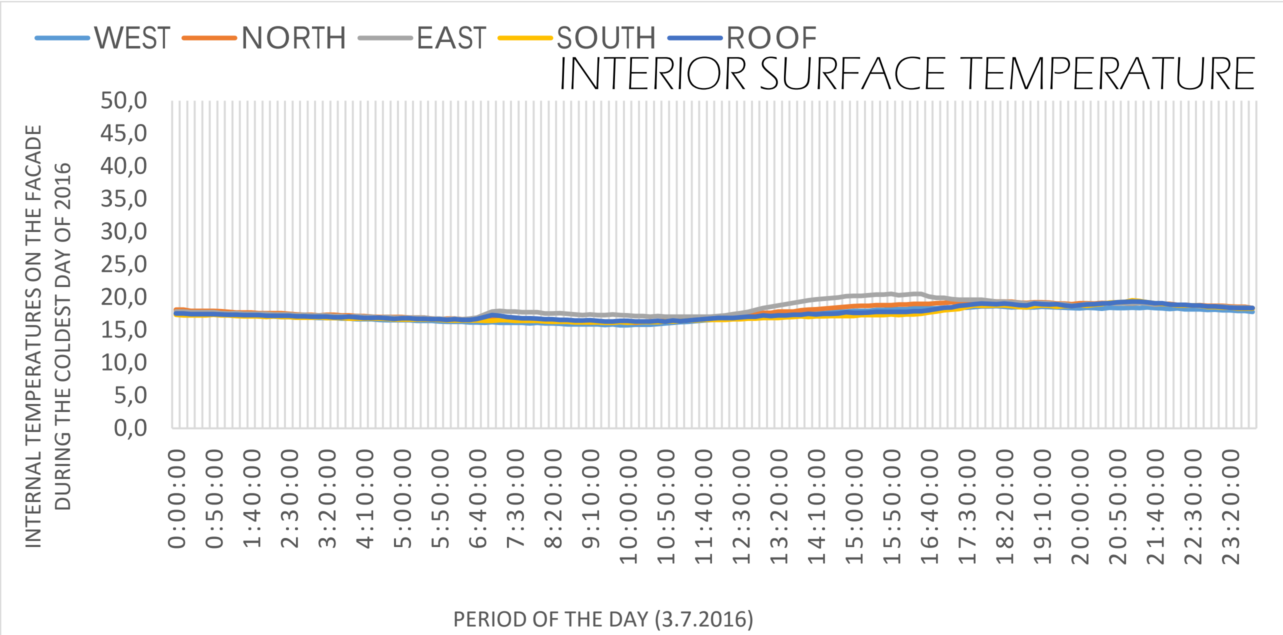
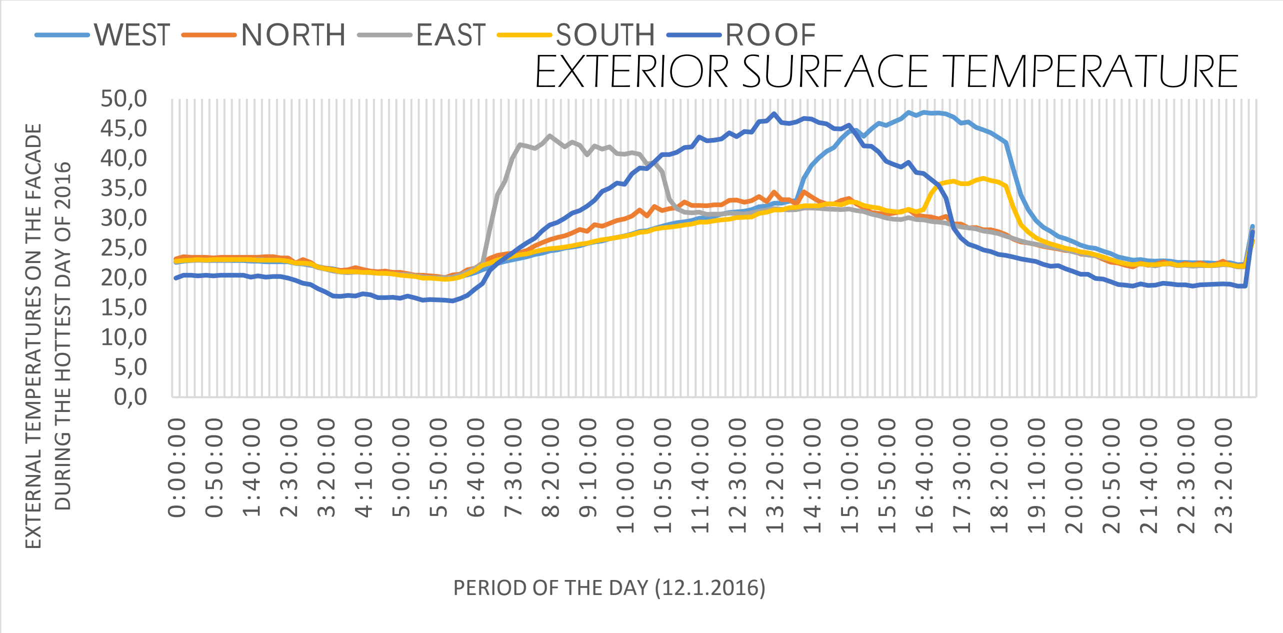


Figure 8: Surface temperatures based on the orientation during the coldest day of 2016

The following graphs show the same situation for the hottest day of the year (Figure 9). The interior temperatures are not affected by exterior temperature fluctuations. The highest temperature were noted for west side.



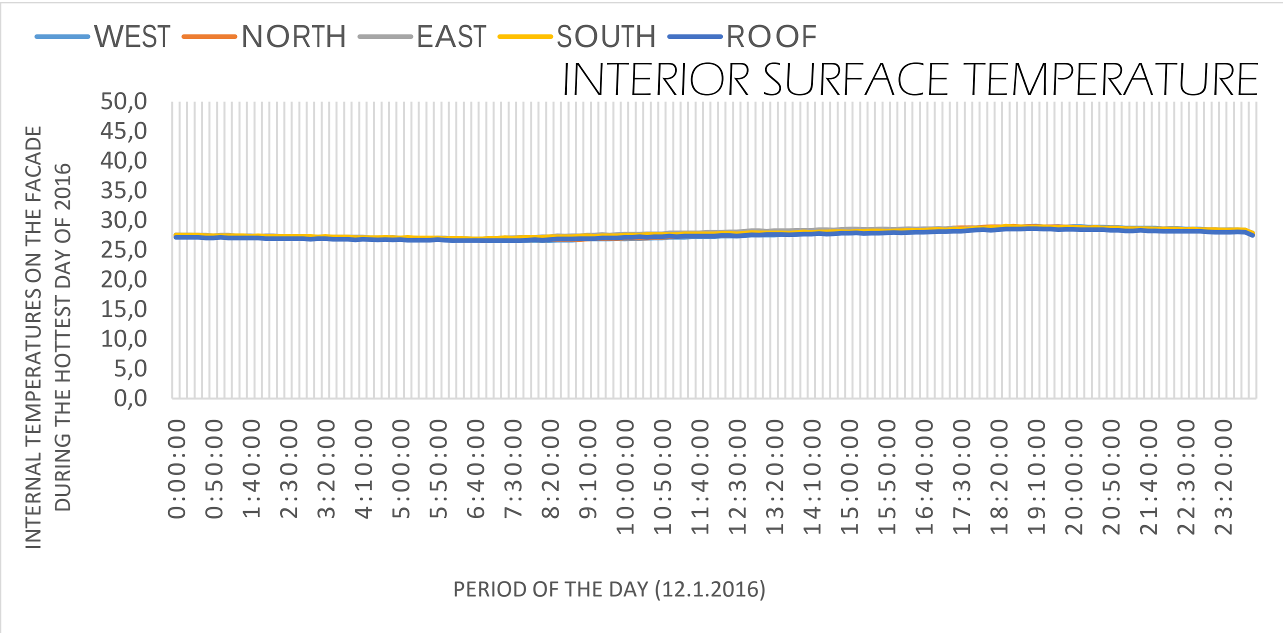


Figure 9: Surface temperatures based on the orientation during the hottest day of 2016

The average temperatures and minimal and maximal surface temperatures are shown at following pictures (Figure 10). The average temperatures in interior during the coldest day is around 17-18 °C. The average temperatures during the hottest day is around 27 °C which signifies little overheating. It can be caused large windows and the fact that nobody was present in the house that day and the house was not ventilated properly.

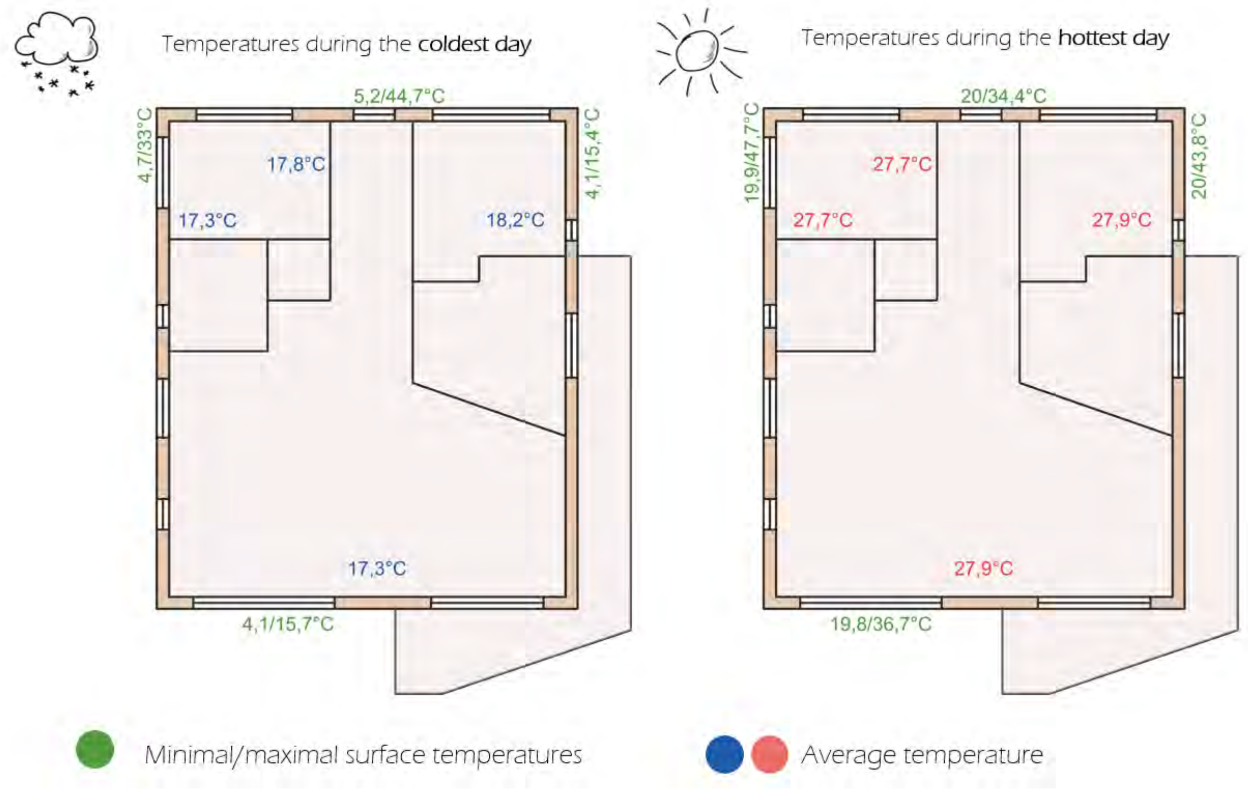


Figure 10: Average internal and minimal and maximal external temperatures

To sum up the results, during winter, heat losses are minimalized by the quality and **thickness** of thermal insulation, quality of windows and whole **airtightness** of the building. During summer, there is an actual danger of possible overheating during summer in South Africa (**large windows, airtightness**). There is a list of factors influencing overheating according to EMPA (Swiss Federal Laboratories for Materials Science and Technology) as shading, ventilation, glazing area, thermal accumulation etc. (Figure 11). The intensity of ventilation can effect the temperature in the interior by 4,5 °C and the shading by 3° C. In the case of Hout Bay House, the house is overheated probably because of large windows without shading.

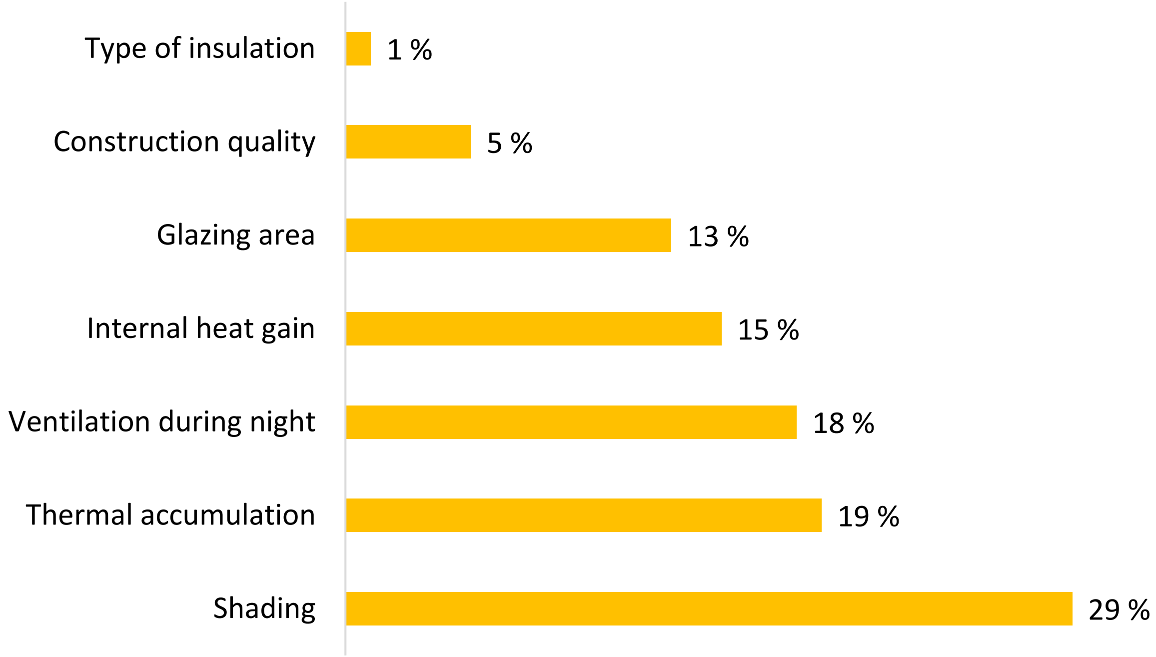


Figure 11: Factors influencing the overheating of the house

The effect of thermal insulation thickness during the summer day is demonstrated in following picture (Figure 12). There are the temperature curves of wall constructions in different periods of the day. At left, the 8 cm of insulation acts together with NOVATOP panel and both layers are decreasing the temperatures from exterior. At the right, there is a difference that the thicker insulation is able to decrease the temperature itself. From this point of view, the 8 cm of insulation in combination with NOVATOP panel seems sufficient from the point of view of thermal properties. There is no need of 12 cm of insulation.

» West facade – insulation thickness 8 cm

» East facade – insulation thickness 12 cm

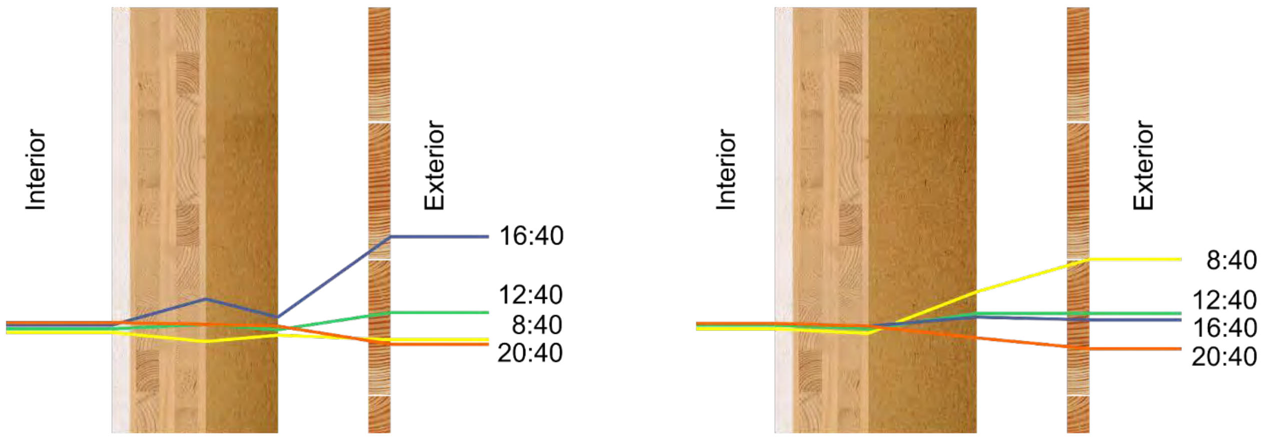


Figure 12: Effect of thermal insulation thickness on the temperature flow

The effect of natural ventilation during summer day is demonstrated in following graph (Figure 13). Since the house is really airtight, we have to ventilate to cool it down and get fresh air. For this reason we compared two days – with and without the natural ventilation during the summer day. When there was no ventilation, the interior temperatures were higher than in exterior up to 27 %. When the house was naturally ventilated during the summer day, the interior temperatures were lower or does not exceed the 8% increasement of temperature according to orientation. There is a visible decreasing effect of only natural ventilation on the temperature in the interior.

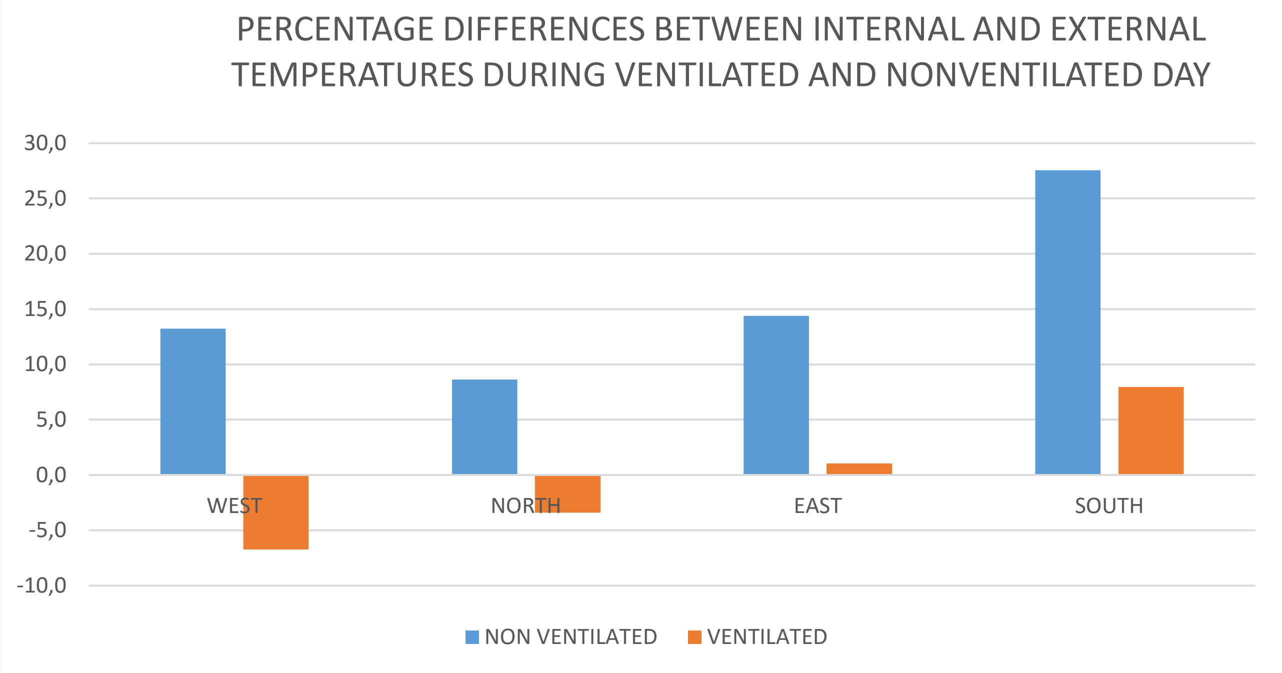


Figure 13: The effect of natural ventilation on the temperature in interior

In conclusion, based on the theoretical calculations and practical measurements, we can declare that during winter the house works well, mainly because of the quality of used materials and high-quality windows which ensure airtightness of the whole house. Without heating, the house has stable temperatures with minimal fluctuations during the day and the insulation thickness of 8 cm in combination with NOVATOP panels is sufficient for the conditions of South Africa proved by theoretical and practical measurements.

During hot days, the house is overheated. The proper ventilation can quickly decrease the temperatures in interior to some point. But in the case of Hout Bay House, the windows areas are large and additional shading solution is needed.

How to work with the house?

Modern house needs intelligent residents. It is important to ventilate to cool down the house and get fresh air when temperature is lower outside. If we prefer large windows, we have to consider possible overheating. It can be decreased by shading. The ideal solution is a combination of adjustable and fixed shading.

2nd RESERCH PART: SURFACE DEGRADATION OF WOOD

This part of Hout Bay House research project is focused on exploring unique type of timber construction located in Western Cape. The aim is to evaluate wood degradation after exposure to weathering process in specific climatic conditions of South Africa**.**

Wooden façade and terrace decking react to the weather and its changes. For the proper use of wood in exterior it is necessary to be familiar with the suitable constructional solution, properties of individual wood species, surface treatments and climate conditions in specific location. In the case of respecting these facts during design, the wood degradation affects only the surface of wood and does not cause any structural damages. However, wood is an organic material and when is exposed outdoors, it is subjected to process called weathering - combination of factors (mainly UV light and water) under which wood degrades. Unlike decay or insect attack, weathering is typically not a significant factor in the failure of wood components and the collapse of a structure. Weathering affect surface properties and as a result unprotected wood changes colour to grey and gets typical rough structure. The whole process of wood degradation can be decreased by using proper wood species or additionally surface treatment.

The Siberian larch wood and thermally modified pine, in European conditions considered as durable, were selected for the façade cladding and terrace decking at Hout Bay House (Figure 14). Larch has high resistance to climatic factors but without a suitable surface treatment it tends to turn grey and crack. Thermally modified pine wood has been produced by controlled process during which was the wood being exposed to high temperatures in range of 185-215 °C. This material is generally considered to be very durable with regard to given climatic conditions and does not undergo substantial dimensional changes. It is also noted for increased resistance to rotting and cracking. The test samples were prepared, one part of them was left untreated, the other part was treated with 2 layers of natural oil wood stain UV OSMO.

Figure 14: Test samples (from left: thermally mod. pine untreated and treated, Siberian larch untreated and treated)

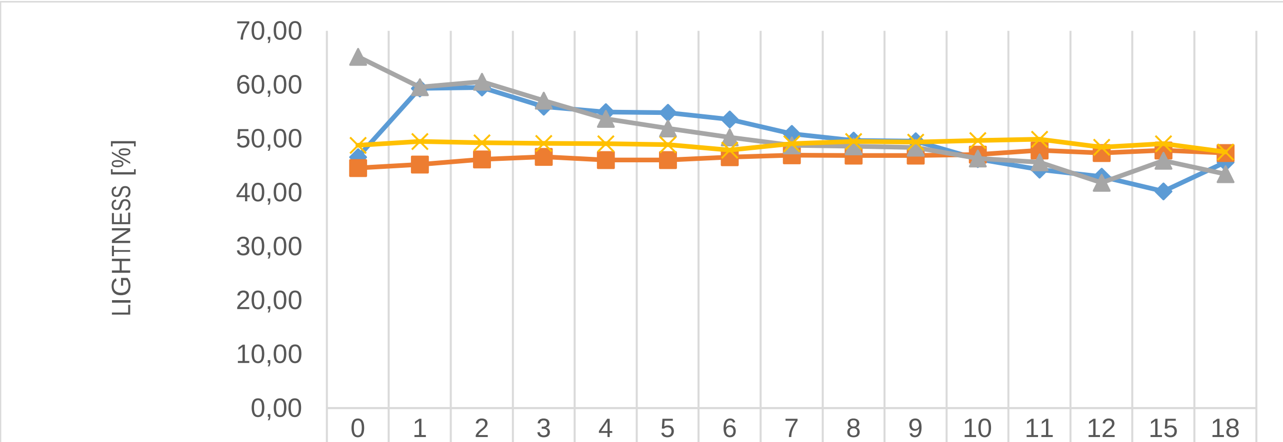
These samples were exposed to natural weathering in special stands facing north in the inclination of 45° according to European standards. The test samples were cut off from the exposed elements and evaluated on the basis of change of colour, gloss, roughness, wettability and other visual properties during three years of exposure, monthly in the first year of the research (so far 18 months), then in longer periods (Figure 15). In addition, the degradation process of wooden façade and terrace was also regularly visually evaluated.

Figure 15: The test samples marking and measurements using spectrophotometer and profilometer.

The colour changes during weathering

The colour reflects the basic chemical composition of wood. If the wood contains a high amount of extractives, the chemical processes of the colour changes quickly take place. The change of colour is mainly affected by UV light and moisture. The colour was measured by the device spectrophotometer which records the basic colour parameters L*a*b* in CIELab colour space (Figure 16, Figure 17, Figure 18):

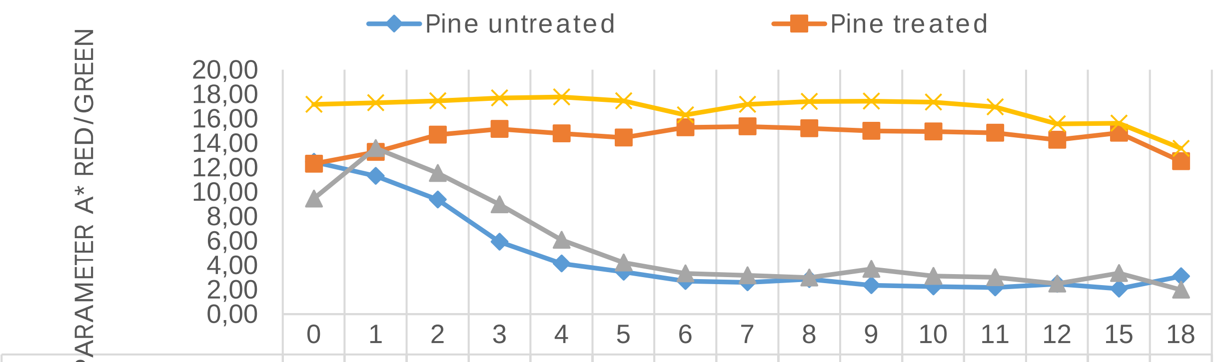
› Parameter L* – LIGHTNESS from black (0) to white (100)



	0	1	2	3	4	5	6	7	8	9	10	11	12	15	18
Pine untreated	46,5	59,3	59,4	55,9	54,9	54,8	53,5	50,9	49,6	49,5	46,2	44,2	42,9	40,2	45,6
Pine treated	44,5	45,2	46,1	46,6	46,0	46,0	46,5	46,9	46,8	46,8	47,0	47,8	47,3	47,8	47,3
Larch untreated	65,2	59,5	60,5	57,0	53,6	51,9	50,2	48,7	48,6	48,3	46,3	45,6	41,8	45,9	43,4
Larch treated	48,7	49,4	49,2	49,1	49,0	48,8	47,8	49,0	49,4	49,3	49,6	49,8	48,4	49,0	47,5

Figure 16: Change of lightness parameter during weathering

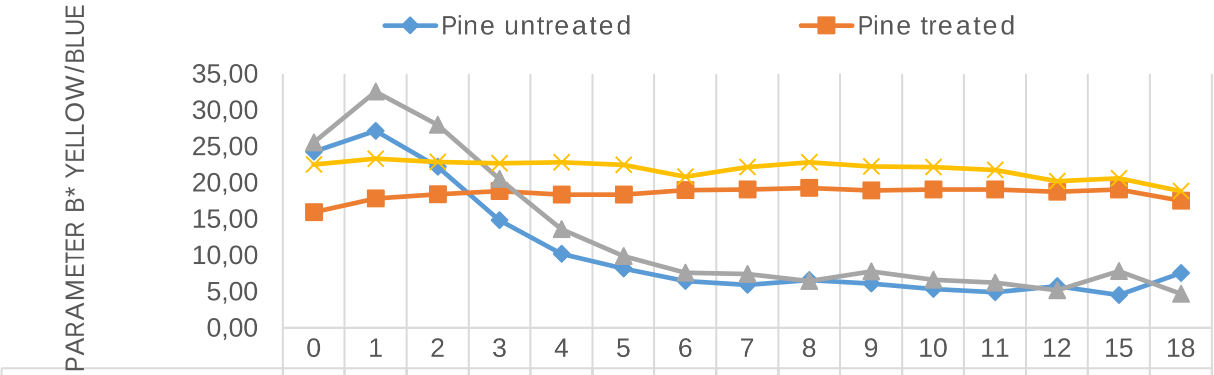
› Parameter a* – shades from red (+60) to green (-60)



	0	1	2	3	4	5	6	7	8	9	10	11	12	15	18
Pine untreated	12,4	11,3	9,37	5,92	4,14	3,46	2,69	2,60	2,86	2,37	2,25	2,17	2,45	2,08	3,09
Pine treated	12,3	13,2	14,6	15,1	14,7	14,4	15,2	15,3	15,2	14,9	14,9	14,8	14,2	14,8	12,4
Larch untreated	9,44	13,5	11,5	8,97	6,06	4,21	3,33	3,17	2,98	3,70	3,12	3,01	2,49	3,36	1,99
Larch treated	17,1	17,3	17,4	17,6	17,7	17,4	16,2	17,1	17,3	17,4	17,3	16,9	15,5	15,6	13,5

Figure 17: Change of a* parameter during weathering

› Parameter b* – shades from yellow (+60) to blue (-60)



	0	1	2	3	4	5	6	7	8	9	10	11	12	15	18
Pine untreated	24,2	27,1	22,2	14,8	10,2	8,17	6,46	5,93	6,56	6,09	5,32	4,89	5,74	4,52	7,55
Pine treated	15,9	17,8	18,4	18,8	18,3	18,3	18,9	19,0	19,2	18,9	19,0	19,0	18,7	19,0	17,5
Larch untreated	25,5	32,5	27,9	20,5	13,5	9,89	7,57	7,41	6,46	7,76	6,61	6,21	5,17	7,81	4,69
Larch treated	22,5	23,3	22,8	22,6	22,7	22,4	20,8	22,1	22,8	22,2	22,1	21,7	20,2	20,6	18,8

Figure 18: Change of b* parameter during weathering

The results confirmed that in the early stages of weathering, dark wood trend to become light and light woods become dark according to lightness parameter values (Figure 16). The values a* and b* of untreated samples followed a similar trend shown in previous studies, increased at the beginning of weathering and then decreased in the case of untreated samples (Figure 17, Figure 18). The initial increase in b* values indicates the degradation of lignin. The final decrease of yellowness of untreated samples may be attributed to leaching of decomposed lignin and extractives by water. The changes in a* values are determined mainly by the changes of the chromophore groups in extractives. The colour parameters of treated wood had more stable results without any important fluctuations.

The total colour difference was then calculated from the colour parameters using the formula:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

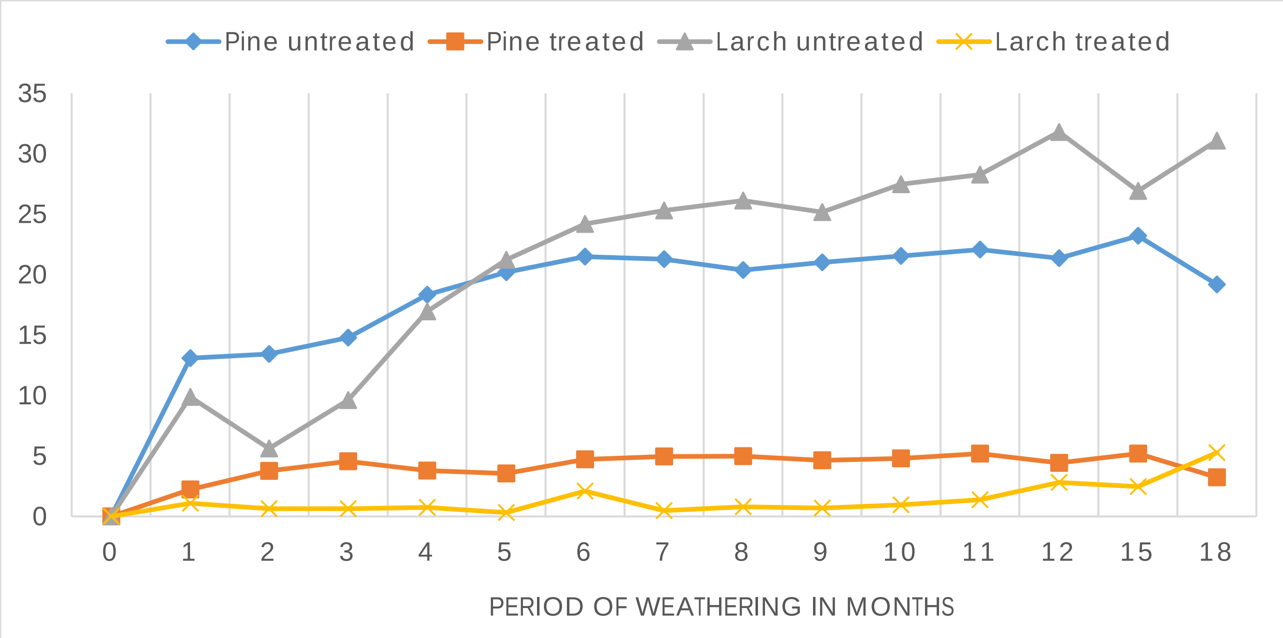


Figure 19: Total colour difference of tested samples during weathering

Quick evaluation of the colour difference using the following standardized table:

0,2 < ΔE*	invisible colour difference
0,2 < ΔE* < 2	low colour difference
2 < ΔE* < 3	colour change visible with the high quality filter
3 < ΔE* < 6	colour change visible with the medium quality filter
6 < ΔE* < 12	high colour differences
ΔE* > 12	different colour

Table 1: Classification of colour changes

The graph shows a trend when surface treated samples showed significantly lower colour changes and stable results during 18 months of outdoor exposure (Figure 19). On the contrary, high colour changes were observed even after 1 month of exposure on the surface of untreated wood (both thermally modified pine and Siberian larch). The total colour difference of thermally modified pine increased during exposure. Regarding the untreated Siberian larch it is possible to observe the trend of large increase in the colour difference after the first month and the drop after other two months. This can be due to the degradation of lignin and extractives caused especially by UV radiation. Thus disturbed photo-degradation products are washed out from the wood surface and significantly affect the colour change, the colour turns yellow first, then gradually darkens and turns grey. The overall lowest colour difference was observed for treated samples – colour changes visible with the medium quality filter (Table 1), the highest for untreated larch after 18 months of weathering – different colour according to Table 1. Generally, the total colour difference of all treated and untreated samples increased with increasing exposure period in natural weathering.

The surface roughness changes during weathering

The surface roughness of wood is mainly caused by leaching of UV degradation products and exposed and eroded underlying cell layers and erosion. The surface roughness parameter – Ra – was measured by the contact profilometer.

› Average roughness value – Ra [µm]

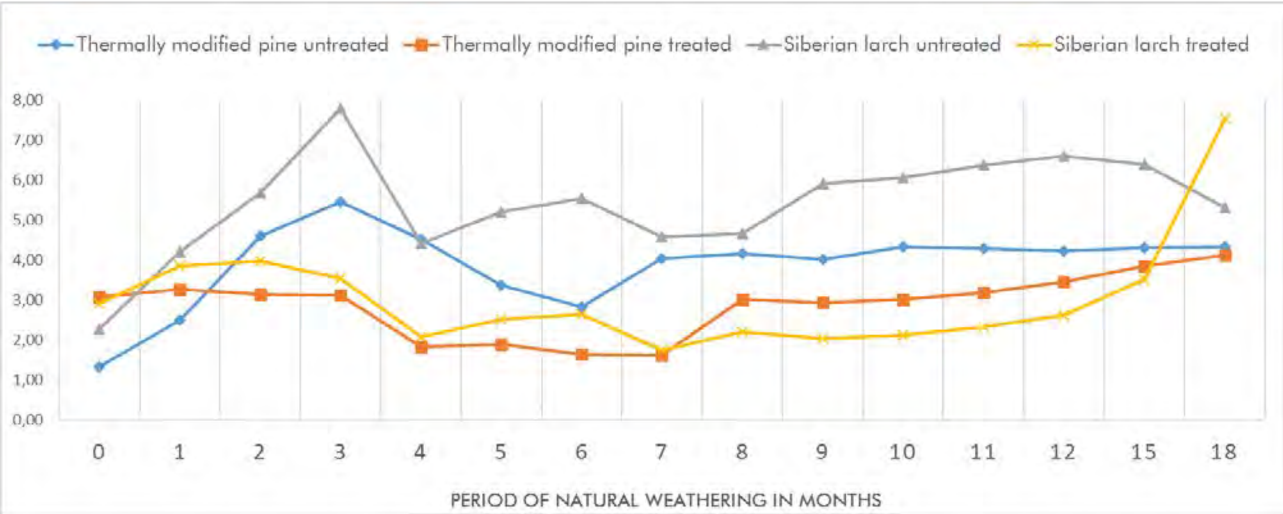


Figure 20: Change of roughness during weathering

The treated samples show a similar stable results during the 15 months of exposure (Figure 20). After 15 months of exposure, the surface treatment started to degrade. It is obvious from the increased roughness value after this period of weathering. For untreated wood species a high increase in surface roughness can be observed mainly in the beginning of weathering. This trend can be explained by leaching of the products of photo-degradation reactions (lignin, extractives, as well as hemicellulose), which can lead to the tearing of cellulose fibres exposed on the wood surface. The arisen asperity are later filled with dust particles and decomposed products which leads to greying and smoother surface. The little fluctuations are rather caused by variability of wood than any significant trend.

The change of surface wettability during weathering

This graph shows a change of surface wetting during exposure – it express the ability to absorb water (Figure 21). In the case of untreated samples the full wettability of surface after 18 months of weathering is observed. The treated samples maintain good wettability.

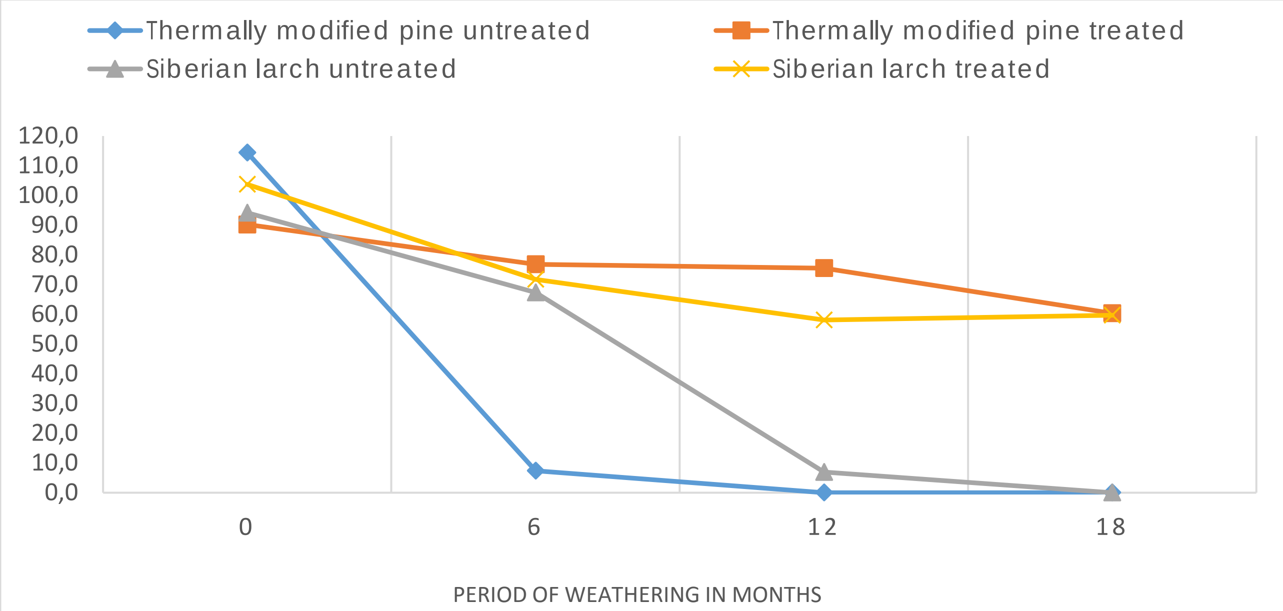
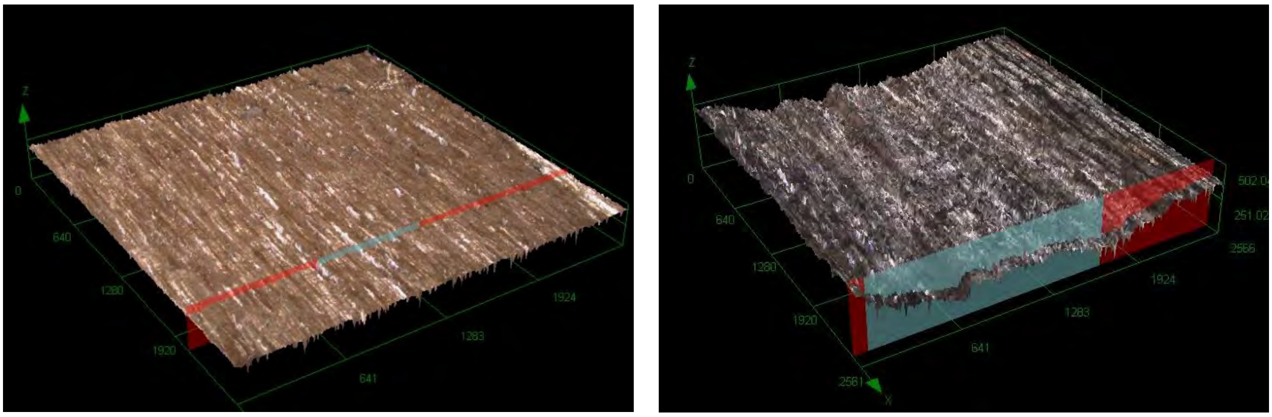


Figure 21: Change of wettability during weathering

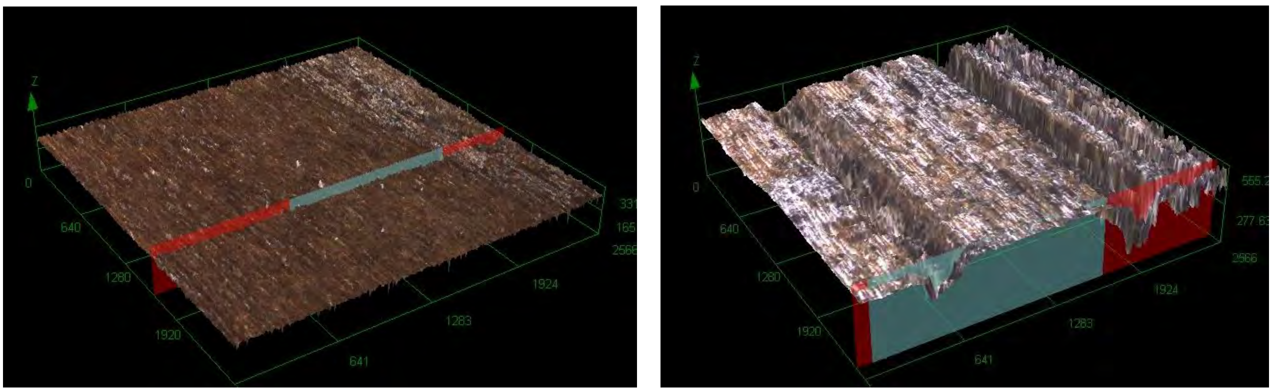
Laser scanning microscopy

The laser scanning microscopy revealed visible greying of untreated wood caused by dust settling and formation of surface mould (Figure 22). Also degradation of surface treatment applied both on thermally modified pine and Siberian larch (flaking, chalking etc.) after 18 months of exposure was observed.

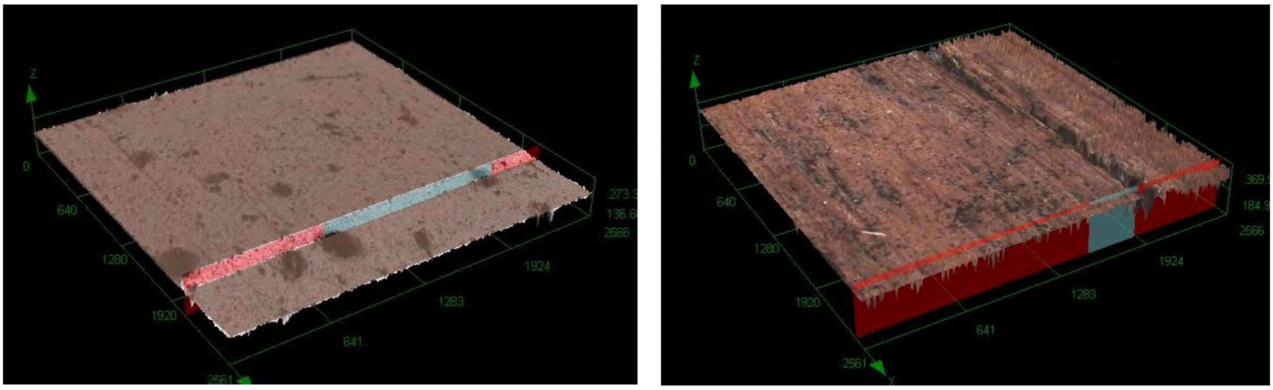
Untreated Siberian larch before (left) and after 18 months of weathering (right)



Untreated thermally modified pine before (left) and after 18 months of weathering (right)



Treated Siberian larch before (left) and after 18 months of weathering (right)



Treated thermally modified pine before (left) and after 18 months of weathering (right)

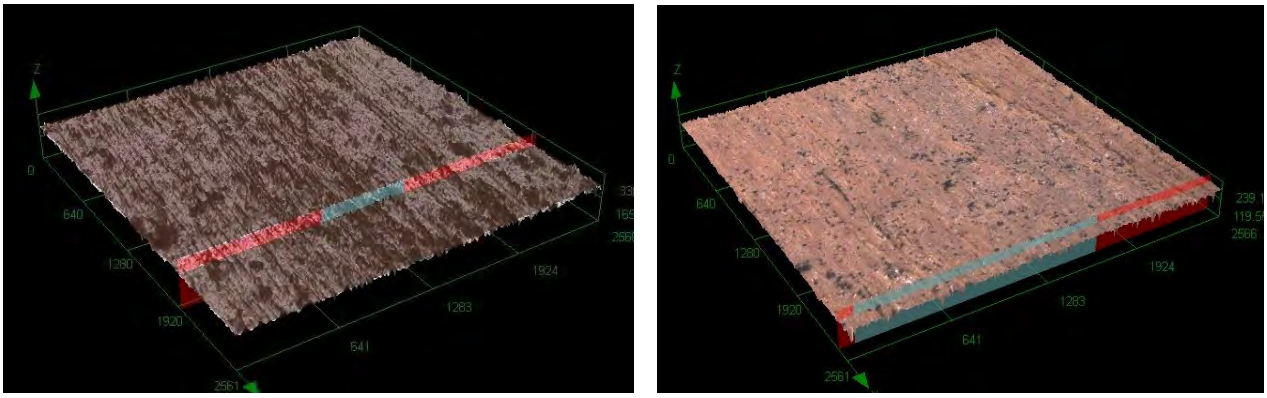


Figure 22: Laser scanning microscopy of samples before and after weathering

The visual appearance of the samples

The samples were evaluated also visually (Figure 23). The formation of cracks which basically ran in the direction of wood fibres was observed on untreated samples (first and third line).

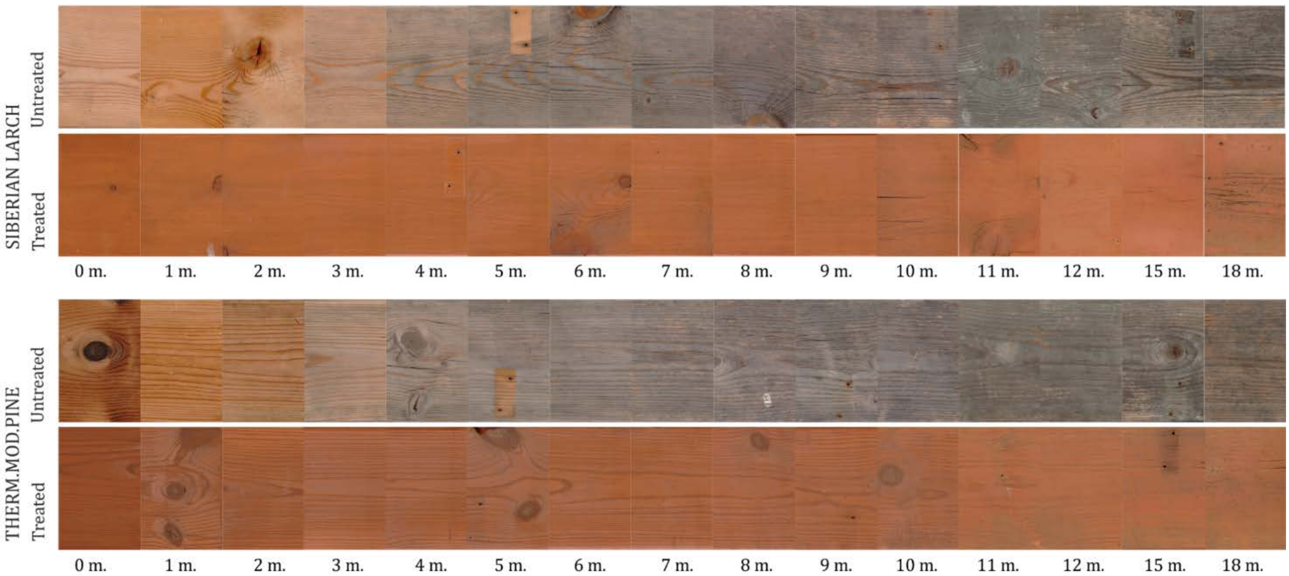


Figure 23: The appearance of test samples during 0 – 18 months of natural weathering (from the top line: Siberian larch untreated and treated, thermally modified pine untreated and treated).

Visual appearance of wood constructions (façade cladding and terrace decking) in the case of Hout Bay House was evaluated (Figure 24). The façade with untreated cladding from Siberian larch and untreated thermally modified pine degrades unequally, since the profiles cover each other and the rain reaches only the lower parts of profiles. Also the effect of roof overhangs is visible – wood under it turned yellow, not grey, as a result of solar radiation effect. Every protrusion causes unequal discoloration. It is not a mistake but we have to consider that when we design untreated façade. In the case of treated façade, there is also a change of colour which is more apparent in the lower parts of façade – as an effect of roof overhangs. The surface is significantly less glossy and cracks started to appear. The terrace decking is significantly more exposed to weathering than cladding. The untreated terrace is grey and rough after 2 years of weathering. It degraded unequally. Once this grey surface is formed, further degradation is slow to develop. The Siberian larch tends to be more susceptible to cracking than thermally modified pine in the case of wood decking.

Figure 24: The appearance of wood constructions after 2 years of weathering: untreated facade, treated facade and terrace decking (from left to right)

Conclusion

The treated samples showed significantly more stable results than untreated ones after 18 months of weathering, as expected. With the increasing period of weathering untreated samples distinguished by increasing colour and roughness changes. They turned grey even after 4 months of weathering. For the future we assume that untreated samples will continue to turn grey, the mould or even fungi and more cracks can appear. The treated samples showed more damages in the surface treatment (flaking, chalking etc.) after 12 months of weathering. From the overall results - measured values and visual evaluation, the better performance was so far observed for Siberian larch in the case of untreated samples and thermally modified pine treated in the case of treated samples.

In conclusion, currently the trend of using treated or even untreated wood elements in the exterior is becoming more progressive. But wood is a natural material and it behaves accordingly. It is our decision if we accept the fact that untreated wood eventually turns grey and gets typical plastic structure. If we do not, it is necessary to use suitable surface treatment which has to be renewed after several years.