Note by the translator.

This “Final note on Testing of Water reed as sustainable roof and facade material - with a focus on the insulating ability of the reed”, is originally written in Danish. This language has historically a lot of references to straw as thatching material, but there are hardly any roofs left made of straw. Only in Open Air museums are they still to be found.

- Because of this fact has the focus of these researches been only on roofs and items made with Water reed, which scientific name is: *Phragmites australis.*

- Where a complete section of roof is mentioned, eighter in sito, as a piece taken out of old thatch or sample, I tried to use solemnly the term “Thatch”.

Translation has been done with the help of “Google translate”. These translations by Google, have been read and after ability, adjusted by the responsible translator.

This report contains Version no .: 03

Date: February 1, 2020

(Version 03 of this report includes corrections of the roof surface (Sepatec section) and

the structure of the wall.

Other small mistakes that occurred, especially dates, have been corrected without reference in this English translation.

Ruud Conijn,

09th of september 2019.

Final note on Testing of thatch with waterreed as sustainable roof and facade material - with a focus on the insulating ability of the reed.

Initial conclusion

Almost two years of work on measuring and assessing the roof's insulation ability has now resulted in the insulation capacity being twice as high as the standard used hitherto - when the thatch is fixed directly on plate or boards without underlying air gap.

It is the first time in the EU that the thatched roof's insulation ability is measured in practice, both over time, in different roof constructions, in different weather conditions and at the same time old roofs have been measured.

A very specific result of Realdania's TEST-grant for the Straatagets Kontor is that the thatches insulation's thermal insulation capacity is now included in a completely new SBi instruction (Statens Byggeforskningsinstitut, no. 273, "Tage, materialer, opbygning, egenskaber, detaljer" December 2018). This has never happened before.

The following text can be read in the SBi instruction:
"Thatched roofs are heat insulating. The thermal insulation capacity typically corresponds to 50-60 mm mineral wool, if fixed on a fire-approved glass fiber cloth with ventilated airspace below, and 90-120 mm, if fixed on a closed substrate, eg. a plywood sheet according to the fire-approved solution. "

The reason why the numbers fluctuate (50-60 mm and 90-120 mm) is that thatch varies slightly in thickness, between 250 mm and 300 mm for a newly thatched roof.

A reasonable average for thermal insulation capability for a thatched roof on a solid underlayment, would be 100 mm. With this project, documentation has been provided that the thatched roof can be included when the insulation of the climate shield is calculated and documented.

This means that the overall roof construction can be at least 160 mm thinner than today, because both 10 cm other insulation and the ventilated air gap are saved. This is a great advantage in a number of constructions, both in terms of the constriction itself, and architecture.

The fact that a ventilated thatched roof, fire-resistant with glass fiber tissue, also insulates 50-60 mm, is also documented through a number of concrete measurements. In this way, different thatched roof constructions are differentiated in contrast to hitherto, where the calculated value of 60 mm applied to all types of roof constructions, both the fire-resistant with ventilated airspace, for completely open structures without underlying cladding and for the relatively few constructions where there are covered directly on solid surfaces, plywood or boards.

PHOTO 1. Caption: The thermal insulation capacity of thatch is for the first time included in an SBi instruction. Here is a newly built house in Northern Denmark.

This TEST project has shown that the WIND has much greater significance for the thermal insulation capacity than the AGE of the thatch.

10 old, thatched roofs have been measured by the Danish Technological Institute - the oldest was 54 years old - and the result is, overall, that the ability to isolate is not reduced as violently as assumed.

In contrast, the in situ measurements on a specially build test house in Hadsten show clearly that strong winds significantly reduce the thermal insulation capacity. This applies both to the ventilated and the non-ventilated roof, as a well-done thatch today is made relatively airy for durability and the ability to rapidly dry up after rain. It blows through the roof because there is space around the individual bodies of the warerreed.

The results of this two-year TEST project cause the thatching buisness to consider two things:

1) Is it possible to reduce the air flow in a ventilated roof? Most of the air comes from below, ie from the eaves and at the top of the wallplate. Can a form of "valve" be developed that shuts off air flow from below as the wind increases? Or will a windshield mounted on the lower battens be beneficial? Or both?

The Danish Technological Institute has measured moisture transport through construction and thatched roofs in another project - at The Breatheble House in Ringsted. The report is not yet complete, but the owner of the house, the company Eigen Vinding and Datter, informs the Straatagets Kontor that "… Insulation with waterreed and Miscantus here has proved to have a positive effect on handling moisture in the overall construction." If this type of roof structure, Thatch on 1 inch planks with feathers and grooves, does not give rise to moisture problems in the thatched roof, this may lead to

2) Further tests, done with breathable, insulated constructions with thatched roofs to determine whether this type of roof can vent and dry without underlying ventilating cavities?

The Breathable House is insulated with paper, linen and hemp - in total with 410 mm insulation. Unfortunately, there is only one moisture meter inside the thatch itself.
At no time has the humidity at this meter -placed in the middle of the approx. 270 mm thick thatched roof- showing a humidity above 13%. Most measurements in the thatched roof have shown between 9 and 12% moisture, which is completely unproblematic.

PHOTO 2 Text: There is never more than a maximum of 13% humidity in the straw roof of the breathable house - and so low humidity is completely unproblematic

With this, the project has answered the question asked by the advisory board in a letter of 2 July 2015:

"What is the significance of the air gap for the insulation ability ..?"

The answer is that the air gap under a thatched roof, fire-protected with glass fiber tissue, insulates half as much as when the thatch is fixed directly on solid underlayments.

The second question from the advisory board,

"…Is an air gap necessary ",

the thatching buisness, represented by the Technical Committee of the Taekkelaug, must subsequently seek answers for.
With this TEST project, solid documentation - the first of its kind in Europe - has been provided for the significance of thermal insulation of various constructions.

Project implementation and changes, 2016 - 2018

It turned out very quickly that the Danish Technological Institute thought it to be too uncertain to measure on the existing roofs mentioned in the application (newly built house with facade cover, The Breathable House and the Wadden Sea Center).
The reason is that the desire was to get concrete measurements for documentation of the insulation ability under changing conditions and weather conditions. Not least, the influence of wind is interesting, but also humidity and roof thickness. These measurements of lambda values can only be made by measuring the entire roof structure, ie. including other insulation with paper wool, mineral wool etc. When the result of such a measurement was available, the calculated isolation value of other insulation had to be subtracted, after which one would have the roof's insulation ability.

This kind of calculated value would be too uncertain, said the Danish Technological Institute. Therefore, this part of the project was changed to measure continuously in the winter on a test house, built specifically for this TEST project.

Quote from note to Realdania about this change of project, from 15.04.2016:

"A thorough analysis of how to measure, compared to what is already available from measurements from Germany, has shown that the most secure method for determining a new thatch roof insulation (lambda value) is implementing a longer time series of measurements in a non-heat insulated thatched roof and facade with the two types of roof construction that will be used in engineering in Denmark.
The analysis has been carried out by the Danish Technological Institute's project manager on the case, civil engineer Bent Lund Nielsen in collaboration with chief consultant Niels Strange, Dansk Byggeri and director Jørgen Kaarup, Straatagets Kontor."

The house for these measurements was build and thatched at Den Jydske Haandvaerkerskole in Hadsten, which is the technical school in Denmark, where thatchers trainees carry out schooling and thus complete education. The testhouse was constructed, following a proposal from Bent Lund Nielsen, the Danish Technological Institute's expert and executive party in the TEST project.

PHOTO 3 Text: Thatching trainees at the Jydske Haandvaerker Skole in Hadsten in the process of thatching the test house that has been used for most TEST measurements.

The house was thus tailored for measurements of the insulation properties of the thatch, both on the covered facade and on the roof. The house can be heated to 20 degrees Celsius, which is the ideal internal temperature for the measurements.

In the winters 2016/17 and 2017/18 there have been carried out continuous measurements of the insulation capacity.
At the same time, a series of measurements were taken of two newly thatched samples in the Danish Technological Institute's HotBox. The measurements were used to calibrate the remaining measuring equipment and to document what wind flow means for the insulation ability.

In addition, information has been obtained from the Institut für Bauen mit nacwachsenden Rohstoffen in Lübeck and a collaboration on the exchange of data with the institute has begun during visits to Lübeck. (see Appendix 3, Note Lübeck)

Old thatched roofs

A total of 10 old roofs, taken down by thatchers across the country, have been included as an essential element of the TEST project. The requirement for these roofs was that the thatcher with certainty should be able to determine the age of the roof, which is an important parameter, both in terms of measuring lambda value, but also in order to be able to consider the decay in old thatched roofs. The thatch is worn from the outside by the fact that the bottom parts of the individual bodies of the warerreeds break off, for example after snowfall when wet snow on the roof slides down - and other climatic and weather conditions that contribute to the roof slides.

PHOTO 4
Text: Thatcher Ruud Conijn and his apprentice have cut a piece out of a 32-year-old thatched roof that was tested at the Danish Technological Institute in Aarhus.

It has been surprising to note that the thermal insulation capacity is not reduced as much as one could have expected and feared. (see Appendix 1, Heat Conductivity of thatch)

All test pieces were removed when old thatch had to be replaced. They were then transported to the Danish Technological Institute in Aarhus, where these pieces of roof (75 x 75 cm) were tested and measured with heat flow meters in a special box, modified for this TEST project.
The oldest roof was, as mentioned initially, 54 years old! The measurements of old roofs were compared with two completely new samples, made especially for "the special box" with heat flow meters, which were used for the 10 old roofs.

Taekkelaugets registration of 27 thatched roofs.

The Taekkelauget has completed registration of 27 thatched roofs in the period 2001 - 2015, and these registrations have been included in the Test project to support the measurements of the 10 old roofs.
These 27 roofs have been crafted in 2000-2001.
1st Follow-up 1. control measurement was carried out in 2007
They were originally 28 thatched roofs, but a thatched roof was originally registered incorrectly and is therefore excluded from the study. 27 roofs are thus included in the further study program.
2. Follow-up 2nd control measurement was carried out in 2015
Of the 27 roofs, 5 are no longer existing as they are either burned, demolished or rebuilt.
Of the 27 thatched roofs, very large measurement deviations of 7 were noticed between the 1st and 2nd control measurements in 2007 and 2015. These 7 deviating thatched roofs have been rejected as the basis for this short note, but may be included in later studies with reference to 2nd control measurement.

The reason why great deviations have been found for the 7 thatched roofs, between the 1st and2nd control measurement, is considered to be that 1st control measurement was made by local thatchers, carried out according to guidelines that were not perceived alike. The 2nd control measurement was carried out by 2 men who followed the same survey system according to the guidelines on all thatched roofs.

Based on the above, therefore, only 15 samples are included in the following results after control measurement in 2015.

A. Average roof thickness: 300 mm.
B. Average wear (note 1) on thstch: 8. mm.
C. Average life expectancy: 46 years and> 50 years (note 2)

Note 1. The biological degradation on the surface starts at the completion of the roof, but during the first 8 - 10 years no wear on the roof thickness is expected.
Note 2. A lifetime over 50 years can be expected when the conditions for a healthy thatch are present.

The above-mentioned lifetimes are confirmed in the Danish Technological Institute's study of the thermal insulation capacity of thatch, where 10 older roofs have been examined for age and thickness.

PHOTO 5
Preparing to test an old, cut out piece of thatch for thermal insulation at the Danish Technological Institute in Aarhus.

The environmentally friendly thatched roof

In recent years, the Straatagets Kontor, branch office for the Danish thatchers, has carried out a total of three projects focusing on the environmental and climate characteristics of the thatched roof:
- Environmental assessment of roof with Waterreed and Miscantus (Danish Technological Institute, 2014)
- Nature's own thatch – Miscantus for thatching in Denmark (Danish Environmental Protection Agency, 2017)
- The ecological and sustainable thatched roof (Miljøstyrelsen, 2017), which also relates to an EPD report, Environmental Product Declaration, of the roof made of Waterreed.

All 4 reports can be found in their entirety here:

http://straatagetskontor.dk/baeredygtighed/

The SPD is also available on the EPD Denmark's website:
http://www.epddanmark.dk/site/images/gallery/md-17001-en/md-17001-en.pdf

In summary, it can be stated that the thatched roof is the most climate-friendly of all. Even when the Waterreed is imported from China, the thatched roof emits less carbon footprint than a Danish tile roof with underlay.

Waterreed is one of Denmark's most productive plant and produces more biomass than a well-fed wheat field. Waterreed, through their photosynthesis, counteracts the rising carbon dioxide level in the air and thus also the greenhouse effect and climate change.

PHOTO 6

Harvesting Miscanthus on a field at Laasby west of Aarhus. Miscanthus is a Danish quality product that can be appied for groundwater protection. The sloped roof on The Breathable House is made of Miscantus.

Cultivation of another roofing material on Danish fields - Miscanthus, which was used on the roof of the Breathable House - can be used advantageously as an active tool for protecting groundwater, because Miscanthus can be grown without the use of spray poisons and without leaching nitrogen from the field.

Finally, it can be stated that waterreed does not contain any environmentally hazardous substances, and that 99% of the thatched roof can be used either in power plants or composted at disposal.

When the thatch at the same time insulates quite well - and presumably, through the reduction of airflow, can be developed to provide an even greater thermal insulation capacity, then with this TEST project another argument has been added to choose waterreed as roof and facade material, when increased needs to be built environmentally friendly and sustainable must be met.

Aarhus, November 27, 2018, Jørgen Kaarup, director, Straatagets Kontor
Translation: Glesborg, june 26, 2019, Ruud Conijn, Head technical board.

APPENDIX:

1. **Varmeisoleringsevne af stråtækning.** Teknologisk Institut, november 2018
2. **Notat – in situ målinger Hadsten** primo 2017. Teknologisk Institut, maj 2018
   Not added, in this raport is only made a conclusion that the testhouse was not wind tight enough in the first winter.
3. **Uddrag om stråtag fra teknisk rapport**, Egen Vinding og Datter, juni 2018
   Not added due to too few references.
4. **Notat – studietur til Lûbeck**. Bent Lund Nielsen, Teknologisk Institut, november 2016.
5. **Notat – Hotbox målinger på TI –Aarhus.** April 2017.
6. **Dutch note on calculated thermal insulation value for thatch roof.**
   Not added since this document is already available for the ITS-members

APPENDIX 1: **Thermal insulation ability of Thatch**

6 in situ measurements in test housing and 12 laboratory measurements on sampled samples from old roofs

Original titel:

Varmeisoleringsevne af stråtækning

6 in situ målinger i testhus og 12 laboratoriemålinger på udtagne prøver fra gamle tage

Requested by:

Stråtagets Kontor

Att.: Direktør Jørgen Kaarup

Store Torv 9

8000 Aarhus C

Processed by:

Teknologisk Institut

Kongsvang Allé 29

8000 Aarhus C

Tlf. 7220 2000

Byggeri og Anlæg

Glas og Vinduer

Bent Lund Nielsen

Quality assurance:

Responsibility: Bent Lund Nielsen, tlf. 7220 1147, btl@teknologisk.dk

Approved by: Lars Thomsen Nielsen, tlf. 7220 1116, ltn@teknologisk.dk

Case nr: 0108/664103

Version no .: 03

Date: February 1, 2020

(Version 03 of this report includes corrections of the roof surface (Sepatec section) and the structure of the wall - according to information from thatcher Ruud Conijn who instructed thatching work on the test house, cf. picture B1a).

PART 1: In situ measurements

Description of test house

The performed in situ measurements have been made at 6 points in a test house build for that purpose at The Jydske Haandvaerker Skole in Hadsten. See picture B1a og B1b.

B1a: Thatching of the test house

B1b: Completed test house

In the sloping roof surface facing north, have been established 4 test fields: TA1, TA, 2 and TB1, TB, 2:
Test fields TA are made with 28 cm Waterreed directly on a solid underlayment (2 measurements)
Test fields TB are made with 28 cm Waterreed on Sepatec fiberglass fireprotection, on battens (2 measurements). In test fields TB, a plywood board was mounted on the back of the laths and along the boundaries of the test field all cavities were stuffed with mineral wool.

In the wall below the sloping roof surface 2 test fields VA and VB have been established:
Test field VA is made with 32 cm thatch directly on a plate substrate (2 measurements)
Test field VB is made with 32 cm thatch directly on a plate substrate (2 measurements)
Both test panels on the wall are located near the end of the wall towards the floor, ie in an edge zone.

Picture B2-B4 shows the test fields from the inside with mounted measuring equipment.

B2: Test field TA2 seen from the inside

B3: Test field TB2 seen from inside

B4: Picture of sample fields VA and VB on wall surface (data loggers on the test house floor).

Measuring equipment

Data loggers (type ALMEMO 2690), thermo elements (type K) and

heat flow meters (type FQ) from fa. Ahlborn, see picture B4 and B5.

Data loggers collect the measured values from the connected sensors so that they can later be transferred and processed on a computer.

The thermo elements are approx. 1mm thick wires with 2 conductors, which are soldered together at the end where the temperature is measured.

The heat flow meters are approx. 1.5 mm thick plastic sheets and consist of one measuring field and an edge field. In the measuring field there is a large amount of thermo elements which detects the temperature difference between the inner and outer surfaces of the plastic sheet and which emits a voltage difference proportional to the heat flow through the meter.

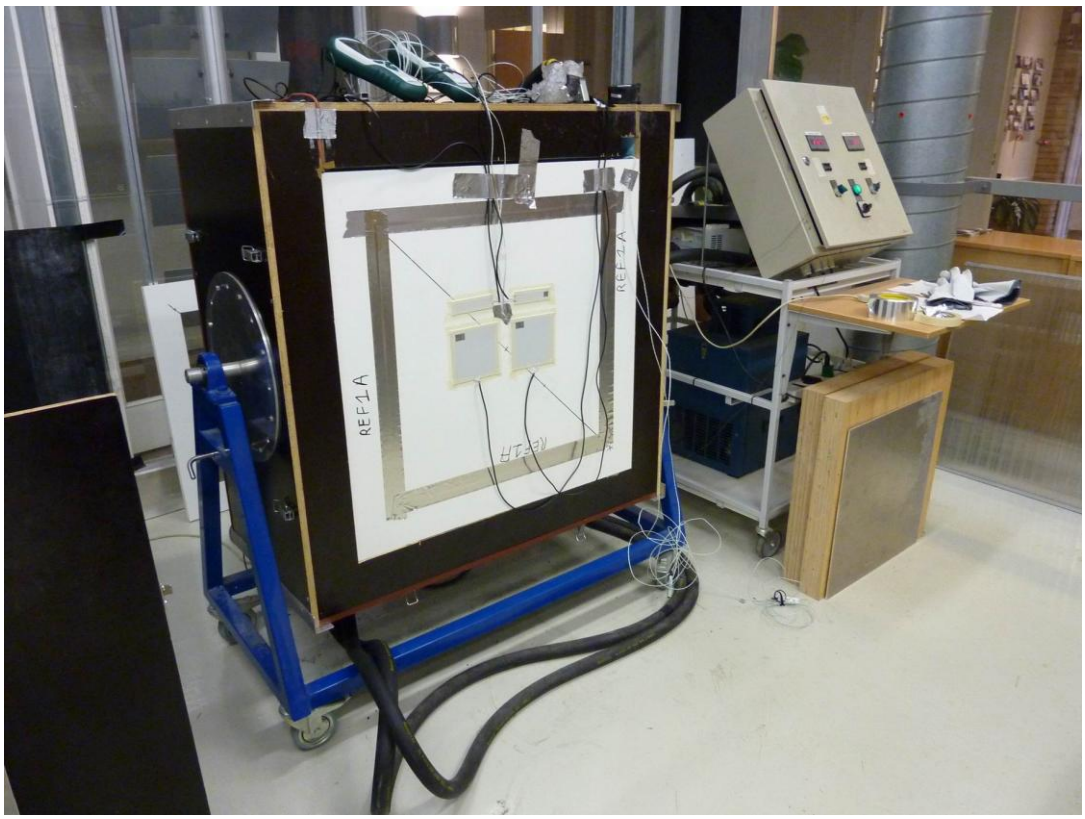
Metering / measuring methodology

The measurement method is described in DS / ISO 9869-1 from 2014. Here it is recommended here that for lightweight constructions only measurement data are taken from 1 hour after sunset until sunrise. We have chosen instead to turn the test surfaces to the north, so that direct sunlight is avoided.

Thermo elements were mounted externally to the outermost waterreed (retained by strips) in test fields TA and TB, and the wires were passed through openings in the gable walls of the data loggers. On the internal wall surfaces of the test fields, heat flow meters with plastic tape were mounted in the plate edge field and immediately next to the heat flow meter a thermocouple with alu-tape and paint tape.

The measuring equipment has been used for several tasks in the laboratory's Hotbox and has been calibrated for measurement on test pieces of varying isolans.

For this task, it was decided to check the calibration by making a control measurement on a reference plate with known isolation in TI's equipment for U-value measurement, according to EN 675, see picture B5.



B5: Control of heat flow meters

Experiences with laboratory measurements using heat flow meters for U-value determination shows that the uncertainty of the results is max. 0-5% in EN

675 equipment (where cold and hot temperature is constant and where there is no

air flow at the surface of the heat flow meter) and 5-10% when used in

The Hotbox, where there is a controlled airflow at the surfaces.

By insitu measurements in general, where especially the outside temperature varies and where convective airflows are present at the surface of the heat flow meter, ISO 9869-1 states an uncertainty for well-executed measurements of 14-28%.

Treating of the measurement data

Acc. averaging method in ISO 9869-1 can the thermal conductivity of the test item be found by dividing the mean value of the measured heat flows by the mean of the measured temperature differences.

If one, as chosen in this task, uses surface temperatures, the U value is found by calculating the isolation R, add a rated value for transition isolances (0.17 m2K / W) and invert.

The isolation is found by the term

$$R = \frac{\sum_{j=1}^{n} \left(T_{sij} - T_{sej} \right)}{\sum_{j=1}^{n} q_j}$$

Where the counter represents the temperature differences and the denominator the heat flows.

When calculating the above estimate after each recorded measured value, one will usually observe a convergence towards an asymptotic value that is close to the real U value, if the internal energy (same temperature) and moisture distribution in the test item, are the same at the beginning and end of the measurement period. This is considered applicable to lightweight structures when over a 72 hours period of measurement, the start and end values differ by less than 5%.

The current test item - thatch - may have variations in moisture content in the period of measurement.

In the preparation of test items for laboratory measurements (see pictures in appendix 1), it was clear, however, that the moisture from rainwater only affected the outer 2-3 cm of the roofing.

Measurement results in situ measurements

The measurements were taken over 2 winter seasons 2016/17 and 2017/2018. After the first season it turned out that the test house was not sufficiently airtight to allow the indoor temperature to be kept fairly constant.

Therefor an inner plastic foil with taped joints was mounted before the second season

It also turned out that the test house should preferably be heated for approx. 14 days before mounting the heat flow meters to avoid moisture-related curvatures of the heat flow readings.

For heating the test house in season 2, a better oil radiator with a better fan was built in (led to better air circulation and more constant temperatures, but greater turbulence on the heat flow recordings). Below are shown figures with graphs of selected measurement data from the 2 measurement periods. In all figures, the following colors are used on the graphs:

Red line: indoor temperature ° C (Tsi)

Blue line: outdoor temperature ° C (Tse)

Black line: (Tsi –Tse) ° C

Dark green line: 1 / R W / m2K (corresponds to the U value - but without transition isolations) - Channel 0.12 or 90.91. The U-value is usually stated with the addition of transitions isolates 0.17 m2K / W to R value (transition isolations are the insulating capacity of stagnant air layers at the inner and outer surfaces)

Light green line: heat flow W / m2

Purple line: running medium –U value W / m2K (formula page 7)

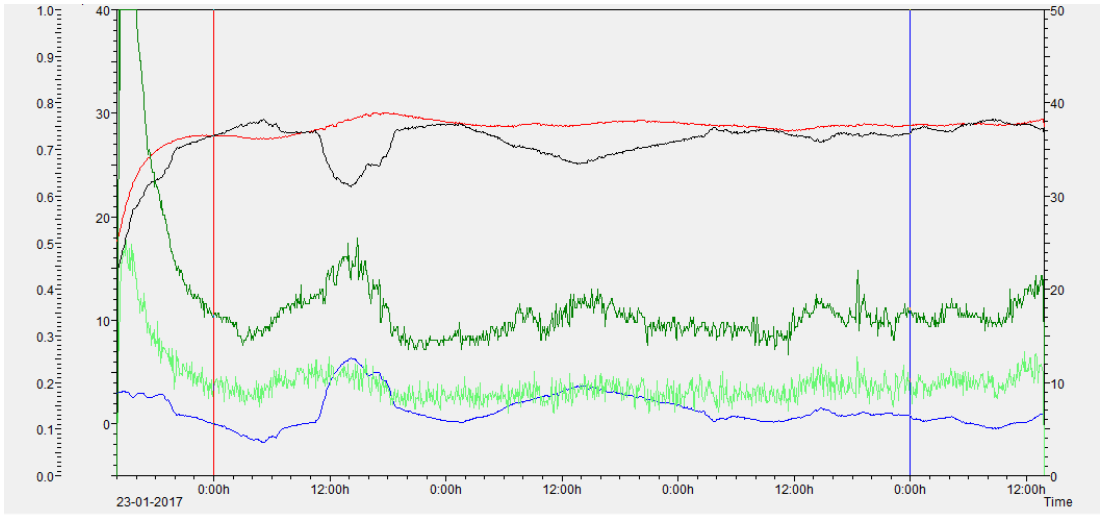
The measurement period considered is between left cursor (red vertical line) and right

cursor (blue vertical line).

λ straw is determined from the general U-value formula:

U = 1 / (0.17 + Σ d / λ) where d is the thickness of the thatch, and λ heat conductivity for

each layer in the construction.

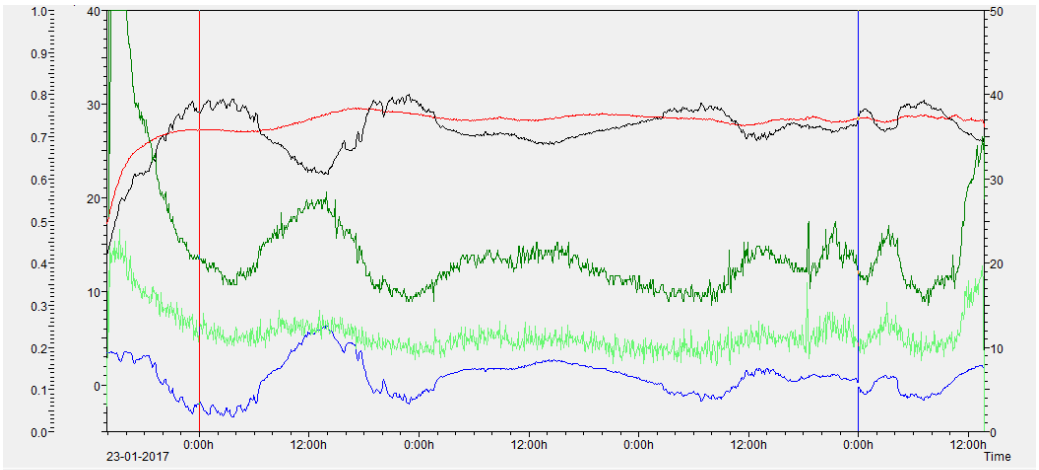


Channel	Left Cursor	Right Cursor	Difference	Minimum	Maximum	Max - Min	Average	Std. Deviation
Time	24-01-2017, 00:02:09	26-01-2017, 23:56:43	2:23:54:33					
0.0 -	27,8 °C	28,8 °C	1 °C	27,5 °C	30 °C	2,5 °C	28,79 °C	0,555 °C
0.1 -	0 °C	0,8 °C	0,8 °C	-1,8 °C	6,4 °C	8,2 °C	1,45 °C	1,695 °C
0.2 -	10,12 W	10,02 W	-0,1 W	6,7 W	12,77 W	6,07 W	9,2446 W	1,12392 W
0.5 -	27,8 °C	28 °C	0,2 °C	22,9 °C	29,4 °C	6,5 °C	27,339 °C	1,3785 °C
0.12 -	0,35 W	0,35 W	0 W	0,26 W	0,51 W	0,25 W	0,337 W	0,04128 W

Fig 1 TA1 23-01-2017 to 27-01-2017 (plate), measurement no. TA1

At the very first measurement period, the indoor temperature was set slightly high, but the outdoor climate had almost constant outdoor temperature. Calculation of U-value: U = 1 / [1 / (0.337) + 0.17] = 0.32 W / m2K

Calculation of lambda value for 28 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and subtracts): λ_{reed} = 0.28 / (1 / 0.32 -0.13-0.17) = 0.099 W / mK

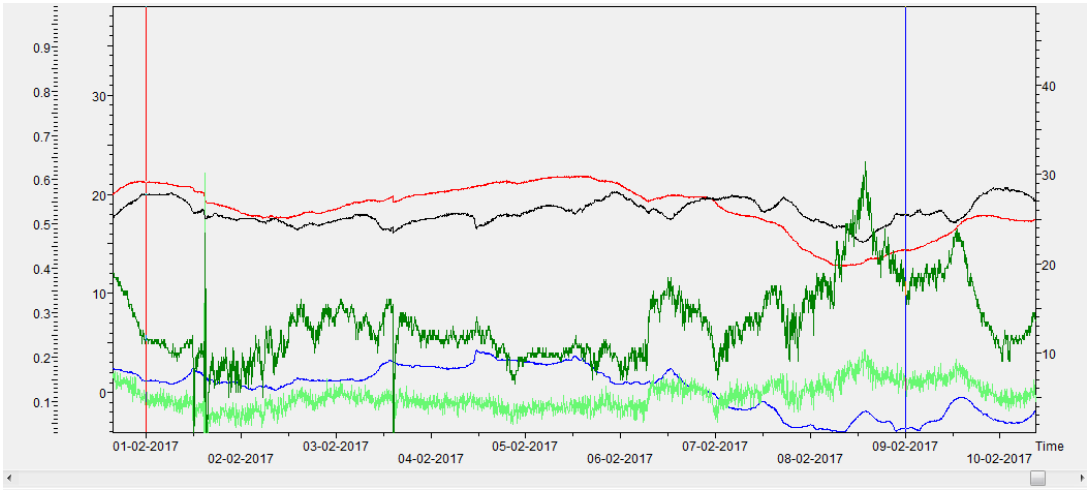


Channel	Left Cursor	Right Cursor	Difference	Minimum	Maximum	Max - Min	Average	Std. Deviation
Time	24-01-2017, 00:01:57	26-01-2017, 23:58:43	2:23:56:46					
0.0 -	27,3 °C	28,5 °C	1,2 °C	27 °C	29,6 °C	2,6 °C	28,36 °C	0,601 °C
0.1 -	-1,9 °C	0 °C	1,9 °C	-3,4 °C	6,4 °C	9,8 °C	0,89 °C	1,997 °C
0.2 -	12,09 W	10,58 W	-1,51 W	7,89 W	17,64 W	9,75 W	10,9555 W	1,18307 W
0.5 -	29,2 °C	28,5 °C	-0,7 °C	22,5 °C	31 °C	8,5 °C	27,465 °C	1,8506 °C
0.12 -	0,41 W	0,38 W	-0,03 W	0,3 W	0,57 W	0,27 W	0,3989 W	0,05586 W

Fig 2 TB1 23-01-2017 to 27-01-2017 (Sepatec), measurement no. TB1

At the very first measurement period, the indoor temperature was set slightly high, but the outdoor climate had almost constant outdoor temperature. Calculation of U-value: U = 1 / [1 / (0.3989) + 0.17] = 0.37 W / m2K

Calculation of lambda value for 28 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and subtracted): λ_{reed} = 0.28 / (1 / 0.37 -0.13-0.17) = 0.117 W / mK .

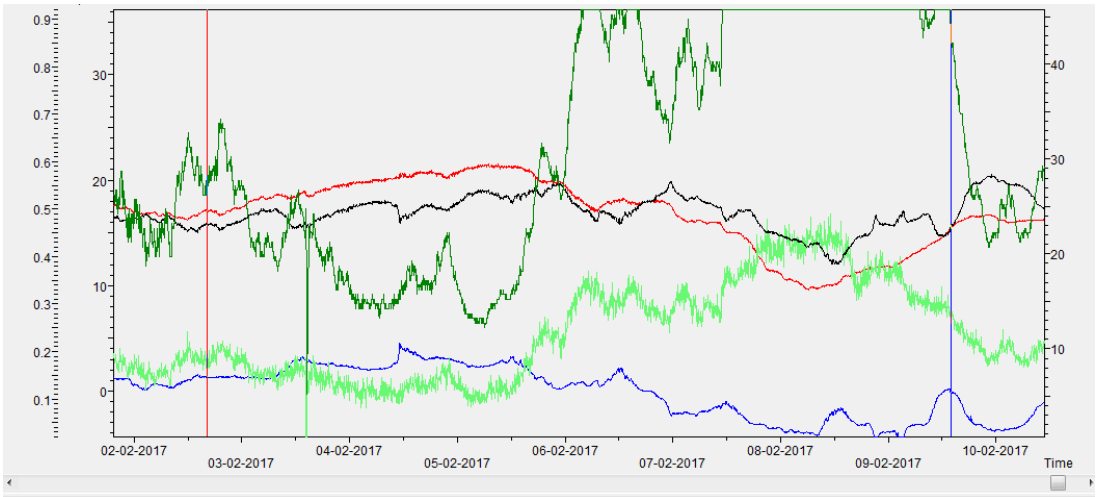


Channel	Left Cursor	Right Cursor	Difference	Minimum	Maximum	Max - Min	Average	Std. Deviation
Time	31-01-2017, 23:56:16	09-02-2017, 00:05:10	8:00:08:54					
0.0 -	21,2 °C	14,4 °C	-6,8 °C	12,7 °C	21,8 °C	9,1 °C	18,75 °C	2,513 °C
0.1 -	1,2 °C	-3,6 °C	-4,8 °C	-4 °C	4,3 °C	8,3 °C	0,71 °C	2,18 °C
0.2 -	4,91 W	7,23 W	2,32 W	-14,36 W	30,13 W	44,49 W	4,8491 W	1,64976 W
0.5 -	20 °C	18 °C	-2 °C	15,1 °C	20,3 °C	5,2 °C	18,039 °C	1,1097 °C
0.12 -	0,25 W	0,37 W	0,12 W	0 W	0,64 W	0,64 W	0,267 W	0,08386 W

Fig 3 TA 31-01-2017 to 09-02-2017 (plate)

comments:

Here, the criteria for a valid measurement are not met. Something strange happens as the internal surface temperature drops to approx. 13 ° C in a period with windy conditions. It is decided to seal the test house better.

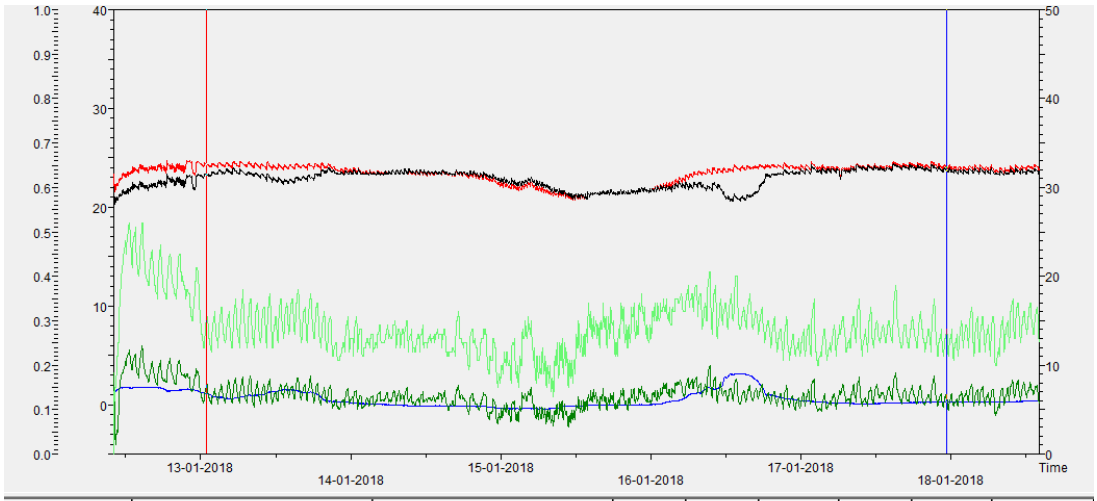


Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	02-02-2017, 16:09:16		09-02-2017, 14:03:11		6:21:53:55											
0.0 -	17,1	°C	15,6	°C	-1,5	°C	9,6	°C	21,5	°C	11,9	°C	16,85	°C	3,532	°C
0.1 -	1,4	°C	-0,1	°C	-1,5	°C	-5	°C	4,5	°C	9,5	°C	0,09	°C	2,505	°C
0.2 -	8,02	W	13,86	W	5,84	W	-2,08	W	24,2	W	26,28	W	12,2606	W	5,51707	W
0.5 -	15,7	°C	15,7	°C	0	°C	12	°C	19,9	°C	7,9	°C	16,757	°C	1,594	°C
0.12 -	0,54	W	0,85	W	0,31	W	0,11	W	1,82	W	1,71	W	0,7538	W	0,40037	W

Fig 4 TB 31-01-2017 to 09-02-2017 (Sepatec)

comments:

Here, the criteria for a valid measurement are not met. Something strange happens as the internal surface temperature drops to approx. 10 ° C in a period with windy conditions. It is decided to seal the test house better. Major fluctuations are seen than at the sample field with solid underlayment (Fig. 3).



Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	13-01-2018, 00:54:07		17-01-2018, 23:18:26		4:22:24:19											
0.0 - T3 type K	24,4	°C	24	°C	-0,4	°C	20,7	°C	24,6	°C	3,9	°C	23,34	°C	1,024	°C
0.1 -	1,1	°C	0,3	°C	-0,8	°C	-0,5	°C	3,1	°C	3,6	°C	0,44	°C	0,771	°C
0.5 -	23,3	°C	23,7	°C	0,4	°C	20,6	°C	24,4	°C	3,8	°C	22,894	°C	0,9418	°C
90.0 -	7,51	W	6,42	W	-1,09	W	3,08	W	9,93	W	6,85	W	6,356	W	1,011	W
90.91 -	0,3	W	0,28	W	-0,02	W	0,13	W	0,41	W	0,28	W	0,273	W	0,0446	W

Fig 5 TA2 13-01-2018 to 18-01-2018 (plate), measurement no. TA2, a

comments:

There was an almost constant outside temperature, the recording from the heat flow meter fluctuates around a middle value, probably due to influences from the air circulation and the thermostat control in the room (not considered to have any effect on the result).

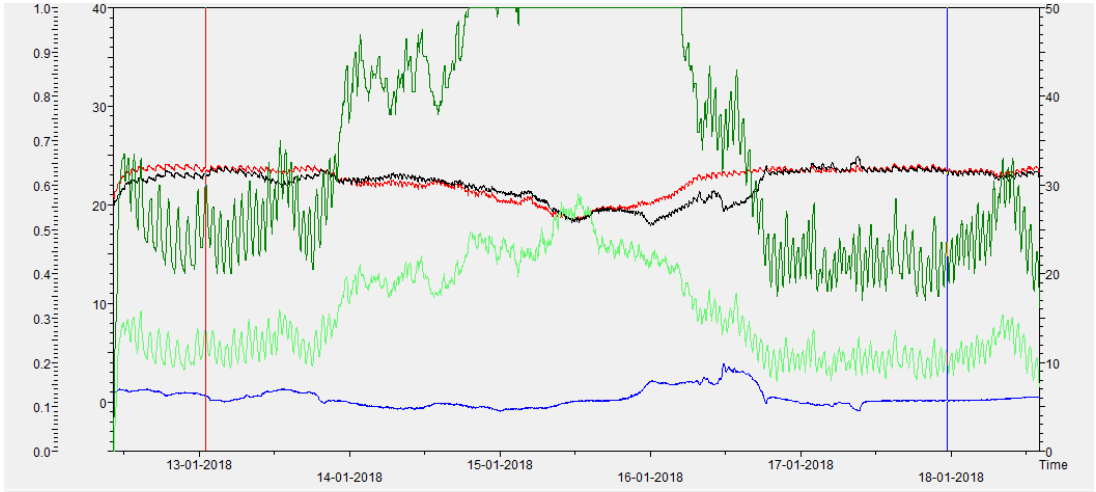
Calculation of U-value:

U = 1 / [1 / (0.273) + 0.17] = 0.26 W / m2K

Calculation of lambda value for 28 cm thatch (the plywood plate insulation is added

0.13 m2K / W and subtracted):

λ_{reed} = 0.28 / (1 / 0.26 -0.13-0.17) = 0.079 W / mK



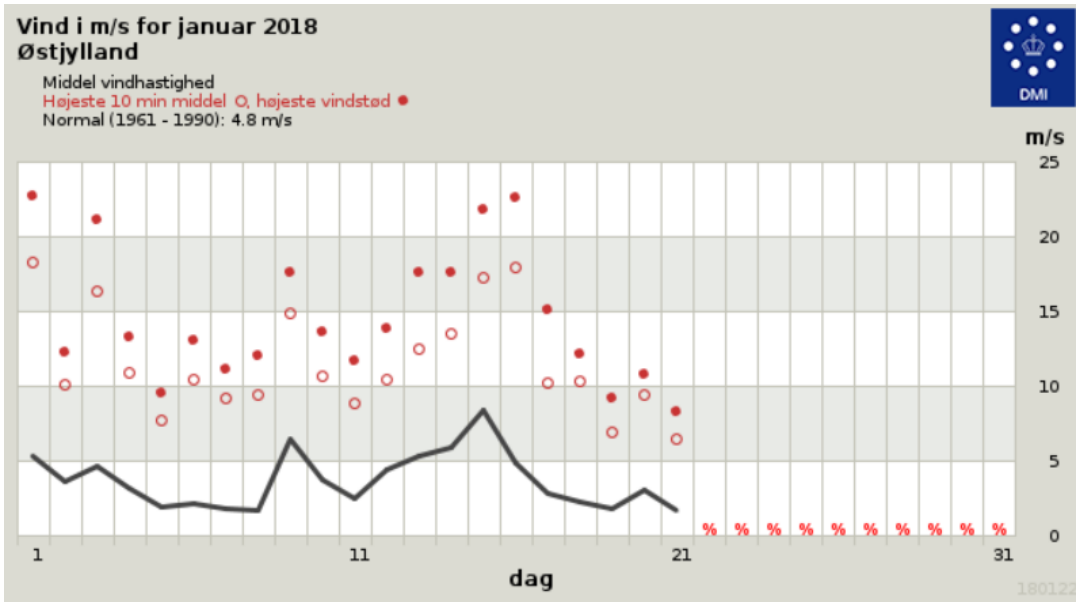
Channel	Left Cursor	Right Cursor	Difference	Minimum	Maximum	Max - Min	Average	Std. Deviation
Time	13-01-2018, 01:02:47	17-01-2018, 23:18:15	4:22:15:28					
0.0 - T2 type K	23,7 °C	23,4 °C	-0,3 °C	18,3 °C	24,2 °C	5,9 °C	22,24 °C	1,584 °C
0.1 -	0,6 °C	0,2 °C	-0,4 °C	-1 °C	3,9 °C	4,9 °C	0,35 °C	0,984 °C
0.5 -	23,1 °C	23,2 °C	0,1 °C	17,9 °C	24,9 °C	7 °C	21,894 °C	1,7026 °C
90.90 -	13,53 W	11,1 W	-2,43 W	7,9 W	29,08 W	21,18 W	16,526 W	5,4958 W
90.91 -	0,6 W	0,47 W	-0,13 W	0,34 W	1,53 W	1,19 W	0,77 W	0,3088 W

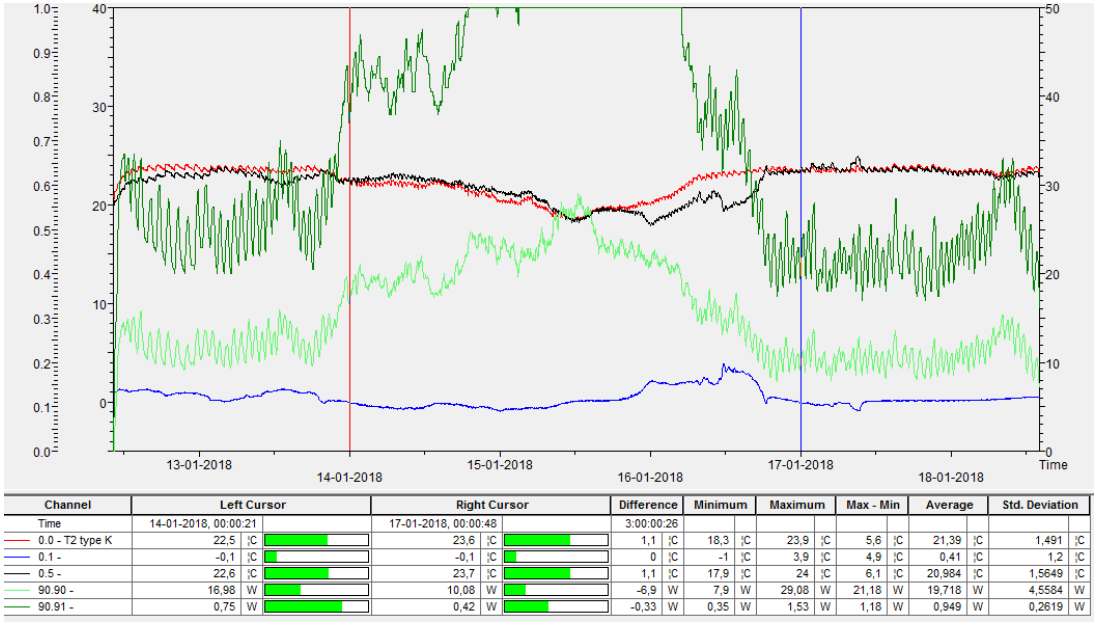
Fig 6 TB2 13-1-2018 to 1-18-2018 (Sepatec)

comments:

The outdoor climate was fine with almost constant outdoor temperature, the registration from the heat flow meter fluctuates around middle value, presumably due to influences from the air circulation in the room (not considered to be significant).

Because of the Sepatec solution, a clear influence from the wind effect is seen. In some way (eg ventilation between the thatch / ventilation between outdoor air and cavities behind waterreed layers) increases the U value. During the period there was strong wind, see fig. below, and it is therefore chosen to divide the observations .





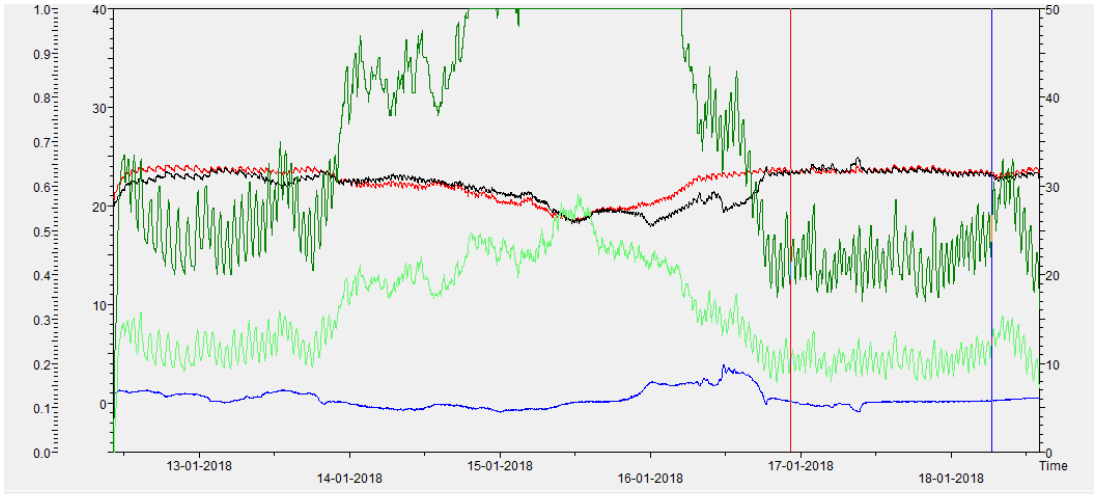
Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	14-01-2018, 00:00:21		17-01-2018, 00:00:48		3:00:00:26											
0.0 - T2 type K	22,5	°C	23,6	°C	1,1	°C	18,3	°C	23,9	°C	5,6	°C	21,39	°C	1,491	°C
0.1 -	-0,1	°C	-0,1	°C	0	°C	-1	°C	3,9	°C	4,9	°C	0,41	°C	1,2	°C
0.5 -	22,6	°C	23,7	°C	1,1	°C	17,9	°C	24	°C	6,1	°C	20,984	°C	1,5649	°C
90.90 -	16,98	W	10,08	W	-6,9	W	7,9	W	29,08	W	21,18	W	19,718	W	4,5584	W
90.91 -	0,75	W	0,42	W	-0,33	W	0,35	W	1,53	W	1,18	W	0,949	W	0,2619	W

Fig 6a TB2 14-01-2018 to 17-01-2018 (Sepatec wind), measurement no. TB2, a

Calculation of U-value: (orientation value for the period with strong wind)

U = 1 / [1 / (0.949) + 0.17] = 0.82 W / m2K (mean value in the period)

Calculation of lambda value for 28 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and subtracted): λ_{reed} = 0.28 / (1 / 0.82 -0.13-0.17) = 0,30 W / mK



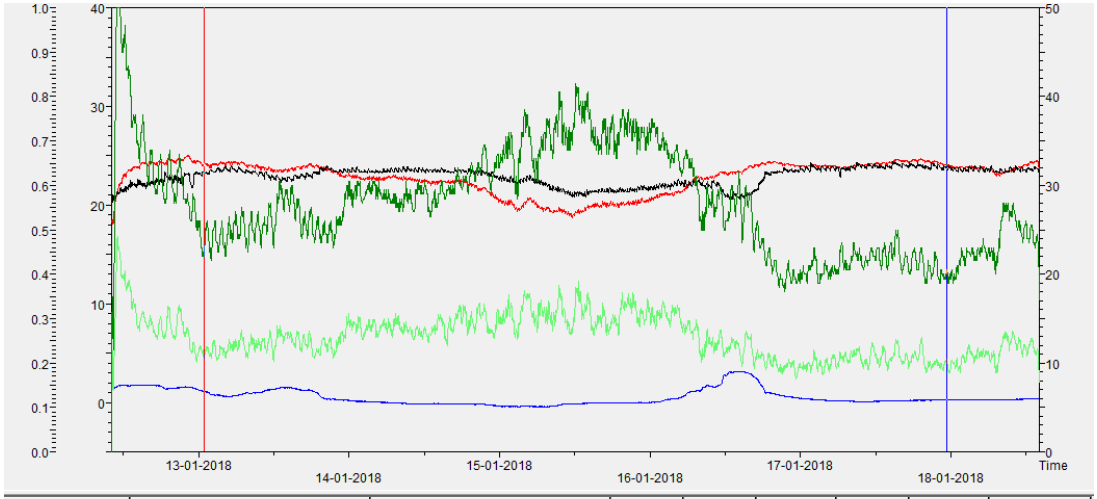
Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	16-01-2018, 22:21:29		18-01-2018, 06:28:18		1:08:06:49											
0.0 - T2 type K	23,7	°C	23,5	°C	-0,2	°C	23,1	°C	24,2	°C	1,1	°C	23,58	°C	0,218	°C
0.1 -	0,2	°C	0,3	°C	0,1	°C	-0,9	°C	0,3	°C	1,2	°C	0,01	°C	0,261	°C
0.5 -	23,5	°C	23,2	°C	-0,3	°C	22,9	°C	24,9	°C	2	°C	23,568	°C	0,3268	°C
90.90 -	10,31	W	12,5	W	2,19	W	7,95	W	13,67	W	5,72	W	10,48	W	1,134	W
90.91 -	0,41	W	0,51	W	0,1	W	0,34	W	0,57	W	0,23	W	0,44	W	0,0474	W

Fig 6b TB2 17-01-2018 to 18-01-2018 (Sepatec, no wind), measurement no. TB2, b

Calculation of U-value: (normal period)

U = 1 / [1 / (0.44) + 0.17] = 0.41 W / m2K

Calculation of lambda value for 28 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and subtracted): λ_{reed} = 0,28 / (1 / 0.41 -0.13-0.17) = 0.13 W / mK



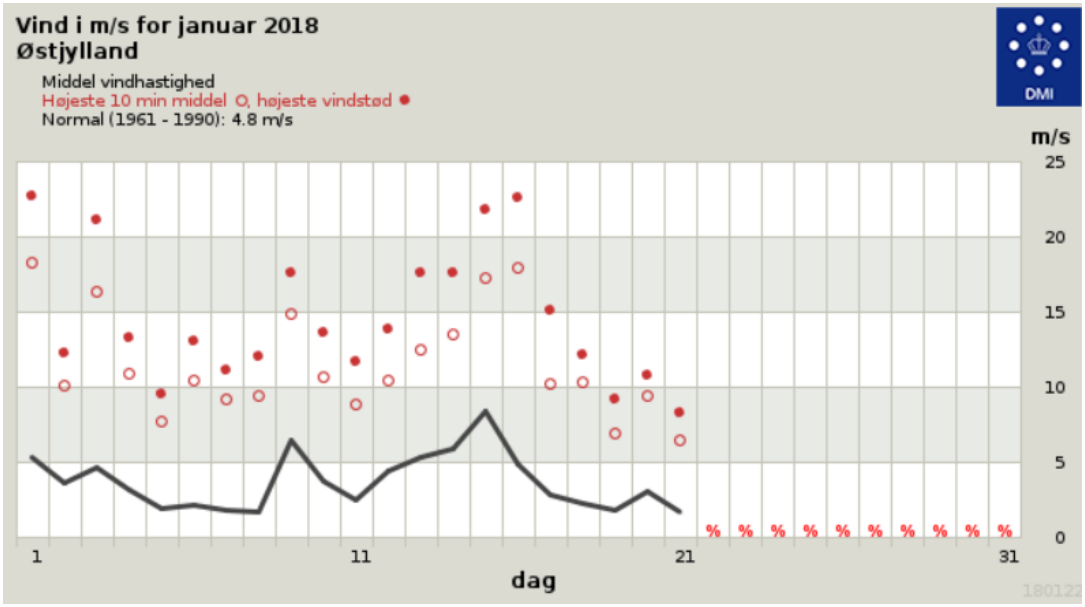
Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	13-01-2018, 00:54:07		17-01-2018, 23:18:26		4:22:24:19											
0.1 -	1,1	°C	0,3	°C	-0,8	°C	-0,5	°C	3,1	°C	3,6	°C	0,44	°C	0,771	°C
0.3 -	24,1	°C	24,1	°C	0	°C	18,7	°C	24,7	°C	6	°C	22,61	°C	1,645	°C
0.5 -	23,3	°C	23,7	°C	0,4	°C	20,6	°C	24,4	°C	3,8	°C	22,894	°C	0,9418	°C
90.90 -	10,5	W	10,25	W	-0,25	W	8,21	W	19,23	W	11,02	W	12,931	W	2,2455	W
90.91 -	0,45	W	0,41	W	-0,04	W	0,36	W	0,83	W	0,47	W	0,56	W	0,1105	W

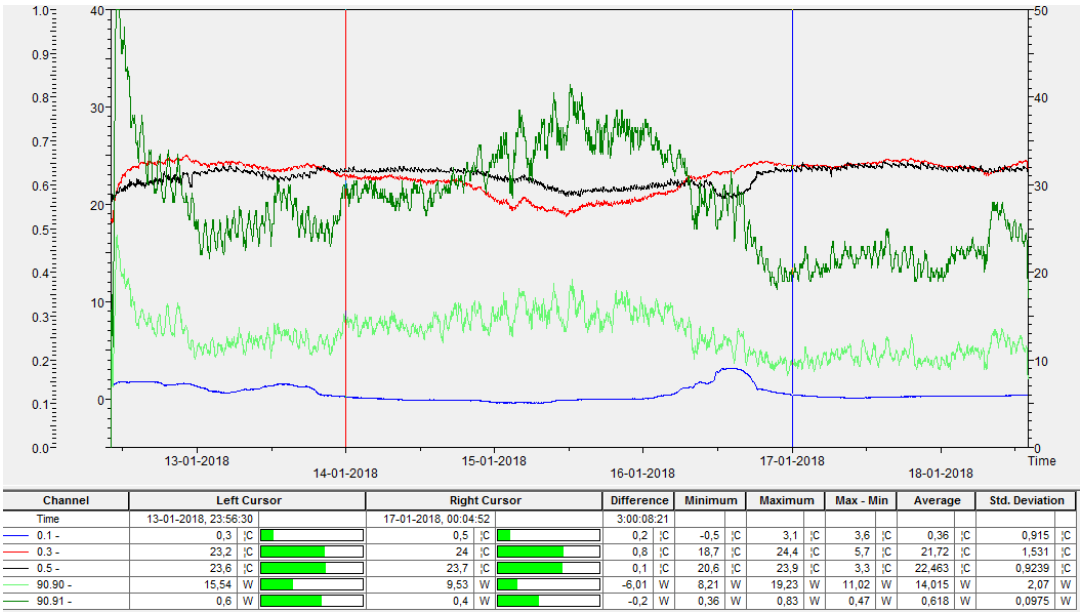
Fig 7 VA 13-01-2018 to 18-01-2018

comments:

The outdoor climate was fine with an almost constant outdoor temperature, the registration from the heat flow meter fluctuates around a middle value, presumably due to influences from the air circulation in the room (not considered to be significant).

Because of the placement close to an edge, a clear influence from the wind effect is seen as in some way (eg ventilation between the individual reeds / ventilation between outdoor air and cavities behind thatched layers) increase the U value. During the period there was strong wind see fig. below, and it is therefore chosen to divide the observations.





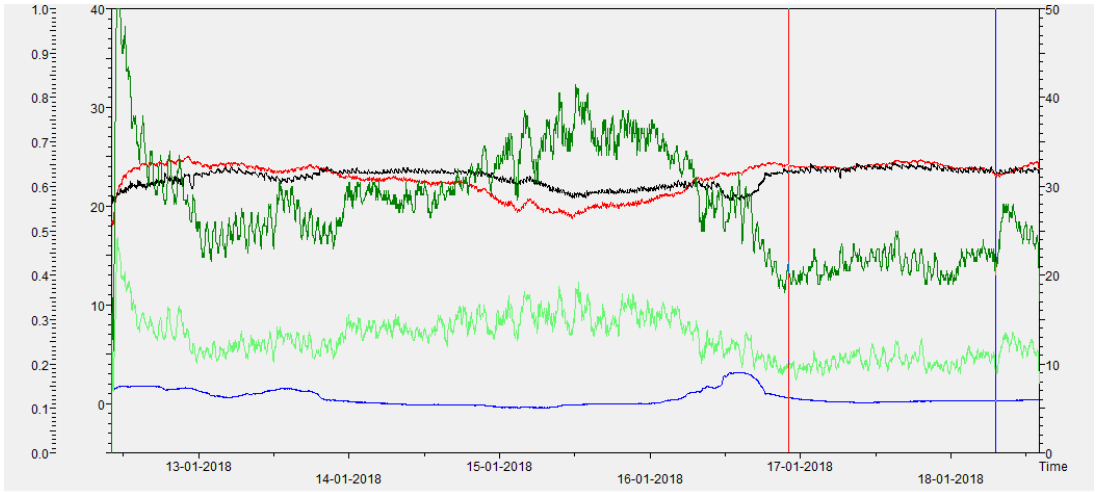
Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	13-01-2018, 23:56:30		17-01-2018, 00:04:52		3:00:08:21											
0.1 -	0,3	°C	0,5	°C	0,2	°C	-0,5	°C	3,1	°C	3,6	°C	0,36	°C	0,915	°C
0.3 -	23,2	°C	24	°C	0,8	°C	18,7	°C	24,4	°C	5,7	°C	21,72	°C	1,531	°C
0.5 -	23,6	°C	23,7	°C	0,1	°C	20,6	°C	23,9	°C	3,3	°C	22,463	°C	0,9239	°C
90.90 -	15,54	W	9,53	W	-6,01	W	8,21	W	19,23	W	11,02	W	14,015	W	2,07	W
90.91 -	0,6	W	0,4	W	-0,2	W	0,36	W	0,83	W	0,47	W	0,618	W	0,0975	W

Fig. 7a VA 14-01-2018 to 17-01-2018 (Edge - wind), measurement no. VA, a

Calculation of U-value: (orientation value for the period with strong wind)

U = 1 / [1 / (0.618) + 0.17] = 0.56 W / m2K (mean value in the period)

Calculation of lambda value for 32 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and subtracted): λ_{reed} = 0,32/ (1 / 0.56 -0.13-0.17) = 0,22 W / mK



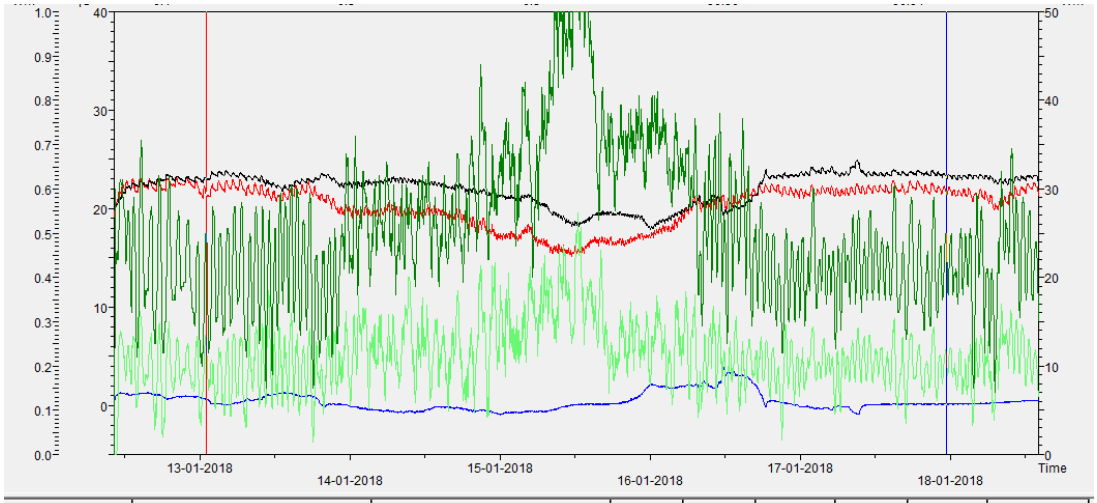
Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	16-01-2018, 22:07:10		18-01-2018, 07:08:20		1:09:01:09											
0.1 -	0,6	°C	0,3	°C	-0,3	°C	0,1	°C	0,6	°C	0,5	°C	0,26	°C	0,099	°C
0.3 -	24,2	°C	23,1	°C	-1,1	°C	23	°C	24,7	°C	1,7	°C	24,07	°C	0,276	°C
0.5 -	23,5	°C	23,5	°C	0	°C	22,8	°C	24,4	°C	1,6	°C	23,808	°C	0,2278	°C
90.90 -	10,37	W	9,15	W	-1,22	W	8,21	W	12,85	W	4,64	W	10,337	W	0,8152	W
90.91 -	0,42	W	0,41	W	-0,01	W	0,38	W	0,5	W	0,12	W	0,425	W	0,0255	W

Fig 7b VA 14-01-2018 to 17-01-2018 (Edge - no wind), measurement no. VA, b

Calculation of U-value: (normal period)

U = 1 / [1 / (0.425) + 0.17] = 0.40 W / m2K

Calculation of lambda value for 32 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and subtracted): λ_{reed} = 0,32 / (1 / 0.40 -0.13-0.17) = 0,15 W / mK



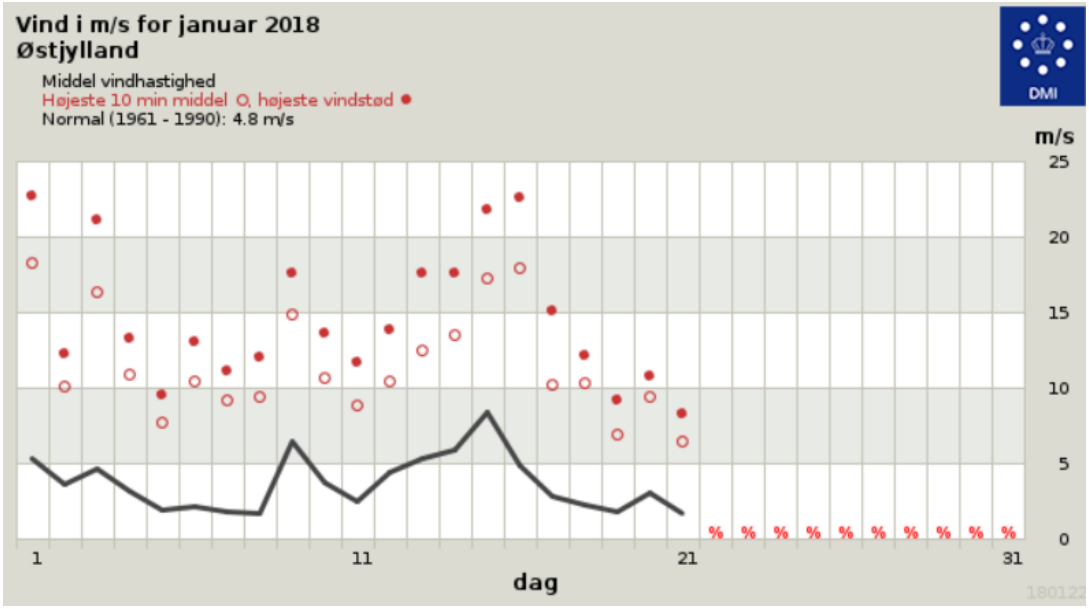
Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	13-01-2018, 01:02:47		17-01-2018, 23:18:15		4:22:15:28											
0.1 -	0,6	°C	0,2	°C	-0,4	°C	-1	°C	3,9	°C	4,9	°C	0,35	°C	0,984	°C
0.3 -	21,4	°C	21,8	°C	0,4	°C	15,1	°C	22,9	°C	7,8	°C	19,93	°C	2,102	°C
0.5 -	23,1	°C	23,2	°C	0,1	°C	17,9	°C	24,9	°C	7	°C	21,894	°C	1,7026	°C
90.90 -	11,82	W	11,44	W	-0,38	W	1,45	W	27,24	W	25,79	W	11,597	W	3,7756	W
90.91 -	0,5	W	0,5	W	0	W	0,15	W	1,19	W	1,04	W	0,538	W	0,1764	W

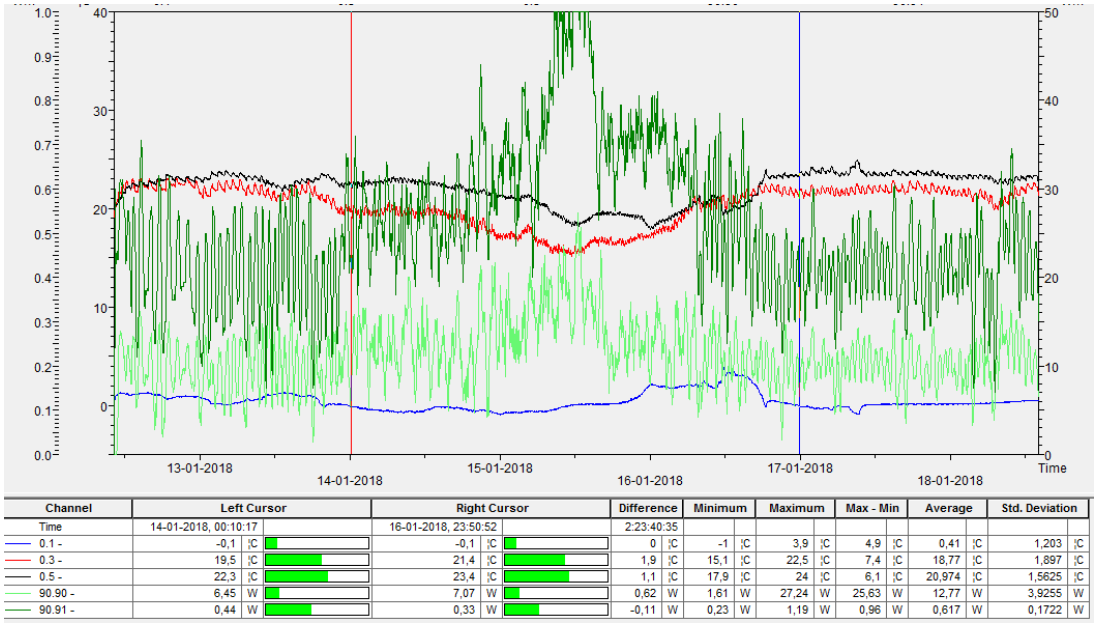
Fig 8 VB 13-01-2018 to 18-01-2018

comments:

The outdoor climate was fine with an almost constant outdoor temperature, the registration from the heat flow meter fluctuates around a middle value, presumably due to influences from the air circulation in the room (not considered to be significant).

Because of the placement close to an edge, a clear influence from the wind effect is seen as in some way (eg ventilation between the individual reeds / ventilation between outdoor air and cavities behind thatched layers) increase the U value. During the period there was strong wind see fig. below, and it is therefore chosen to divide the observations.





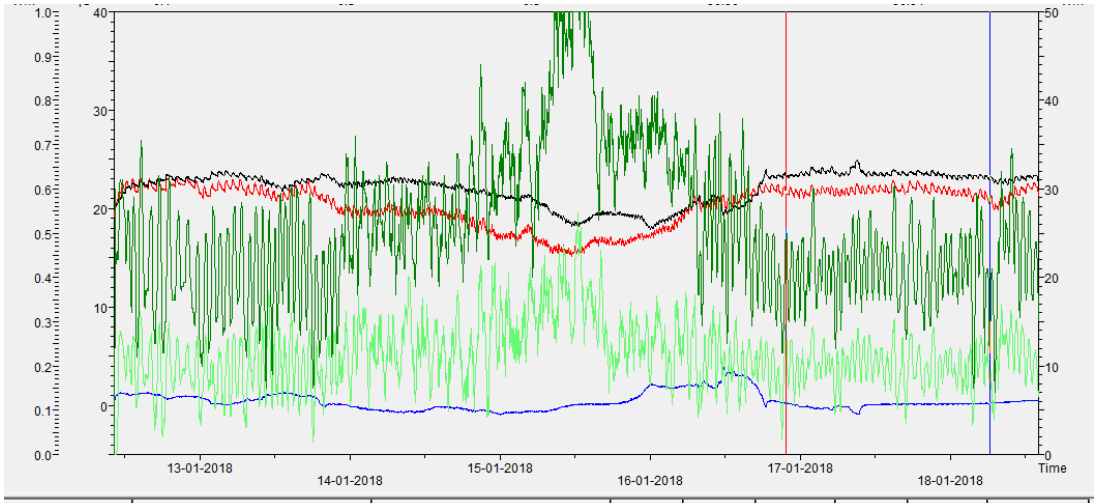
Channel	Left Cursor	Right Cursor	Difference	Minimum	Maximum	Max - Min	Average	Std. Deviation
Time	14-01-2018, 00:10:17	16-01-2018, 23:50:52	2:23:40:35					
0.1 -	-0,1 °C	-0,1 °C	0 °C	-1 °C	3,9 °C	4,9 °C	0,41 °C	1,203 °C
0.3 -	19,5 °C	21,4 °C	1,9 °C	15,1 °C	22,5 °C	7,4 °C	18,77 °C	1,897 °C
0.5 -	22,3 °C	23,4 °C	1,1 °C	17,9 °C	24 °C	6,1 °C	20,974 °C	1,5625 °C
90.90 -	6,45 W	7,07 W	0,62 W	1,61 W	27,24 W	25,63 W	12,77 W	3,9255 W
90.91 -	0,44 W	0,33 W	-0,11 W	0,23 W	1,19 W	0,96 W	0,617 W	0,1722 W

Fig. 8a VB 14-01-2018 to 17-01-2018 (Edge - wind), measurement no. VB, a

Calculation of U-value: (orientation value for the period with strong wind)

U = 1 / [1 / (0.617) + 0.17] = 0.56 W / m2K (mean value in the period)

Calculation of lambda value for 32 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and subtracted): λ_{reed} = 0,32 / (1 / 0.56 -0.13-0.17) = 0,22 W / mK



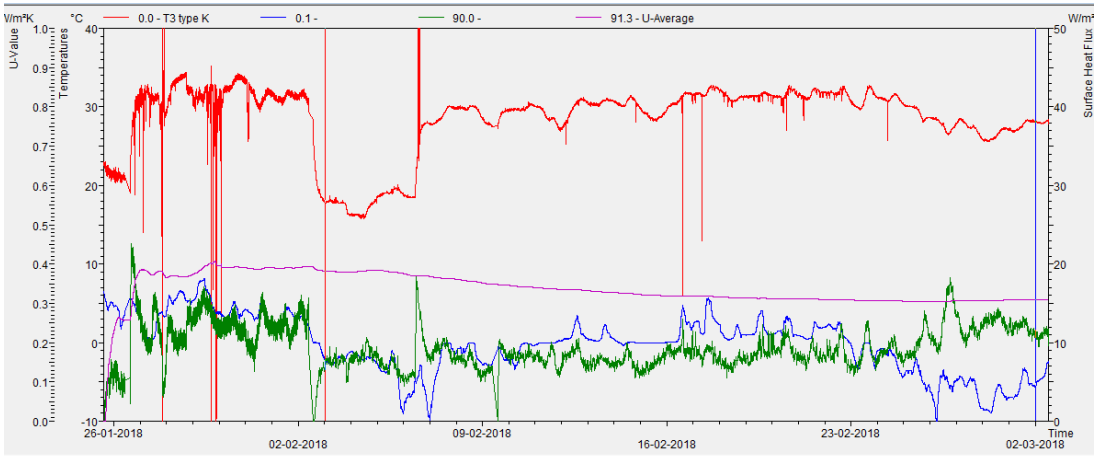
Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	16-01-2018, 21:41:45		18-01-2018, 06:18:22		1:08:36:36											
0.1 -	0,3	°C	0,2	°C	-0,1	°C	-0,9	°C	0,3	°C	1,2	°C	0,01	°C	0,26	°C
0.3 -	21,7	°C	21,2	°C	-0,5	°C	20,5	°C	22,8	°C	2,3	°C	21,82	°C	0,39	°C
0.5 -	23,4	°C	23,3	°C	-0,1	°C	22,9	°C	24,9	°C	2	°C	23,564	°C	0,3264	°C
90.90 -	14,19	W	8,25	W	-5,94	W	3,3	W	15,35	W	12,05	W	9,963	W	2,1271	W
90.91 -	0,49	W	0,23	W	-0,26	W	0,15	W	0,61	W	0,46	W	0,42	W	0,0773	W

Fig 8b VB 14-01-2018 to 17-01-2018 (Edge - no wind), measurement no. VB, b

Calculation of U-value: (normal period)

U = 1 / [1 / (0.42) + 0.17] = 0.40 W / m2K

Calculation of lambda value for 32 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and subtracted): λreed = 0,32 / (1 / 0.40 -0.13-0.17) = 0,15 W / mK



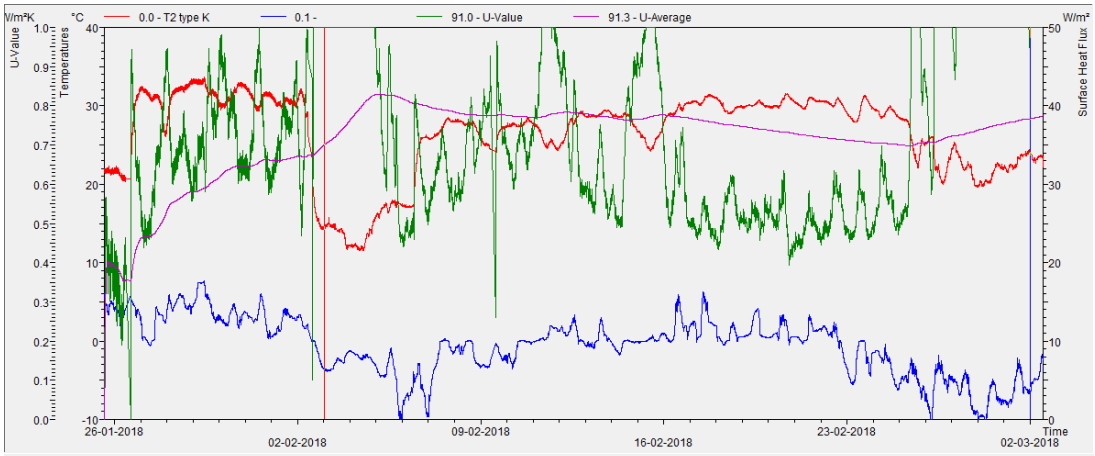
Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	03-02-2018, 00:24:06		01-03-2018, 23:59:04		26:23:34:58											
0.0 - T3 type K	18	°C	28,2	°C	10,2	°C	6	°C	123	°C	117	°C	28,27	°C	4,578	°C
0.1 -	-2,1	°C	-5,3	°C	-3,2	°C	-10,1	°C	5,7	°C	15,8	°C	-1,43	°C	3,056	°C
90.0 -	6,56		11,28		4,72		-4,68		18,44		23,12		8,902		2,1013	
91.3 - U-Average	0,382	W/m²K	0,31	W/m²K	-0,072	W/m²K	0,304	W/m²K	0,384	W/m²K	0,08	W/m²K	0,3301	W/m²K	0,02567	W/m²K

Fig 9 TA2 02-02-2018 to 02-03-2018 (Plate), measurement no. TA2, b

The measurement is from the whole of February. The curve with the dark green color is the U value and the purple is the middle value of the U value (see formula page 19). It is

seen that the U-value with good approximation approaches asymptotically to value U = 0.31 W / m2K (right cursor / vertical line)

Calculation of lambda value for 28 cm thatch (the plywood plate isolation is set to 0.13 m2K / W and subtracted): λ_{reed} = 0.28 / (1 / 0.31 -0.13-0.17) = 0.096 W / mK

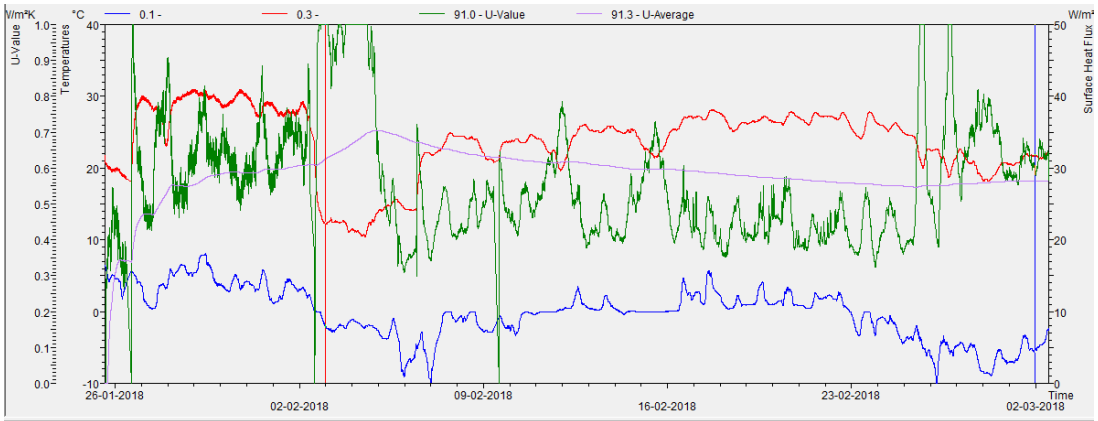


Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	03-02-2018, 00:25:37		01-03-2018, 23:57:35		26:23:31:57											
0.0 - T2 type K	14,4	°C	23,9	°C	9,5	°C	11,5	°C	31,6	°C	20,1	°C	25,76	°C	5,026	°C
0.1 -	-3,6	°C	-5,9	°C	-2,3	°C	-12	°C	6,3	°C	18,3	°C	-1,76	°C	3,246	°C
91.0 - U-Value	1,139	W/m²K	1,013	W/m²K	-0,126	W/m²K	0,26	W/m²K	1,749	W/m²K	1,489	W/m²K	0,7874	W/m²K	0,3252	W/m²K
91.3 - U-Average	0,7	W/m²K	0,767	W/m²K	0,067	W/m²K	0,699	W/m²K	0,83	W/m²K	0,131	W/m²K	0,7561	W/m²K	0,03329	W/m²K

Fig 10 TB2 02-02-2018 to 02-03-2018 (Sepatec), measurement TB2, b

The measurement is from the whole of February. The curve with the dark green color is the U value and the purple is the middle value of the U value (see formula page 19). It can be seen that the purple curve ends in the value U = 0.77 W / m2K (right cursor / vertical line), but the curve does not approach asymptotically to this value due to wind impact.

Calculation of estimate for lambda value for 28 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and deducted): λ_{reed} = 0,28 / (1 / 0.77 -0.13-0.17) = 0,28 W / mK.

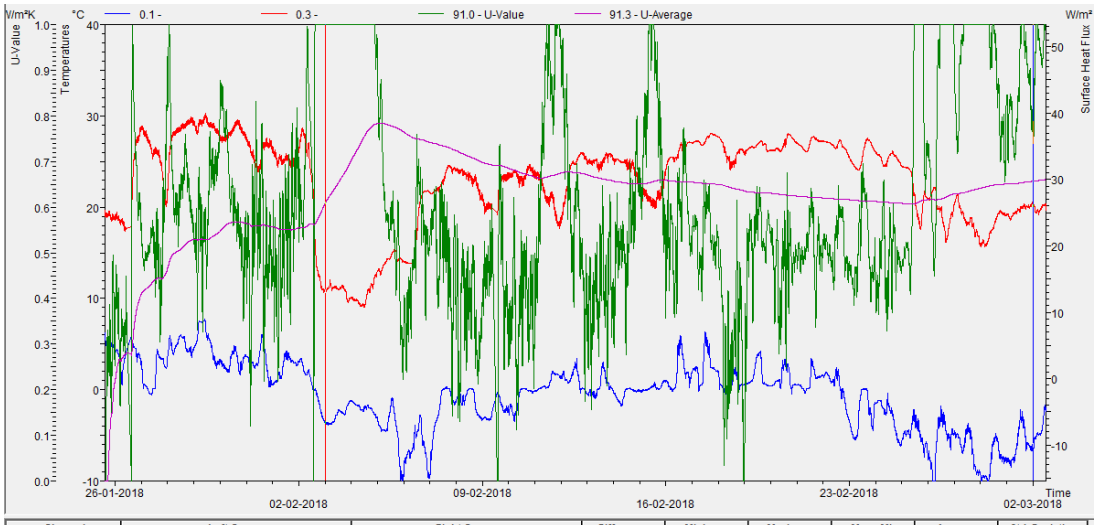


Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	02-02-2018, 23:28:05		01-03-2018, 23:29:39		27:00:01:34											
0.1 -	-1,8	°C	-5,5	°C	-3,7	°C	-10,1	°C	5,7	°C	15,8	°C	-1,43	°C	3,053	°C
0.3 -	12,3	°C	21,9	°C	9,6	°C	10,4	°C	28,1	°C	17,7	°C	22,73	°C	4,419	°C
91.0 - U-Value	1,075	W/m²K	0,585	W/m²K	-0,49	W/m²K	-0,189	W/m²K	1,265	W/m²K	1,454	W/m²K	0,5457	W/m²K	0,18601	W/m²K
91.3 - U-Average	0,625	W/m²K	0,564	W/m²K	-0,061	W/m²K	0,547	W/m²K	0,705	W/m²K	0,158	W/m²K	0,6003	W/m²K	0,04325	W/m²K

Fig 11 VA 02-02-2018 to 02-03-2018 (Edge), measurement no. VA, c

The measurement is from the whole of February. The curve with the dark green color is the U value and the purple is the middle value of the U value (see formula page 19). It can be seen that the purple curve ends in the value U = 0.56 W / m2K (right cursor), but the curve does not approach asymptotically to this value due to wind impact.

Calculation of estimate for lambda value for 32 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and deducted): λ_{reed} = 0,32 / (1 / 0.56 -0.13-0.17) = 0,22 W / mK



Channel	Left Cursor		Right Cursor		Difference		Minimum		Maximum		Max - Min		Average		Std. Deviation	
Time	03-02-2018, 00:23:05		02-03-2018, 00:10:25		26:23:47:19											
0.1 -	-3,6	°C	-6	°C	-2,4	°C	-12	°C	6,3	°C	18,3	°C	-1,76	°C	3,246	°C
0.3 -	10,7	°C	20,1	°C	9,4	°C	9	°C	28,1	°C	19,1	°C	22,09	°C	4,847	°C
91.0 - U-Value	1,527	W/m²K	0,757	W/m²K	-0,77	W/m²K	-0,271	W/m²K	1,848	W/m²K	2,119	W/m²K	0,6712	W/m²K	0,34447	W/m²K
91.3 - U-Average	0,609	W/m²K	0,657	W/m²K	0,048	W/m²K	0,607	W/m²K	0,784	W/m²K	0,177	W/m²K	0,6629	W/m²K	0,04567	W/m²K

Fig 12 VB 02-02-2018 to 02-03-2018 (Edge), measurement no. VB, c

The measurement is from the whole of February. The curve with the dark green color is the U value and the purple is the middle value of the U value (see formula page 19. It can

be seen that the purple curve ends in the value U = 0.66 W / m2K (right cursor), but the curve does not approach asymptotically to this value due to wind impact.

Calculation of estimate for lambda value for 28 cm thatch (the plywood plate's isolation is set to 0.13 m2K / W and deducted): λ_{reed} = 0,28 / (1 / 0.66 -0.13-0.17) = 0,26 W / mK..

PART 2: Laboratory measurements

Purpose and implementation of the test

The purpose of the test was to measure a lambda value for samples of thatch, taken from existing thatched roofs.

Dimensions of test pieces approx. 750mm x 750mm thickness.

The measuring equipment is constructed in accordance with EN 765 and is normally used for determination of the U value for windows. The heat meters used (1 piece on the cold side and 1 piece. on the hot side) measure 310 mm x 310 mm. On the hot side, a 10 mm glass fiber plate was used, on the cold side a 4 mm float glass.

Appendix 1 contains pictures of test equipment.

It should be noted that all test pieces are without fixing materials (metal wire creates a cold bridge, although the thread is very thin) and the test method itself causes the air between the straws to be stagnant, since there are airtight layers (glass, metal, foam foil) on both sides of the specimen.

Test results

The results of the tests are included on the following pages.

Test item nr. 1, description

Sample: Approx. 750 mm x 750 mm x 250 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked nr. 1 was submitted by the customer and received on

Danish Technological Institute 24-02-2017.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was completed 02-03-2017 to 03-03-2017.

The following information of the sample has been received:

"Thatched in 1985, located in the middle of Djursland, between Kolind and Rønde. Sewn withsteel wire, ie before the screwing method. Roof piece taken out on 22-03-2017 in connection with re-thatching, as the entire old roof of this building was taken down. The roof condition was extremely good, considering the age. Expected remaining life: Minimum 10 years. "

The raw material was separated from laths and metal wires (no volume change could be detected) and the thatch was kept in shape by tape, see pictures in Appendix 1. An average value of the thickness was determined in the middle of the sample.

Test item nr 1, measurement result

Measured U-value 0.274 W / m2 K, (Middle temperature 10.5 g C, delta T = 24.7 g C).

The weight of the specimen (including tape) was determined immediately before the test and again after storage in a heated dry cellar for 160 days, and from here the moisture content is estimated. It should have been at least about 18% by weight (most of the moisture has been in the outer cm, see picture page 1 in appendix1)

From the measured U-value, the lambda value of the 250 mm thick thatch is found thus:

(0.274) -1 = 0.17 ± 0.004 + 0.01 / 0.43 + 0.250 / $lambda_{reed}$

λ_{reed} = 0.072 W / mK

Test no. 2, description

Sample: Ca. 750 mm x 750 mm x 240 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked nr. 2 was submitted by the customer and received on

Danish Technological Institute 22-06-2017.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was carried out 22-06-2017 to 03-07-2017.

The following information of the sample has been received:

"Keld 1 from 1991"

The raw material was separated from laths and metal wires (no volume change could be detected) and the thatch was kept in shape by tape, see pictures in Appendix 1. An average value of the thickness was determined in the middle of the sample.

Test no. 2, measurement result

Measured U-value 0.240 W / m2 K, (Middle temperature 10.5 g C, delta T = 24.9 g C).

Sample item conditioned 1 week in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 240 mm thick thatch is found thus:

(0.240) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.240 / $lambda_{reed}$

λ_{reed} = 0.060 W / mK

Test no. 3, description

Sample: Ca. 750 mm x 750 mm x 230 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked nr. 3 was submitted by the customer and received on Danish Technological Institute 22-06-2017.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was carried out 22-06-2017 to 03-07-2017.

The following information of the sample has been received:

"Henrik 28 years south facing"

The raw material was separated from laths and metal wires (no volume change could be detected) and the thatch was kept in shape by tape, see pictures in Appendix 1. An average value of the thickness was determined in the middle of the sample.

Test no. 3, measurement result

Measured U-value 0.258 W / m2 K, (Middle temperature 10.56 gr C, delta T = 24.98 gr C).

Sample item conditioned 1 week in 23 g C and 50% RH before test.

From the measured U-value, the lambda value of the 230 mm thick thatch is found thus:

(0.258) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.230 / $\text{lambda}_{\text{reed}}$

λ_{reed} = 0.063 W / mK

Test no. 4, description

Sample: Ca. 750 mm x 750 mm x 220 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked nr. 4 was submitted by the customer and received at the Danish Technological Institute 22-06-2017.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was carried out 22-06-2017 to 03-07-2017.

The following description of the sample has been received:

"Cold 2 1991"

The raw material was separated from laths and metal wires (no volume change could be detected) and the thatch was kept in shape by tape, see pictures in Appendix 1. An average value of the thickness was determined in the middle of the sample.

Test no. 4, measurement result

Measured U-value 0.250 W / m2 K, (Middle temperature 10.51 g C, delta T = 24.95 g C).

Sample item conditioned 1 week in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 220 mm thick thatch is found thus:

(0.250) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.220 / $\text{lambda}_{\text{reed}}$

λ_{reed} = 0.058 W / mK

Test no. 5, description

Sample: Ca. 750 mm x 750 mm x 160 mm sample of thatch, made of Waterreed.

Withdrawal: The sample number 5 was submitted by the customer and received

at the Danish Technological Institute 22-06-2017.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was carried out 22-06-2017 to 03-07-2017.

The following information of the sample has been received:

"36 years"

The raw material was separated from laths and metal wires (no volume change could be detected) and the thatch was kept in shape by tape, see pictures in Appendix 1. An average value of the thickness was determined in the middle of the sample.

Test no. 5, measurement result

Measured U-value 0.307 W / m2 K, (Middle temperature 10.48 gr C, delta T = 24.81 gr C).

Sample item conditioned 1 week in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 160 mm thick thatch is found thus: (0.307) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.160 / lambda ray

λ_{reed} = 0.052 W / mK

Test no. 6, description

Sample: Ca. 750 mm x 750 mm x 180 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked No. 6 was submitted by the customer and received on

Danish Technological Institute 08-12-2017.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was conducted 12-12-2017 to 14-12-2017.

The following description of the sample has been received:

"Thatched 1976 from a hip-end facing southeast"

The raw material was separated from laths and metal wires (no volume change could be detected) and the thatch was kept in shape by tape, see pictures in Appendix 1. An average value of the thickness was determined in the middle of the sample.

Test no. 6, measurement result

Measured U-value 0.31 W / m2 K, (Middle temperature 10.69 gr C, delta T = 23.19 gr C).

Test specimen conditioned in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 180 mm thick thatch is found thus:
(0.31) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.180 / lambda ray

λ_{reed} = 0.059 W / mK

Test no. 7, description

Sample: Ca. 750 mm x 750 mm x 200 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked No. 7 was submitted by the customer and received on

Danish Technological Institute 15-01-2018.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was conducted 16-01-2018 to 17-01.2018.

The following information of the sampled sample has been received:

“The roof is from Slots Alleen 10 5631 Ebberup. The roof is facing west and is 39 Years old."

The raw material was separated from laths and metal wires (no volume change could be detected) and the thatch was kept in shape by tape, see pictures in Appendix 1. An average value of the thickness was determined in the middle of the sample.

Test no. 7, measurement result

Measured U-value 0.354 W / m2 K, (Mean temperature 10.71 gr C, delta T = 23.22 gr C).

The weight of the specimen (including tape) was determined immediately before the test and again after storage in a heated dry cellar for 160 days, and from here the moisture content is estimated. It should have been at least about 20% by weight (most of the moisture has been in the outer cm, see picture page 1 in appendix1)

From the measured U-value, the lambda value of the 200 mm thick thatch is found thus:

(0.354) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.200 / lambda $_{reed}$

λ_{reed} = 0.076 W / mK

Test no. 8, description

Sample: Ca. 750 mm x 750 mm x 225 mm sample of thatch, made of Waterreed.

Withdrawal: The test sample No. 8 was submitted by the customer and received on Danish Technological Institute 13-03-2018.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was completed 03-04-2018 to 05-04-2018.

The following information of the **test item** has been received:

"The sample is made of new Waterreed placed in a plywood box".

The raw material was separated from the box material and the thatch kept in shape using tape. An average thickness was determined in the middle of the sample.

Test item no. 8, measurement result

Measured U-value 0.235 W / m2 K, (Medium temperature 10.70 g C, delta T = 23.5 g C).

Test specimen conditioned in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 225 mm thick thatch is found thus:

(0.235) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.225 / $\text{lambda}_{\text{reed}}$

λ_{reed} = 0.055 W / mK

Test no. 9, description

Sample: Ca. 750 mm x 750 mm x 225 mm sample of thatch, made of Waterreed.

Withdrawal: The test mark marked No. 9 was submitted by the customer and received on Danish Technological Institute 13-03-2018.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was completed 05-04-2018 to 06-04-2018.

The following information of the **test item** has been received:

"The sample is made of new Waterreed placed in a plywood box".

The raw material was separated from the box material and the thatch kept in shape using tape. An average thickness was determined in the middle of the sample.

Test no. 9, measurement result

Measured U-value 0.235 W / m2 K, (Medium temperature 10.70 g C, delta T = 23.5 g C).

Test specimen conditioned in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 225 mm thick thatch is found thus:
(0.244) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.225 / $lambda_{reed}$

λ_{reed} = 0.058 W / mK.

Test no. 10, description

Sample: Ca. 750 mm x 750 mm x 180 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked nr. 10 was submitted by the customer and received at the Danish Technological Institute 19-03-2018.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was completed 09-04-2018 to 11-04-2018.

The following information of the sample has been received:

"The roof is 43 years old, it was turned south"

The raw material was separated from plywood and metal wires (no volume change could be detected) and the thatch kept in shape with tape. An average thickness was determined in the middle of the sample.

Test no. 10, measurement result

Measured U-value 0.36 W / m2 K, (Middle temperature 10.68 gr C, delta T = 23.15 gr C).

Test specimen conditioned in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 180 mm thick thatch is found thus:
(0.36) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.180 / $lambda_{reed}$

λ_{reed} = 0.070 W / mK

Test no. 11, description

Sample: Ca. 750 mm x 750 mm x 140 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked No. 11 was submitted by the customer and received at the Danish Technological Institute19-03- 2018.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was completed 11-04-2018 to 13-04-2018.

The following information of the sample has been received:

"The roof is 54 years old, it has turned south / southeast, the roof is fire-insulated with wood/concrete plates 50 mm below the laths "

The raw material was separated from plywood, laths and metal wires (no volume change could be detected), and the thatch kept in shape using tape. An average thickness was determined in the middle of the sample.

Test no. 11, measurement result

Measured U-value 0.361 W / m2 K, (Middle temperature 10.78 gr C, delta T = 23.15 gr C).

Test specimen conditioned in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 140 mm thick thatch is found thus:
(0.361) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.140 / $\text{lambda}_{\text{reed}}$

λ_{reed} = 0.054 W / mK

Test no. 12, description

Sample: Ca. 750 mm x 750 mm x 180 mm sample of thatch, made of Waterreed.

Withdrawal: The test piece marked nr. 12 was submitted by the customer and received at the Danish Technological Institute 10-04-2018.

Method: The specimen is tested using heat flow meters (EN 675 method).

Period: The test was completed 16-04-2018 to 18-04-2018.

The following information of the sample has been received:

"The roof is 50 years old, it was turned south"

The raw material was separated from plywood, laths and metal wires (no volume change could be detected), and the thatch kept in shape using tape. An average thickness was determined in the middle of the sample.

Test no. 12, measurement result

Measured U-value 0.281 W / m2 K, (Mean temperature 10.73 g C, delta T = 23.26 g C).

Test specimen conditioned in 23 g C and 50% RH before test.

From the measured U value, the lambda value of the 180 mm thick thatch is found thus:
(0.281) -1 = 0.17 + 0.004 + 0.01 / 0.43 + 0.180 / lambda$_{reed}$

λ_{reed} = 0.054 W / mK.

Assessment of test results

In situ measurements

Summary of measurement results:

Measurement TA1:	λ_{reed}= 0.10 W / mK	solid underlayment	no wind
Measurement TA2, a:	λ_{reed} = 0.08 W / mK	solid underlayment	wind
Measurement TA2, b:	λ_{reed} = 0.10 W / mK	solid underlayment	wind
Measurement TB1:	λ_{reed} = 0,12 W / mK	Sepatec	no wind
Measurement TB2, a:	λ_{reed} = 0,30 W / mK	Sepatec	wind
Measurement TB2, b:	λ_{reed} = 0,13 W / mK	Sepatec	no wind
Measurement TB2, c:	λ_{reed} = 0,28 W / mK	Sepatec	wind

Measurement VA, a:	λ_{reed} = 0,22 W / mK	solid underlayment, edge wind
Measurement VA, b:	λ_{reed} = 0,15 W / mK	solid underlayment, edge no wind
Measurement VA, c:	λ_{reed} = 0,22 W / mK	solid underlayment, edge wind

Measurement VB, a:	λ_{reed} = 0,22 W / mK	solid underlayment, edge wind
Measurement VB, b:	λ_{reed} = 0,25 W / mK	solid underlayment, edge no wind
Measurement VB, c: λ	λ_{reed} = 0,26 W / mK	solid underlayment, edge wind

For thatch on solid underlayment, no significant sensitivity was observed to wind influences - λ_{reed} = 0.08-0.10 W / mK.

for thatch on Sepatec on laths, and for thatch on solid underlayment close to edges (on the wall, the insulation is reduced. Strong wind - λ_{reed} = 0,12 -0,30 W / mK

laboratory measurements

The tested samples taken from old roofs varied in age, thickness, thickness of individual reeds, degree of degradation in 2-3 cm surface layer, moisture content and more. It has shown that the measured heat insulation performance of the laboratory test on all 10 old samples, did not vary a lot from the newly thatched reference items

All items are tested without fixing materials.

Overview:

Lab measurement 1 λ_{reed} = 0.072 W / mK (roof, 1985, not moisture-conditioned)

Lab measurement 2: λ_{reed} = 0.060 W / mK (roof, 1991, moisture-conditioned)

Lab measurement 3: λ_{reed} = 0.063 W / mK (roof, 1990, moisture-conditioned)

Lab measurement 4: λ_{reed} = 0.058 W / mK (roof, 1991, moisture-conditioned)

Lab measurement 5: λ_{reed} = 0.052 W / mK (roof, 1982, moisture-conditioned)

Lab measurement 6: λ_{reed} = 0.059 W / mK (roof, 1976, moisture-conditioned)

Lab measurement 7: λ_{reed} = 0.076 W / mK (roof, 1979, not moisture-conditioned)

Lab measurement 8: λ_{reed} = 0.055 W / mK (new, 2018, moisture-conditioned)

Lab measurement 9: λ_{reed} = 0.058 W / mK (new, 2018, moisture-conditioned)

Lab measurement 10: λ_{reed} = 0.040 W / mK (roof, 1975, moisture-conditioned)

Lab measurement 11: λ_{reed} = 0.054 W / mK (roof, 1964, moisture-conditioned)

Lab measurement 12: λ_{reed} = 0.054 W / mK (roof, 1977, moisture-conditioned)

New topics:

Number of samples: 2

Middle value λ_{reed} = (0.055 W / mK + 0.058 W / mK)

= 0.056 W / mK (s = 0.002 W / mK)

27-54 year old specimens measured in dry condition:

Number of samples: 8

Middle value λ_{reed} = (0.060 W / mK + 0.063 W / mK + 0.058 W / mK + 0.052 W / mK

+ 0.059 W / mK +0.070 W / mK + 0.054 W / mK + 0.054 W / K)

= 0.059 W / mK (s = 0.006 W / mK)

32-39 year old specimens measured with moisture content:

Number of samples: 2

Middle value λ_{reed} = (0.072 W / mK + 0.076 W / mK)

= 0.074 W / mK (s = 0.003 W / mK)

Overall assessment

In Germany, very large research projects have been carried out regarding thatch, but not regarding the thermal insulation capacity. It is not allowed to include the roof covering when calculating the total isolation (insulating capacity) of the climate screen.

The Netherlands have a great deal of experience with thatching and it is allowed for thatch on closed construction to include a computational isolation, calculated from λD_{reed} = 0.20 W / mK.

In practice this means that 30 cm of thatch is considered to heat insulate corresponding to about 5 cm mineral wool, with $\lambda_{minwool}$ = 0.037 W / mK. (The isolation of the layers is 0.3 / 0.2 = 1.5 m2K / W)

In Denmark, it has not been allowed to include thatch when calculating the overall insulation of the climate screen.

Our measurements show that the thermal conductivity of the thatch under normal conditions in Denmark can be considered to be well below λ_{reed}= 0.20 W / mK,

Only with the Sepatec solution (and in a smaller edge zone when thatching on solid underlayment), and strong wind can the thermal conductivity increase above this value.

As a middle value in the heating season, it is therefore proposed to use a value

$\lambda D,_{reed}$ = 0.15 - **0.175** - 0.20 W / mK for thatch on Sepatec fire protection, with mineral wool clogs along field boundaries ("unventilated constructions"). For thatch on closed constructions, the insulation capacity is considerably better and as a middle value during the heating season, it is proposed to use $\lambda D,_{reed}$ = 0.10 - **0.125** - 0.15 W / mK.

For 30 cm of thatch, the proposed values correspond to about 7.5 - **6.5** - 5.5 cm and approx. 11.0 - **9.0** - 5.5 cms mineral wool with $\lambda_{minwool}$ = 0.037 W / mK.

For roofs and facades with retained ventilation by air gap under the battens ("Ventilated constructions") according to DS 418 can only be counted with one isolation increase of 0.09 m2K / W.

Photo 1. Subject no.1, which was submitted

Photo 2. Test item # 1, straw alone

3. Test item no. 1, placed in measuring box

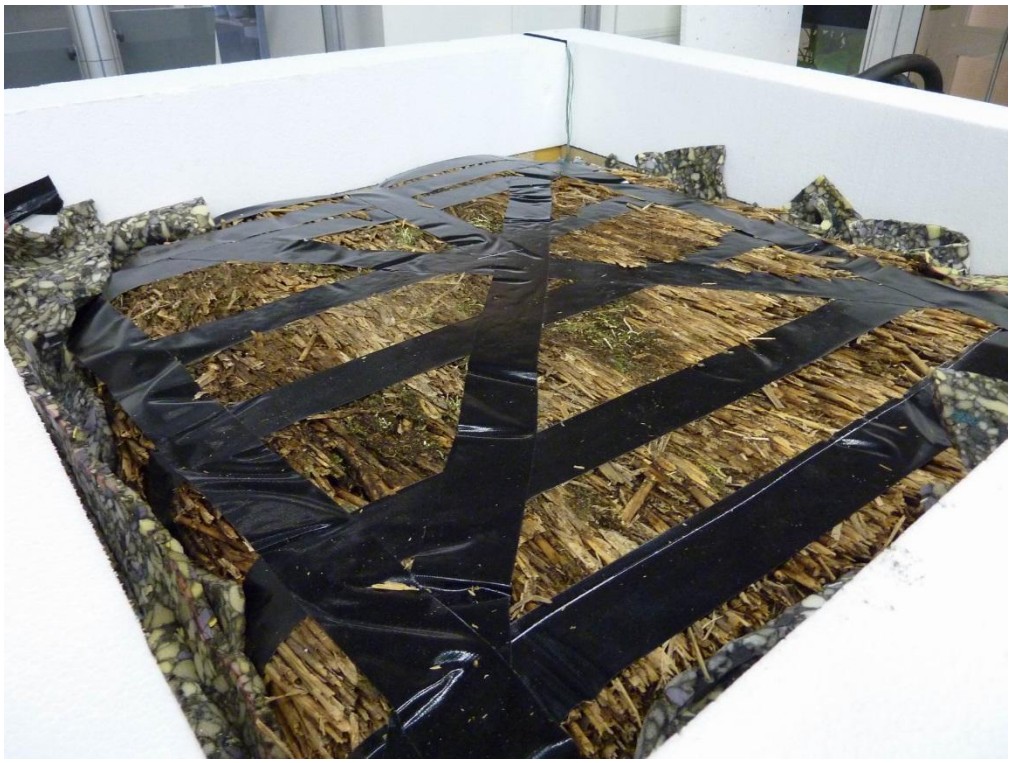


Photo 4. Test item no. 1, placed in measuring box

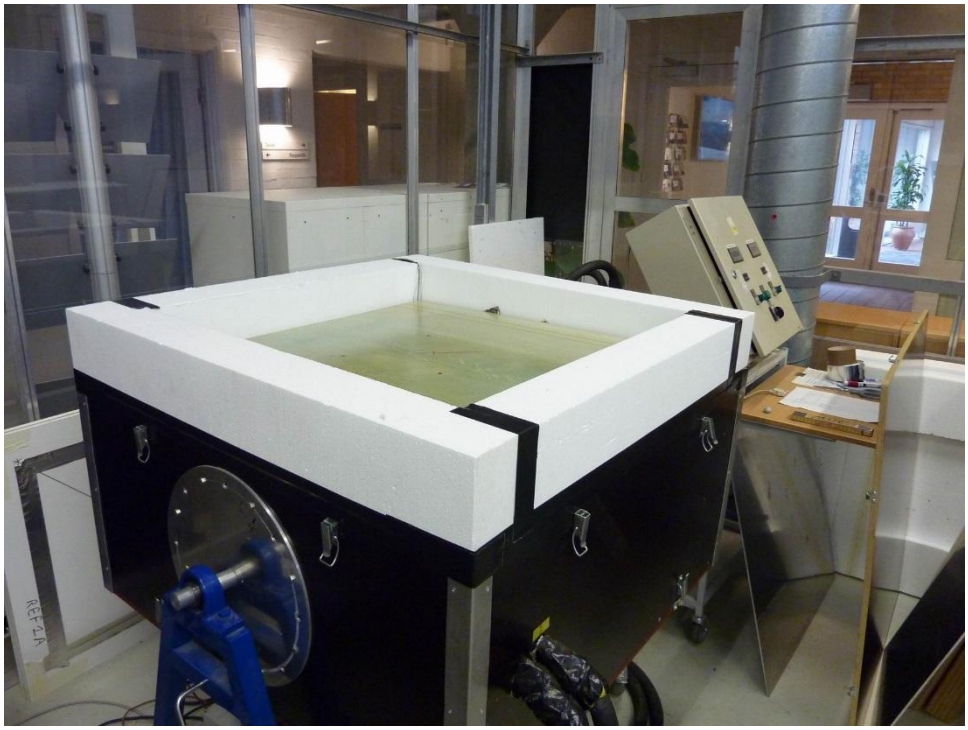


Photo 5. Test item no. 1 in measuring case (glass fiber plate to finish)

Photo 6. Test item no. 1 in measuring case, ready for measurement

APPENDIX 4: **Note - study trip to Lûbeck 3/11 - 2016.**

The importance of global climate change on thatch in northern Germany has been studied in a larger scale project in the period 2009 - 2014. Faghøjskolen in Lübeck by prof. Georg Conradi and diplomed engineer Steffen Slama worked on the sub-project "Klimawandel auf norddeutchen Dächern", which aimed to determine how a thatched roof must be built to be climate-adapted.

On 3/11, Jørgen Kaarup and Bent Lund Nielsen had a meeting with Steffen Slama, who showed them test houses (see pictures below) that have been used in the project and who told about the project's results.

Steffen Slama said that they had not focused on the roof's insulation ability, but that there had been performed a laboratory test of the U-value for a sample consisting of 35 cm dry thatch, 20 mm wood fiber board, 25 cm solid wood, and both with and without a plastic foil on the outside of the straw layer.

The thatched roof with plastic film measured a value U = 0.15 W / m2K, and 0.19 W / m2K without plastic film.

According to Steffen Slama has the applied solid wood an lambda value of 0.079 W / mK. Thus can be calculated a lambda value of 0.12 W / mK for the thatch with plastic film, and 0.24 W / mK for the straw layer without plastic film.

(There was no information about density, air velocities on cold and hot sides, etc., but the test results at least indicate that the insulation capacity is reduced if there are air currents in the straw layer.)

Steffen Slama's immediate thought was, that it would be difficult to set a standard value for the insulation ability of a thatched roof. He offered the use of the green test house, if usefull, in connection with our project.

In one of the project reports we found the following text:

Innovative wood construction technology

The test house of the FH Lübeck as well as the DLRG home in Scharbeutz has a shell construction of a solid wood construction and is thatched with domestic Waterreed, directly on a 210 mm. thick solid wooden plate. In between, there is only a soft wood fiberboard as wind seal. An additional heat insulation can be omitted, since the combination of 210 mm. massive wood and about 350 mm. thatch protects sufficiently against cold (and heat). The measured and calculated U-value is 0.17 - 0.19 W / m2K, depending on the wind force.

The walls also work without extra heat insulation - they consist of 230 mm.thick strong wood elements and have together with the 22 mm. Wood softboard an U-value of 0.21 W / m2K.

If the stated values are converted (in the same way as the referenced laboratory test) is found

the lambda value for the thatch alone to be 0.13 - 0.18 W / mK depending on the wind speed.

Conclusion / assessment

The project in northern Germany has only dealt peripherally with the measurement of the insulation capacity of thatched roofs.

The results from the project indicate that the lambda value for the thatch alone is 0.13 - 0.19 W / mK, but that it should be noted that the insulation capacity is dependent on the moisture content of the straws and on the actual wind speed.

APPENDIX 5: Note - Hotbox measurements at TI –Aarhus. (Project under the Danish Environmental Protection Agency)

Two Hotbox measurements have been carried out at TI-Aarhus (see page 5 for Hotbox) of 1.8m x 1.8m large test items with thatched roof. (TI report no. 0308/2004289). In the picture below, the 2 test topics arriving at the Technological Institute.

Arrival test items for Hotbox trials

Details on edges of test items

Test item 1

Test topic seen from the warm side

Test topic seen from the cold side

This test item was made with about 30 cm thatch of Waterreed directly on a plywood back plate.

If we convert the measured U value to a lambda value for the thatch, we get:

λ_{reed} = 0.2 W / mK (the values of the plywood have been deducted).

Test item 2

Test topic seen from the warm side

Test topic seen from the cold side

This test item was made with about 30 cm thatch of Waterreed on a Sepatec fireprotection base on the battens per 0.3 m.

Between the battens and the plywood back plate were mounted 30mm x 30mm spacer strips, so an air gap was creeted.

If we convert the measured U value to a lambda value for the thatch, we get:

λ_{reed} = 0.4 W / mK ((the values of the plywood sheets, Sepatec, air layers and battens have been deducted).

Discussion of measurement results

The measurements performed, show that the thatch in the test items has an insulation capacity which increases, the less air flow ther is, at edges and through the straw layer itself. The measured lambda values are evaluated to be relatively high, probably because there has been the possibility of unwanted airflow along the edges of the transition between thatch and plywood and possibly the thatch has been executed rather "loose". (note from the thatcher!).

For comparison, a measurement on a sample from about 30 years old thatched roof, which was made with airtight plastic films inside and outside in a "lambda box" showed that Lambda (reed) = 0.07 W / mK. Thus, there is much to be fetched if air flow can be limited. Additional experiments could therefore be interesting to seeing the importance of careful airtightening of the edges of the specimens (eg with foam, which then must be deducted in the results!), partly the significance of airtight plastic film mounted ex.

In the original Note this Appendix ends with a brochure containing general information on Hot Boxes, in danish. This brochure is not available in English. It is therefore not included.