Hygrothermal Analysis (WUFI) Report

CONTENT

PURPOSE OF THE DOCUMENT

This document presents hygrothermal simulations (WUFI calculations) for EcoCocon wall assemblies across several climate regions. Its purpose is to confirm that the proposed wall build-ups are moisture-safe and perform as expected under real climate conditions.

WHO IS THIS DOCUMENT FOR

The reports are intended for architects, engineers, and building designers who are specifying or working with EcoCocon Straw Wall System and need to verify the hygrothermal performance of a wall assembly for a specific region and build-up.

WHAT IF MY REGION OR A BUILD-UP IS NOT LISTED?

If your specific wall build-up or climate region is not covered in these reports, we recommend commissioning a hygrothermal analysis for your location. Please contact the EcoCocon technical team for guidance.

Report

Denmark
Hygrothermal Analysis (WUFI)

Version 1.0 - Updated 23.03.2023

eco cocon

Hygrothermal analysis of *EcoCocon* straw panels in the *JDH* wall systems in the Danish climate

(as of 23rd March 2023)

Passivhusbyrån Ingo Theoboldt

Tel: +46 (0) 762-874-024

Address: Vasared 301, 523 94 Tvärred

E-mail: info@passivhusbyran.se

Content

Background and mission

Passivhusbyrån has been commissioned to produce a hygrothermal analysis of *EcoCocon's* straw panel in combination with JDH built walls of six different designs in the Danish climate. The location chosen is Aarslev, as it is in the middle of Denmark. The climatic conditions and the different types of walls are described below (input data). The aim of the analysis is to obtain results, based on the input below, and to examine the performance and moisture resistance in the long term.

Reservations

The calculations and simulations for this project are based on data received between 29th November 2022 and 11th February 2023. The climate data needed for the simulations were produced with the Meteonorm-8 program. For additional stress testing, a 1 % fraction of the rainfall load was included as seeping into the structure, namely into the straw panel directly behind the weather resistive barrier, in accordance with ANSI/ASHRAE Standard 160-2021. In addition, an intentionally high relative humidity of 80 % was assumed for all components at the time of installation and a very low air turnover in the facade ventilation gap.

Hygrothermal analysis

The simulation was done with *WUFI 6.5 Pro*, which allows hourly dynamic simulation for an unlimited number of years. During the process, the following parameters are considered, among others:

Material properties - these quantities describe the hygrothermal behaviour of the materials to be examined: bulk density [kg/m³], porosity [m³/m³], specific heat capacity [J/(kg·K)], dry thermal conductivity [W/(m·K)], dry water vapour diffusion resistance, moisture storage function [kg/m³], and liquid transport coefficient of suction and redistribution [m²/s]. If applicable, moisture-dependent thermal conductivity [W/(m·K)] and water vapour diffusion resistance number are also included. The weatherproofing membrane supplied by EcoCocon with its panels and used in the model has an sd-value of 0.05 m and the vapour retarder 6.45 m.

Climatic data - these quantities describe the boundary conditions acting on the internal and external surface of the building component: rainfall load on the surface [l/(m²·h)], depending on the slope and orientation of the component, shortwave radiant flux density (solar) [W/m²], depending on the slope and orientation of the component, outdoor air temperature [°C], outdoor air relative humidity [0...100 %], indoor air temperature [°C], indoor air relative humidity [0...100 %] and average air pressure [hPa] during the calculation period.

Input data

Construction wall type M (with weather protection membrane and vapour retarder):

Materials:

- Scandinavian spruce transverse direction	0.025 m
- Air Layer	0.052 m
- Weatherboard 365	0.01 m
- OSB	0.012 m
- Weather resistive barrier (sd=0,05m)	0.001 m
- EcoCocon straw panel	0.4 m
- Vapour retarder	0.001 m
- Wood fibre board	0.045 m
- OSB	0.012 m
- Plaster board	0.013 m

Construction wall type N (like wall type M, but without vapour retarder):

Materials:

- Scandinavian spruce transverse direction	0,025 m
- Air Layer	0,052 m
- Weatherboard 365	0,01 m
- OSB	0,012 m
- Weather resistive barrier (sd=0,05m)	0,001 m
- EcoCocon straw panel	0,4 m
- Wood fibre board	0,045 m
- OSB	0,012 m
- Plaster board	0,013 m

Construction wall type O (like wall type M, but without weather resistive barrier):

Materials:

- Scandinavian spruce transverse direction	0.025 m
- Air Layer	0.052 m
- Weatherboard 365	0.01 m
- OSB	0.012 m
- EcoCocon straw panel	0.4 m
- Vapour retarder	0.001 m
- Wood fibre board	0.045 m
- OSB	0.012 m
- Plaster board	0.013 m

Construction wall type P (like wall type N, but with FERMACELL instead of Weatherboard and OSB on the outside):

Materials:

- Scandinavian spruce transverse direction	0,025 m
- Air Layer	0,052 m
- FERMACELL Gypsum-Fibreboard	0,012 m
- weather resistive barrier (sd=0,05m)	0,001 m
- EcoCocon straw panel	0,4 m
- Wood fibre board	0,045 m
- OSB	0,012 m
- Plaster board	0,013 m

Construction wall type Q (like wall type P, but without the wood fibre layer):

Materials:

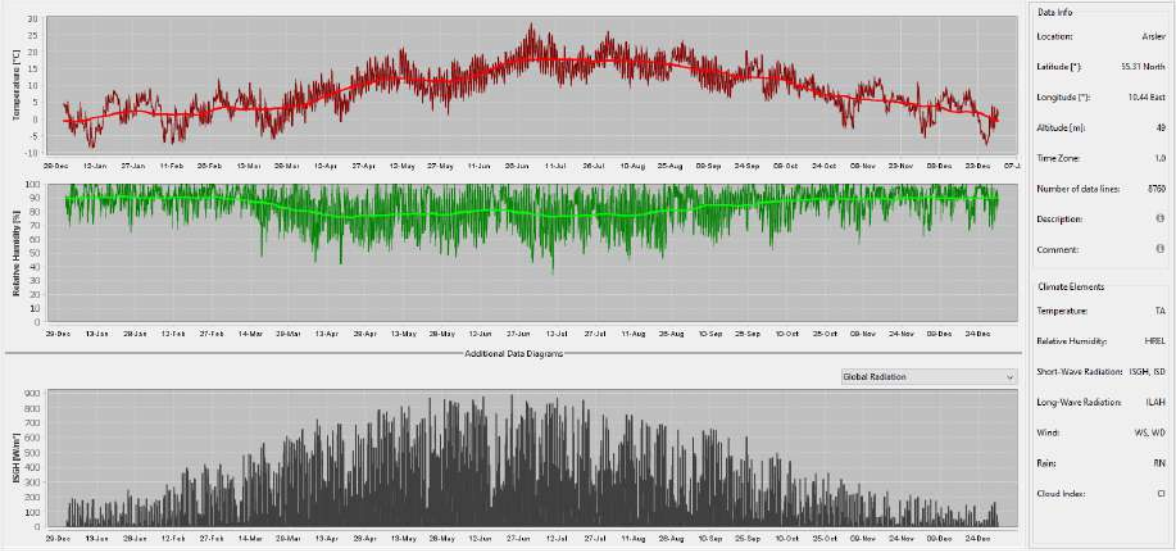
- Scandinavian spruce transverse direction	0,025 m
- Air Layer	0,052 m
- FERMACELL Gypsum-Fibreboard	0,012 m
- weather resistive barrier (sd=0,05m)	0,001 m
- EcoCocon straw panel	0,4 m
- OSB	0,012 m
- Plaster board	0,013 m

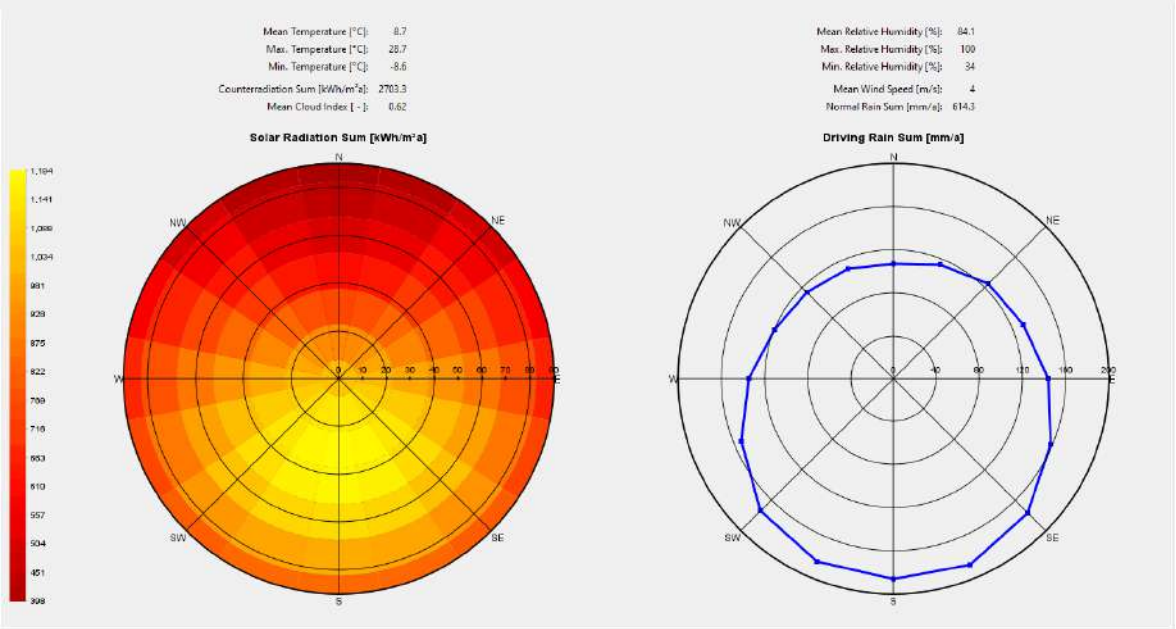
Construction wall type R (like wall type Q, but with interior clay plaster instead of OSB and plasterboard):

Materials:

- Scandinavian spruce transverse direction	0,025 m
- Air Layer	0,052 m
- FERMACELL Gypsum-Fibreboard	0,012 m
- weather resistive barrier (sd=0,05m)	0,001 m
- EcoCocon straw panel	0,4 m
- Clay Plaster	0,025 m

Outdoor climate Aarslev (Denmark)





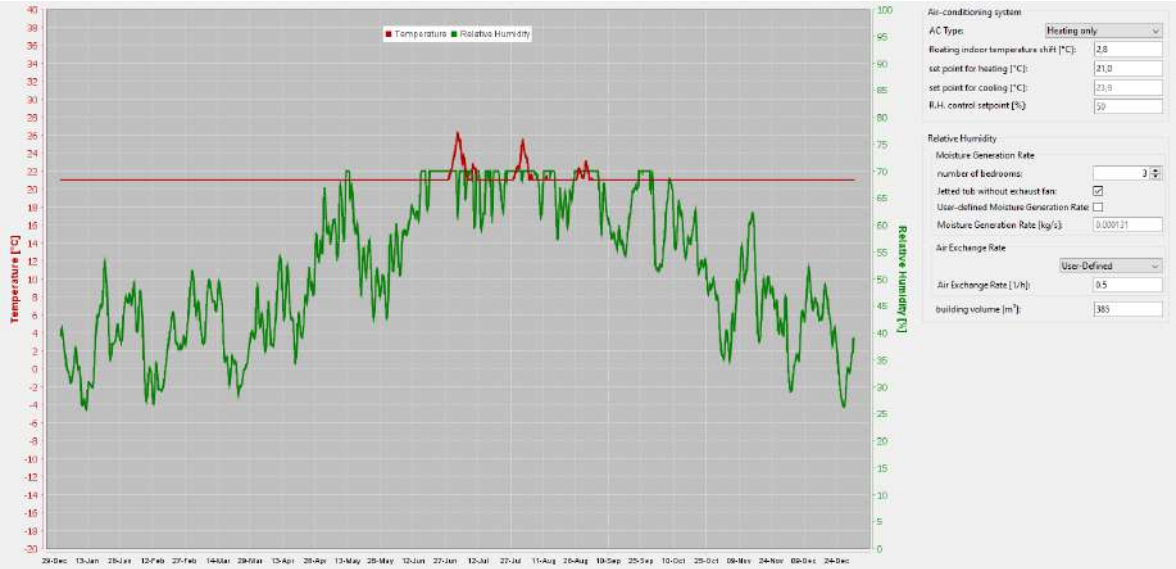
The direction with the most driving rain is straight south. There is also the strongest solar radiation, with high drying capacity. However, for the investigation on ventilated facades, straight north is always the decisive orientation.

Indoor climate Aarslev

The same model building was used for all simulations: a three-bedroom villa with 385 m³ of indoor volume. A whirlpool bathtub without a separate exhaust fan was included for possible additional internal moisture production – for extra stress-testing. An MVHR-unit delivers 0.5 air changes per hour.

Air conditioning is available as heating only, no active cooling. The heating set point is 21 °C (typical value for a single-family house).

The indoor climate model was based on the ASHRAE 160-2021 standard, as it provided the means to represent the above conditions:

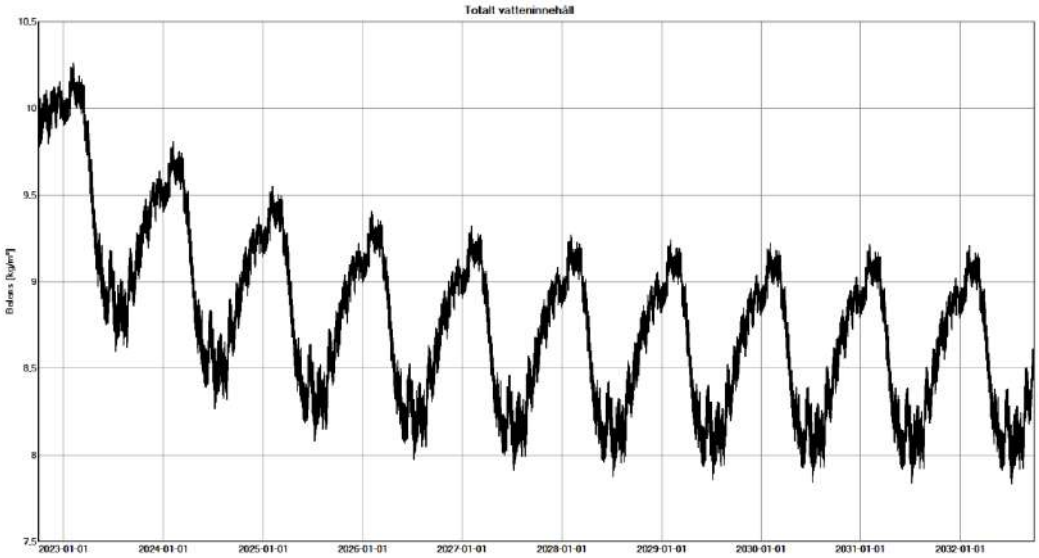


Results

The following diagram shows the water content of the individual layers over 10 years.

Wall type M

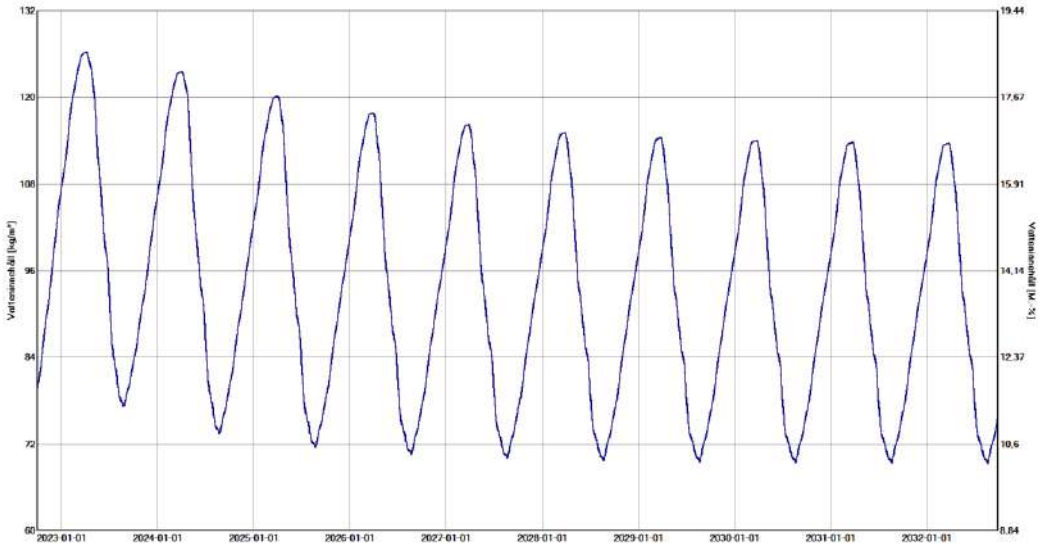
<u>The whole wall</u>



The simulation over 10 years shows that there is no accumulation of moisture over the long term, but it takes a few seasons to release the assumed high level of built-in moisture. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

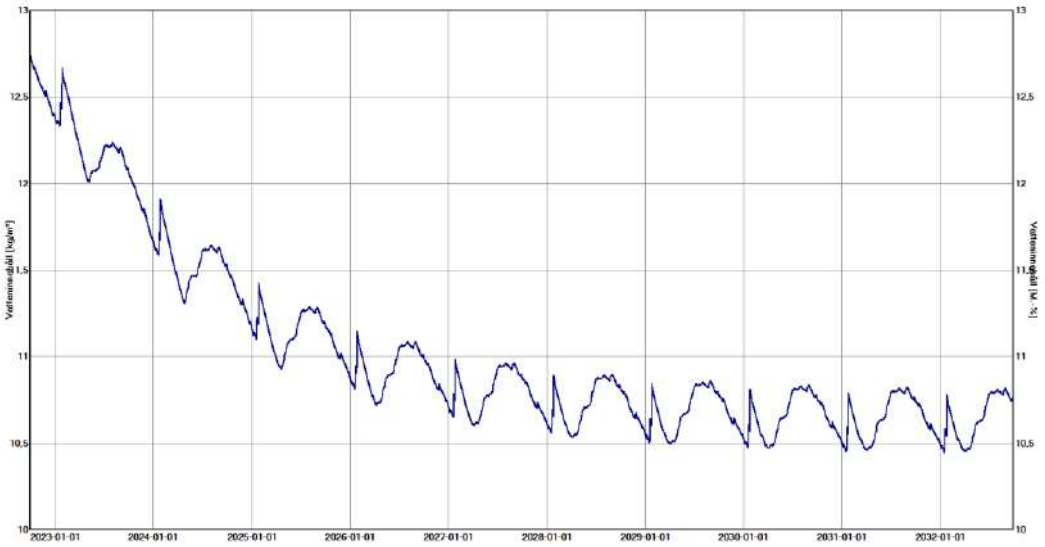
Individual layers

The OSB board towards the outside:



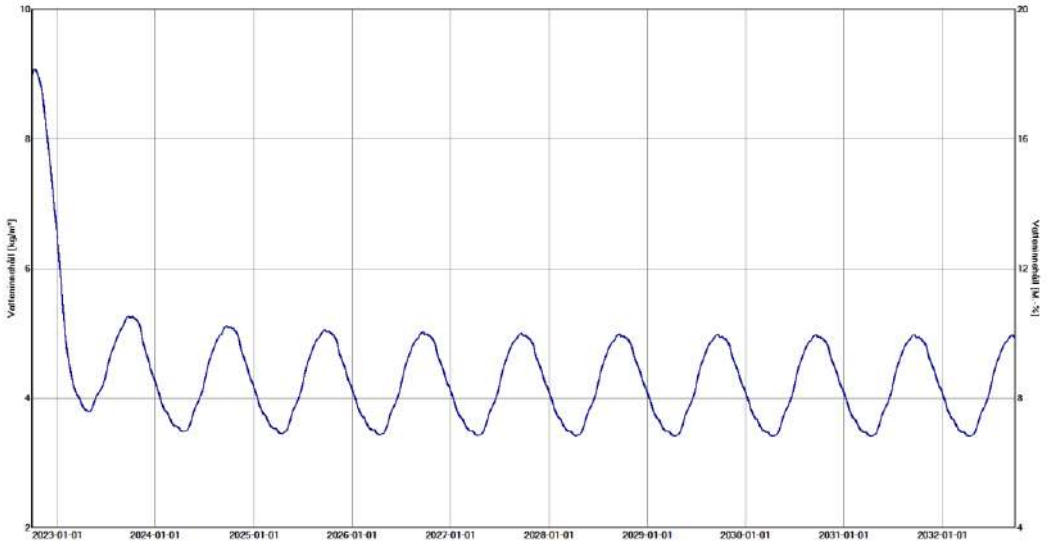
After a few seasons of stagnation, the water content is permanently below 17 M.-%. The use of dry materials at the time of construction will also eliminate the higher moisture content shown at the beginning of the simulation.

EcoCocon panel (straw):



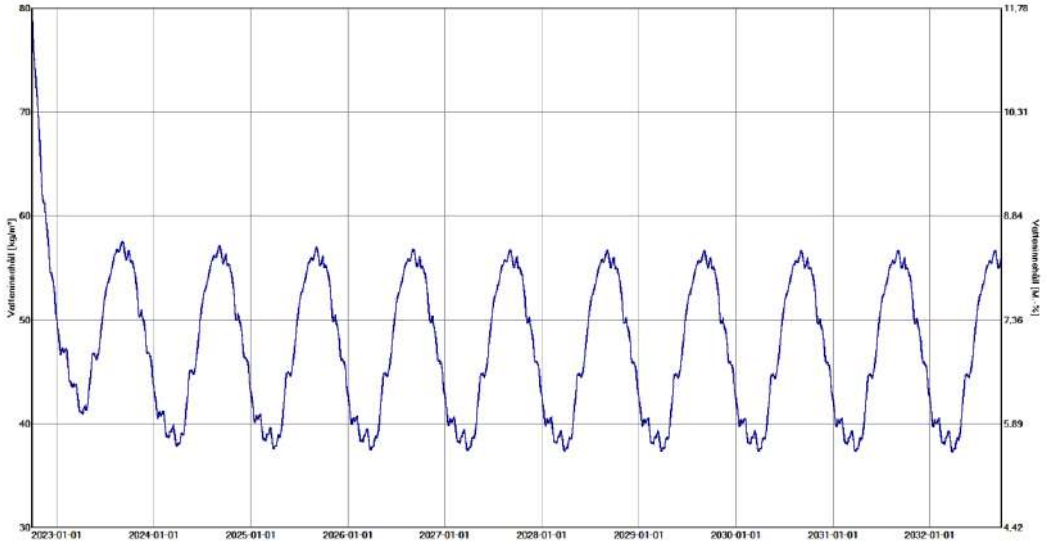
Again, it takes several seasons to stay at a low level, but even after the intentionally high value at the beginning, the water content drops over time and is below 11 M.-% all the time.

The fibreboard:



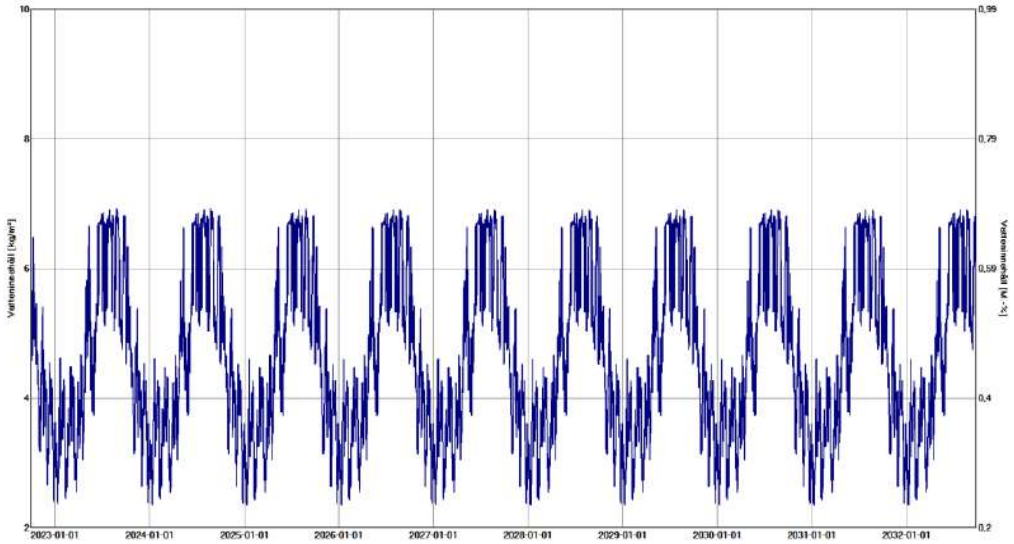
A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 12 M.-%.

The OSB panel towards the inside:



A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 9 M.-%.

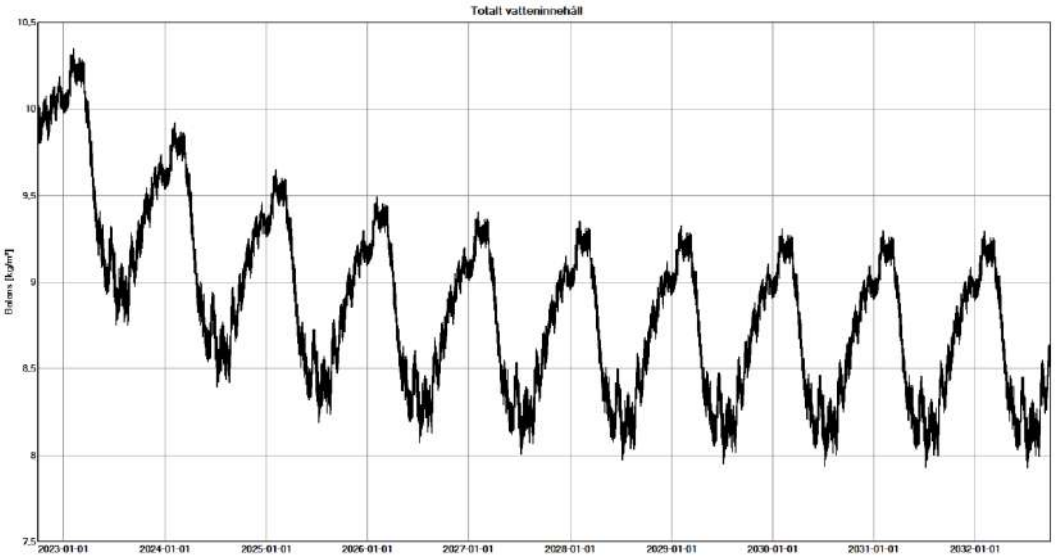
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type N

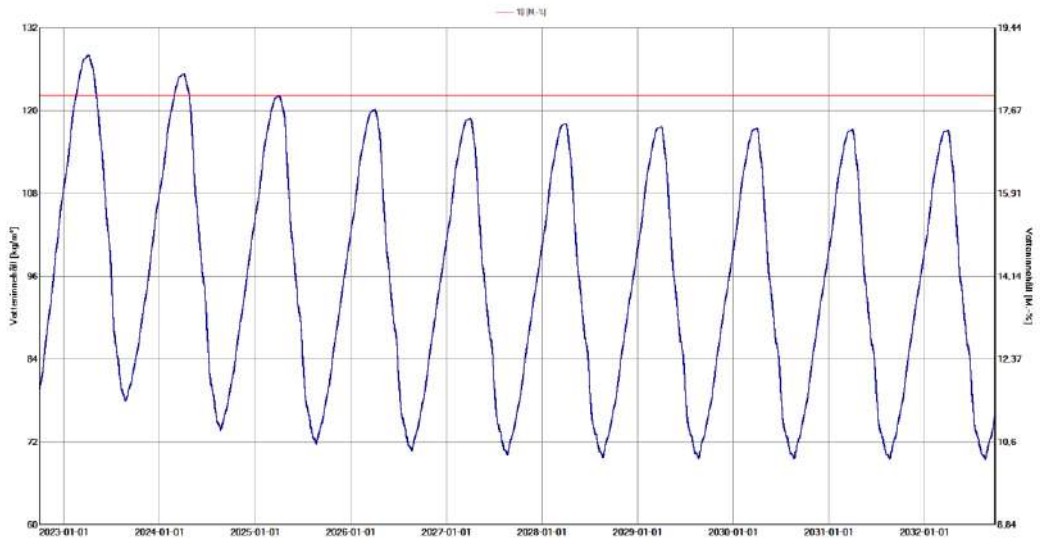
<u>The whole wall</u>



The simulation over 10 years shows that there is no accumulation of moisture over the long term, but it takes a few seasons to release the assumed high level of built-in moisture. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

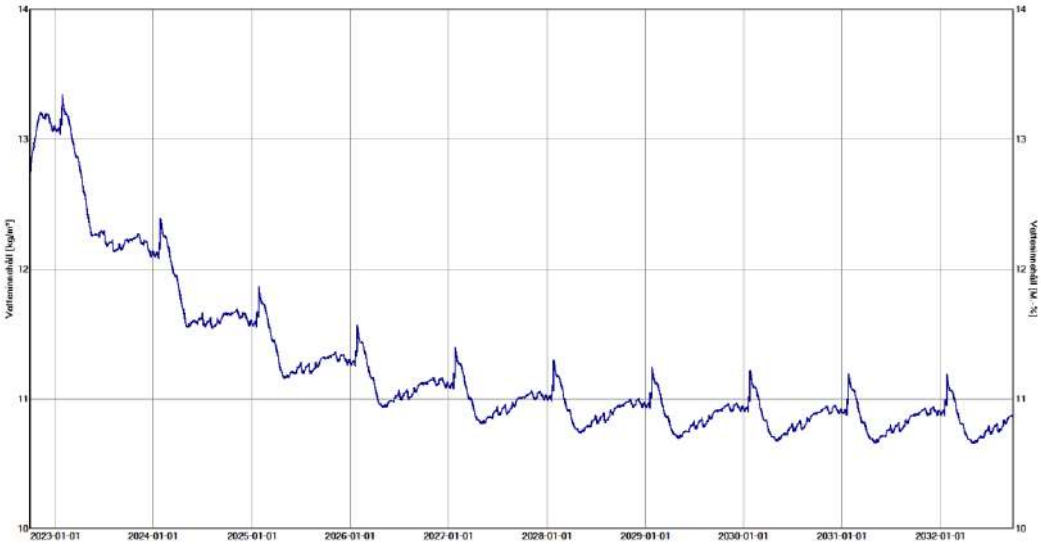
Individual layers

The OSB board towards the outside:



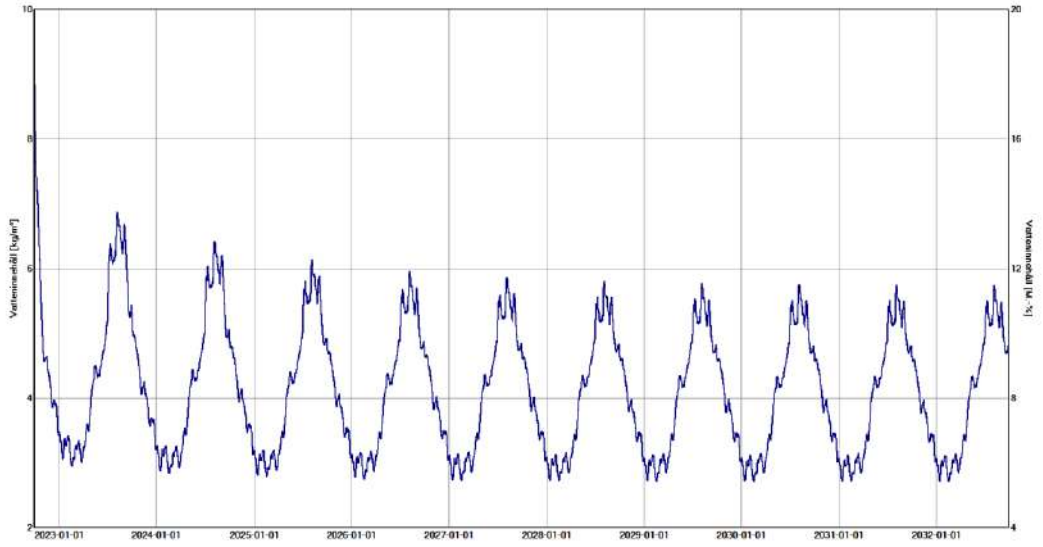
After a few seasons of stagnation, the water content is permanently below 18 M.-%.

EcoCocon panel (straw):



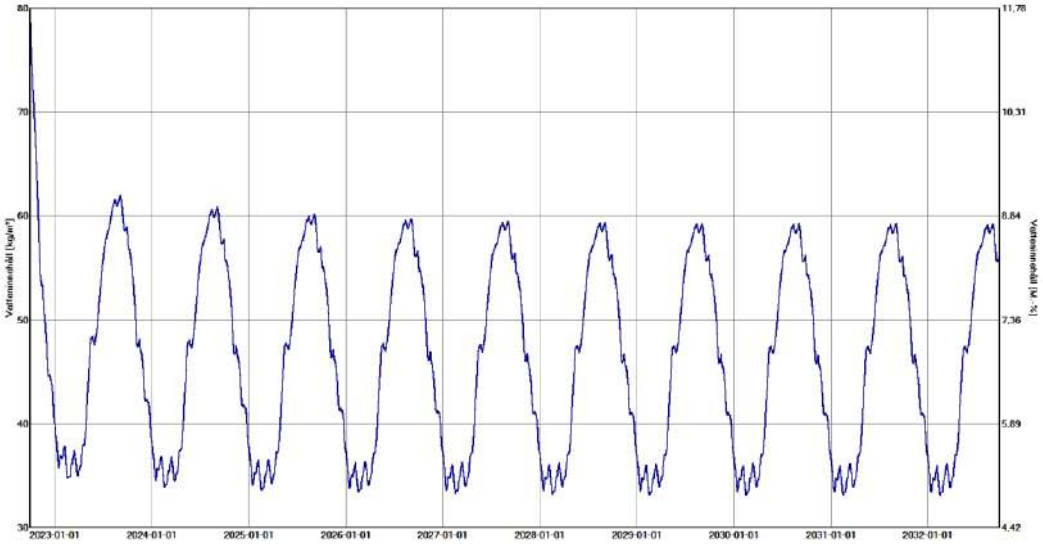
Again, it takes several seasons to stay at a low level, but even after the intentionally high value at the beginning, the water content drops over time and is below 12 M.-% all the time.

The fibreboard:



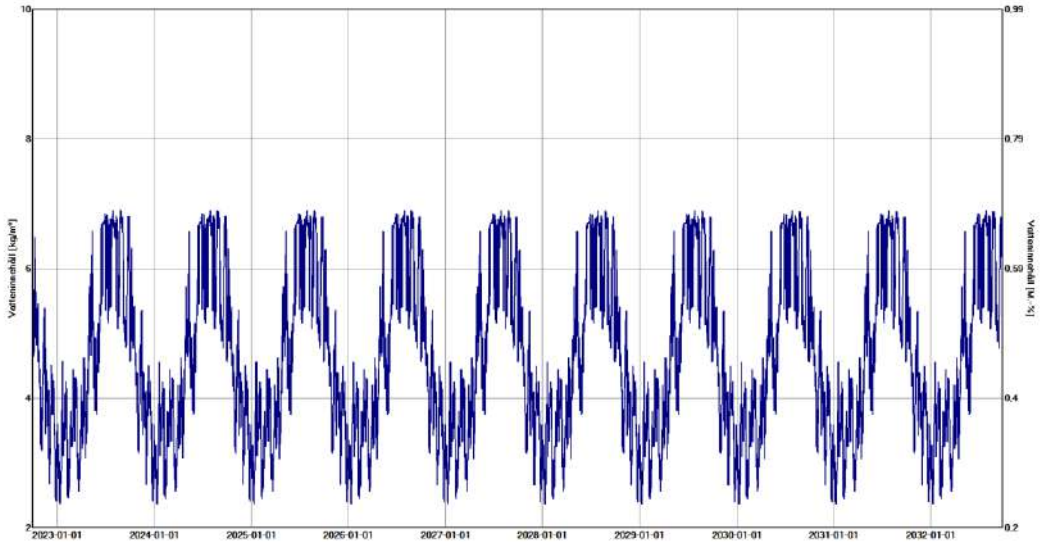
A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 12 M.-%.

The OSB panel towards the inside:



A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 9 M.-%.

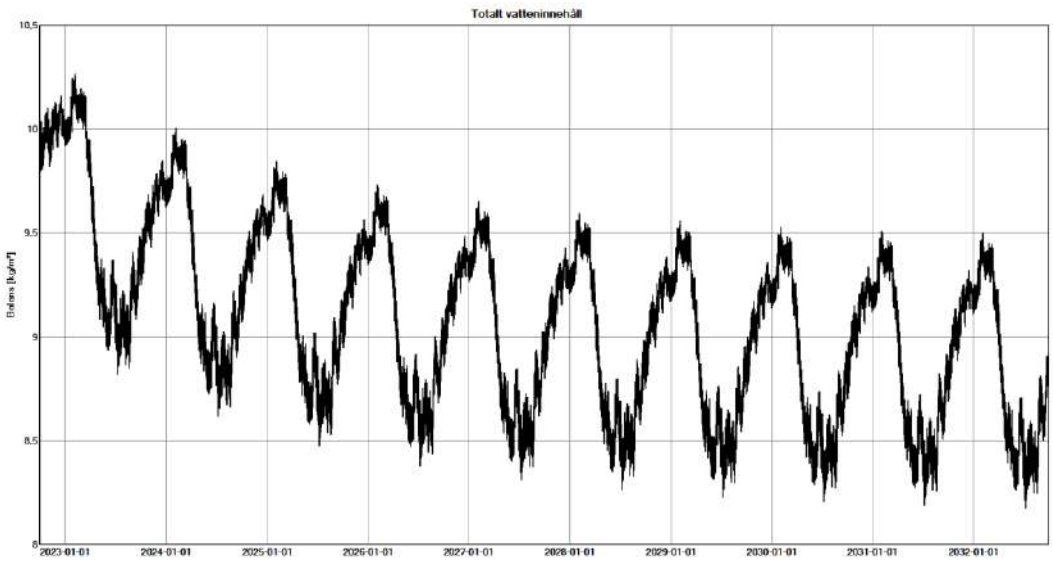
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type O

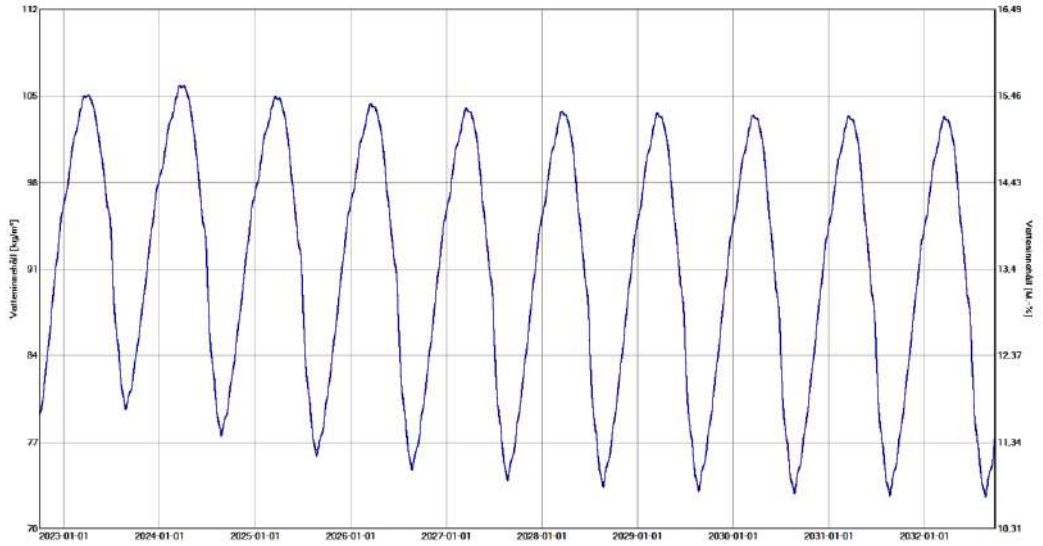
<u>The whole wall</u>



The simulation over 10 years shows that there is no accumulation of moisture over the long term, but it takes a few seasons to release the assumed high level of built-in moisture. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

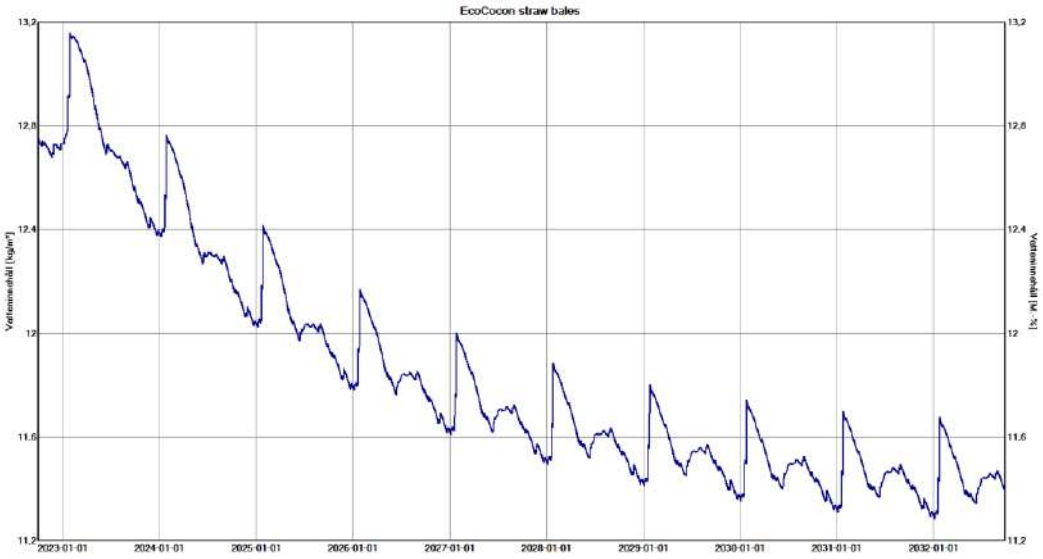
Individual layers

The OSB board towards the outside:



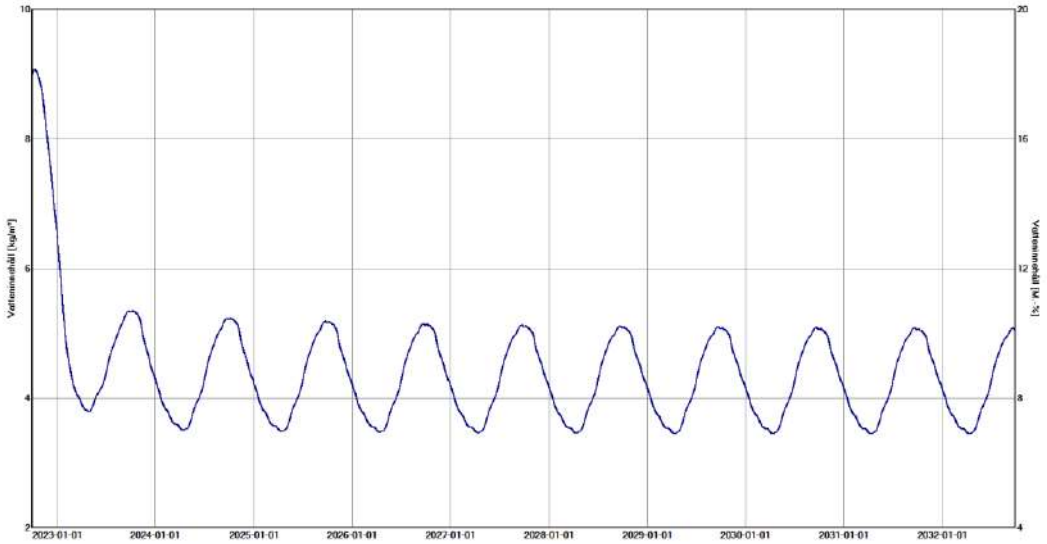
The water content is permanently below 16 M.-%.

EcoCocon panel (straw):



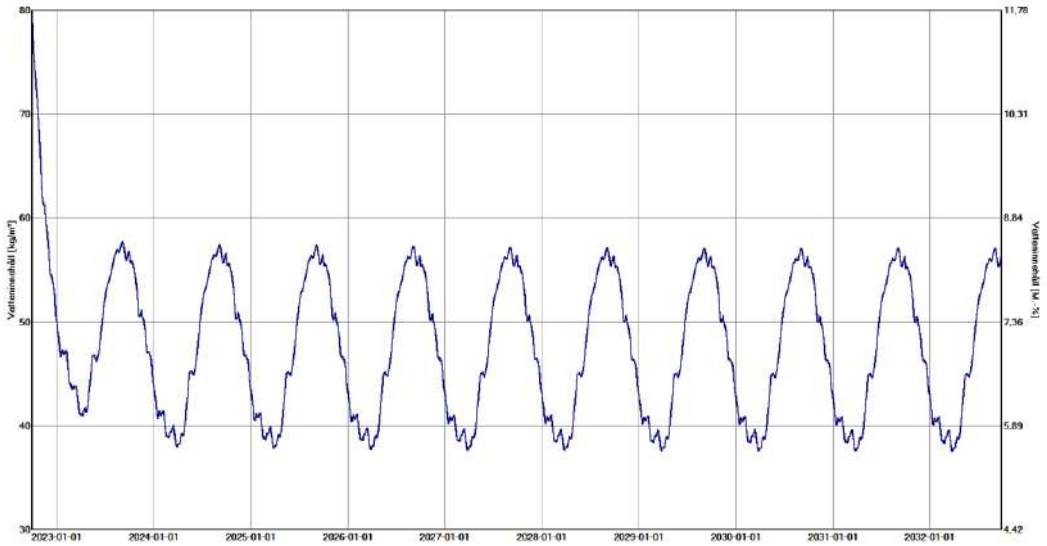
Again, it takes several seasons to stay at a low level, but even after the intentionally high value at the beginning, the water content drops over time and is below 13 M.-% all the time.

The fibreboard:



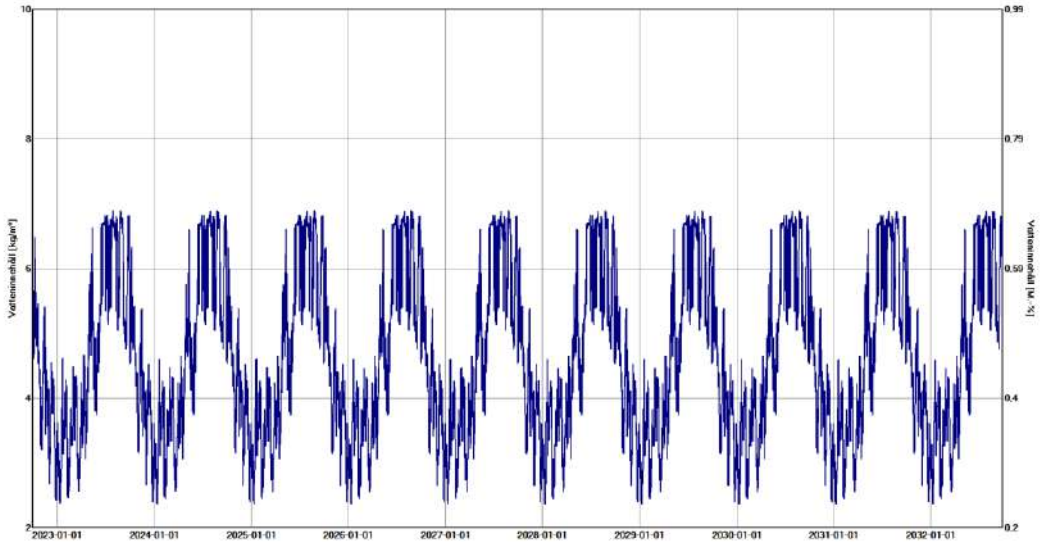
A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 12 M.-%.

The OSB panel towards the inside:



A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 9 M.-%.

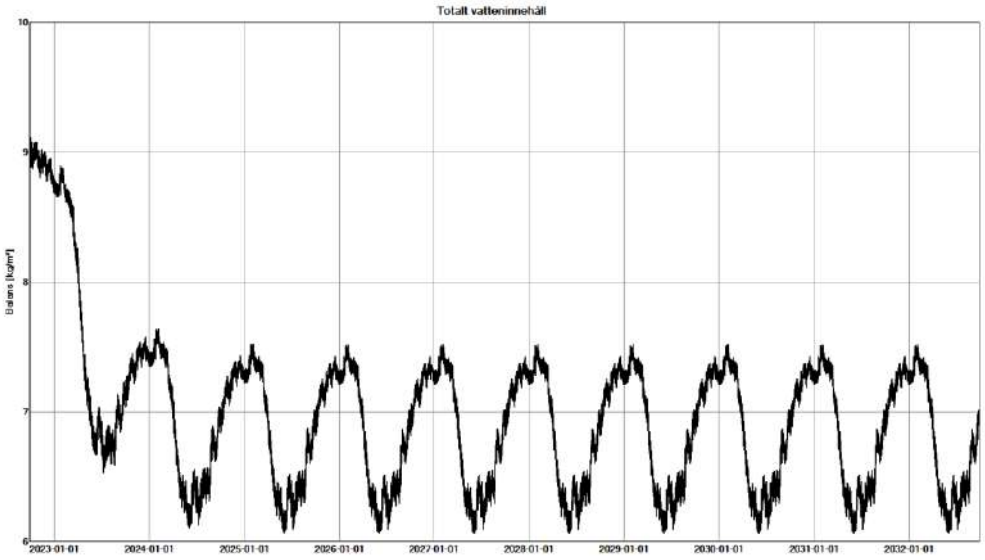
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type P

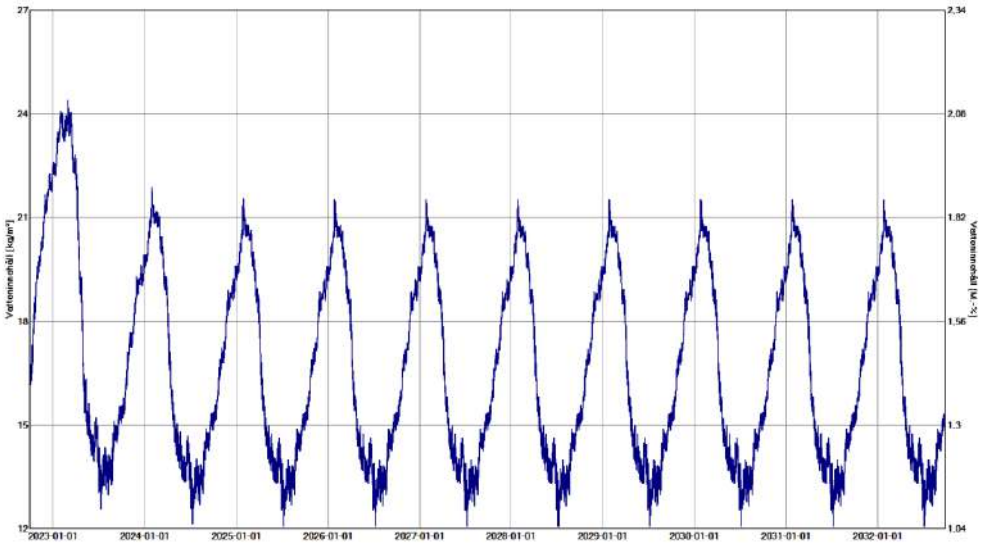
<u>The whole wall</u>



The simulation over 10 years shows that there is no accumulation of moisture over the long term, but it takes one season to release the assumed high level of built-in moisture. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

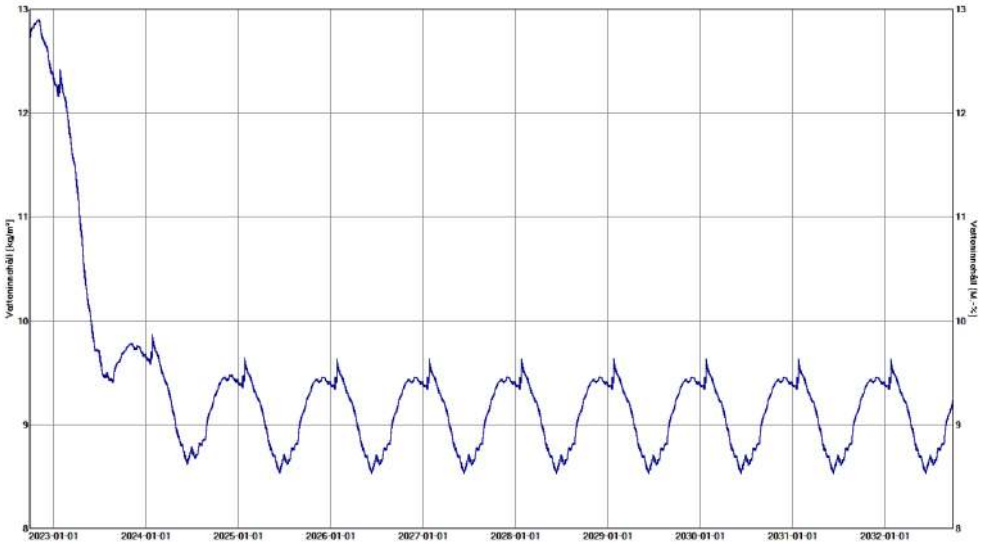
Individual layers

Fermacell board:



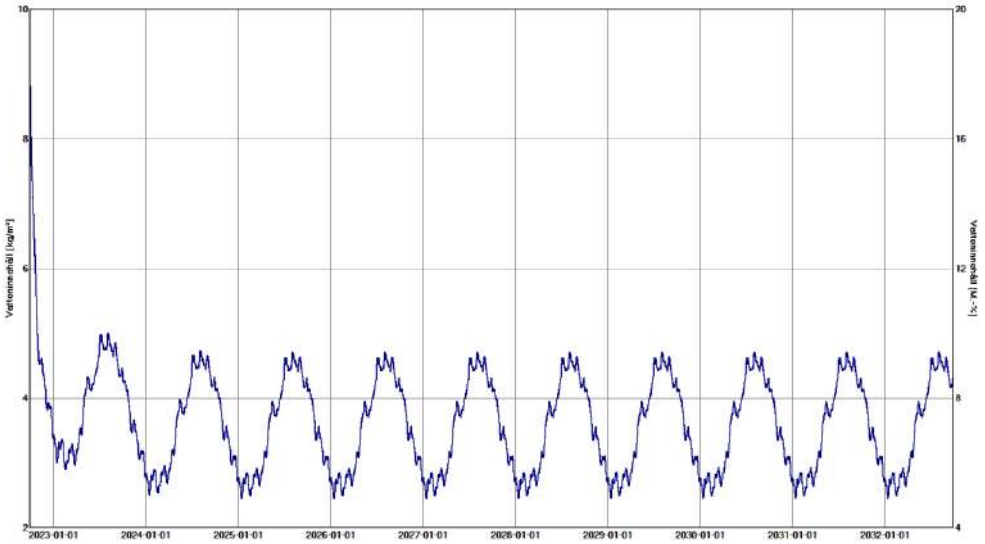
The disc will maintain a low moisture level at all times.

EcoCocon panel (straw):



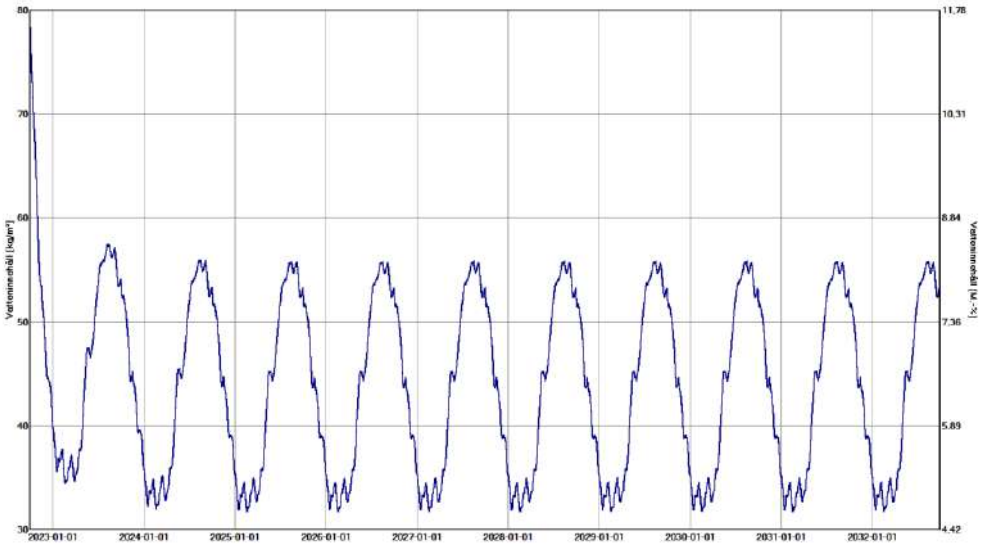
It takes one to two seasons to stay at a low level, but even after the deliberately high value at the beginning, the water content drops below 10 M.-% and stays there all the time.

The fibreboard:



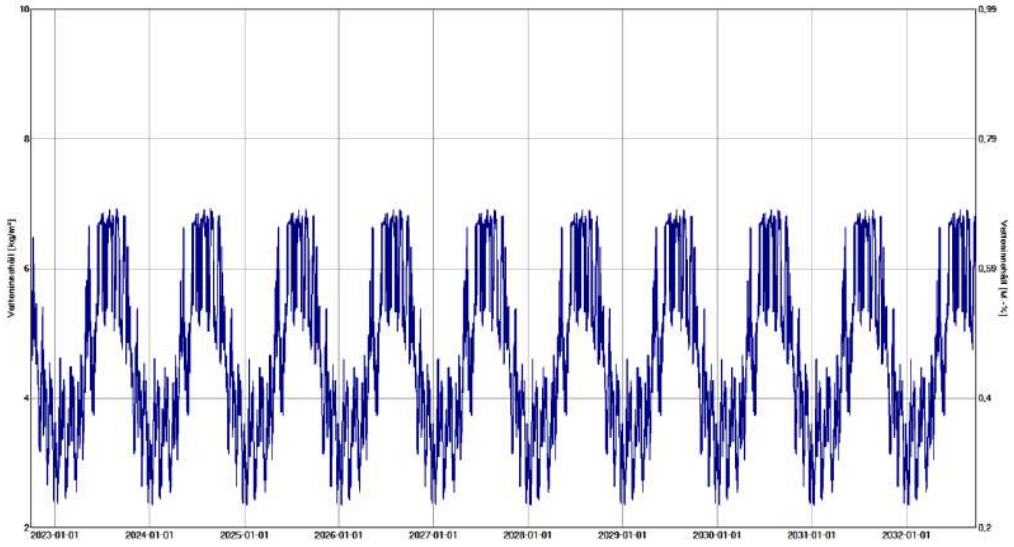
The layer dries out quickly and a low moisture level is reached already after a few months - which stays below 10 M.-%.

OSB board:



A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 9 M.-%.

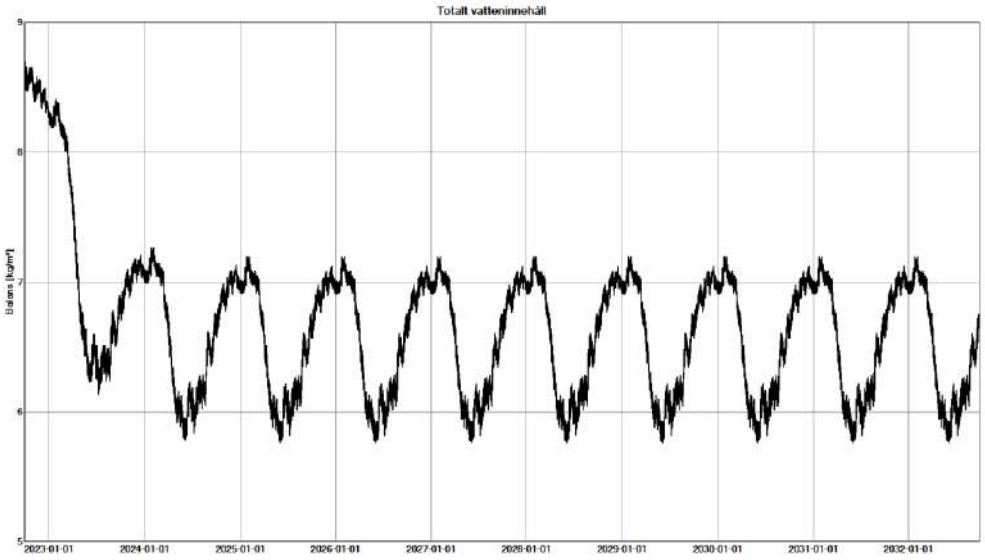
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type Q

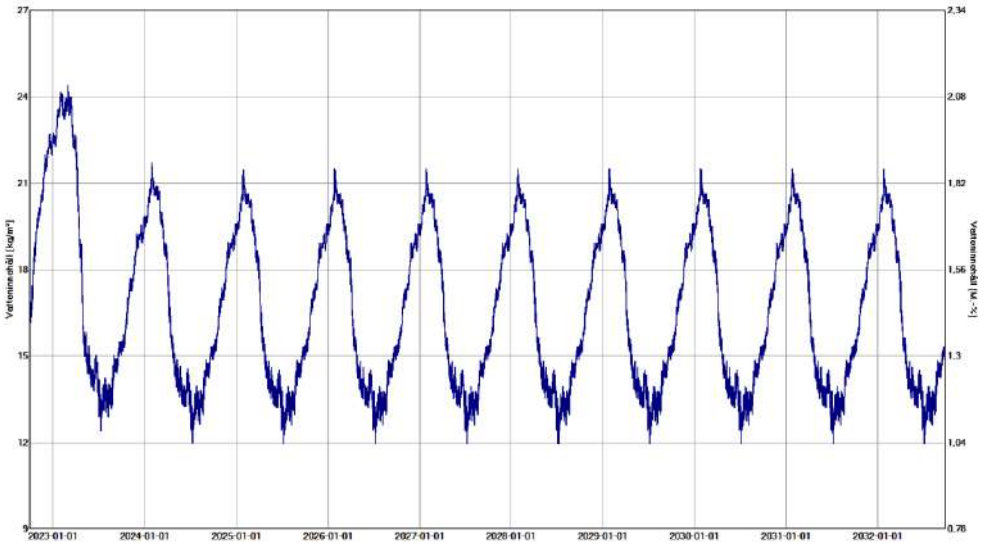
<u>The whole wall</u>



The simulation over 10 years shows that there is no accumulation of moisture over the long term and it takes only one season to release the assumed high level of built-in moisture. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

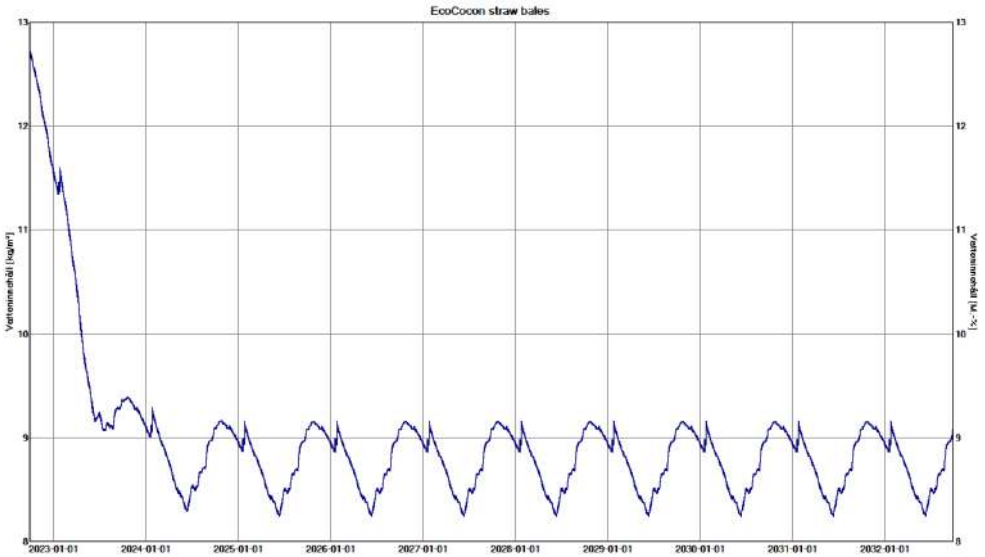
Individual layers

Fermacell board:



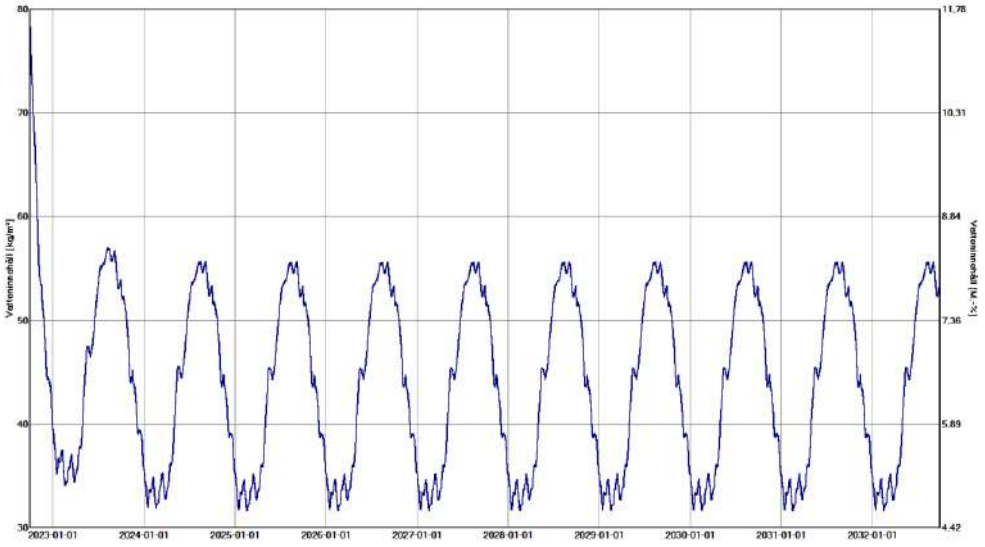
The disc will maintain a low moisture level at all times.

EcoCocon panel (straw):



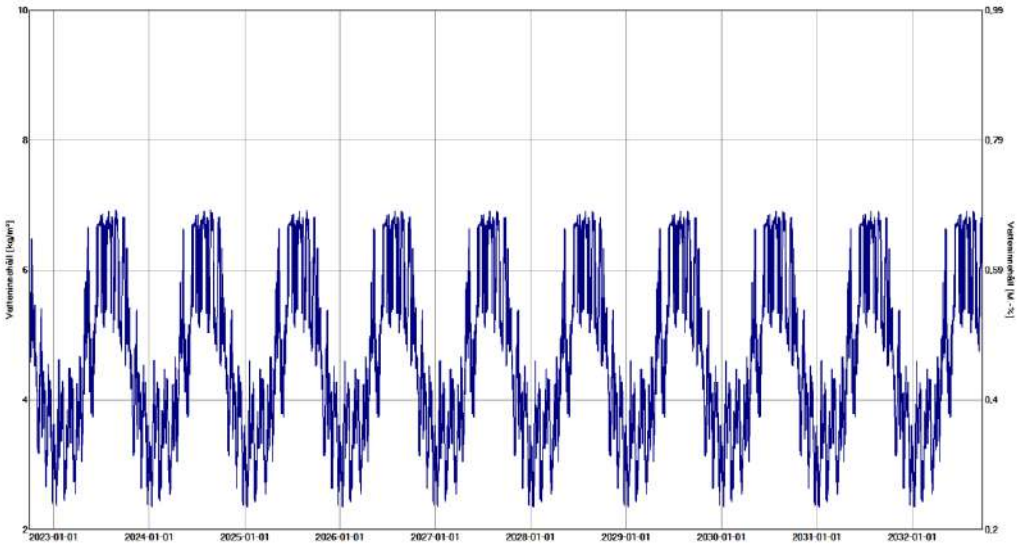
It takes one to two seasons to stay at a low level, but even after the deliberately high value at the beginning, the water content drops to below 9.5 M.-% and stays there all the time.

OSB board:



A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 9 M.-%.

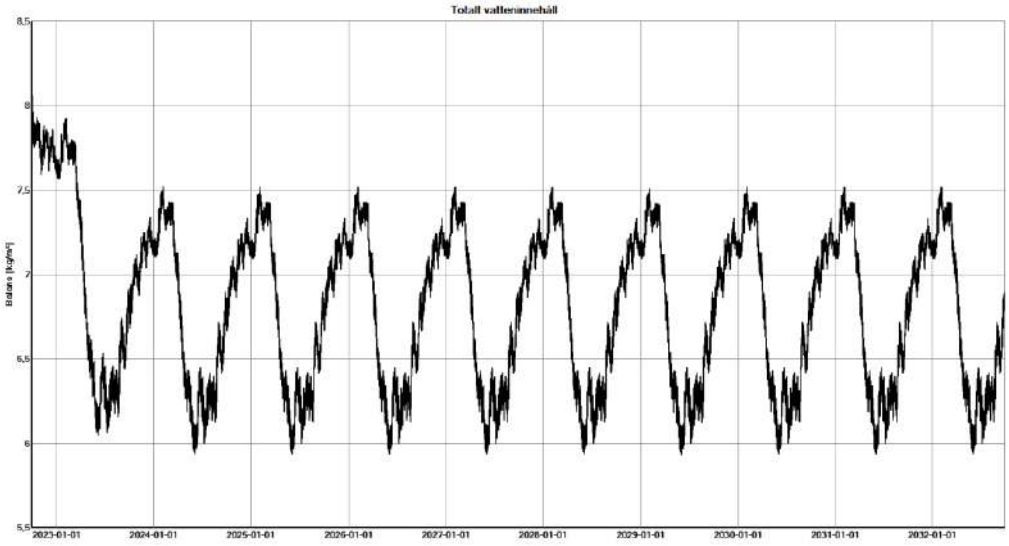
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type R (like wall type **Q**, but with internal plaster)

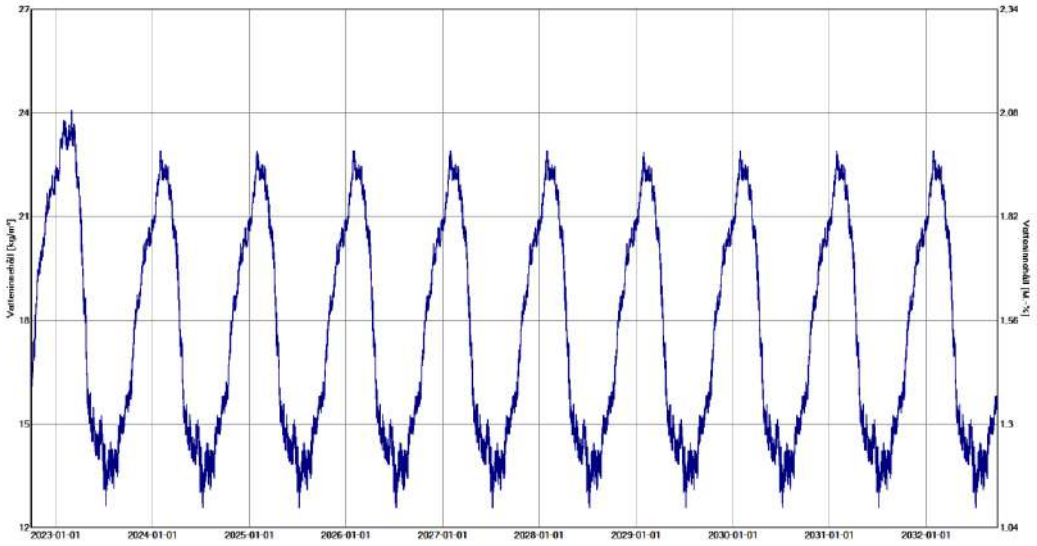
The whole wall



The simulation over 10 years shows that there is no accumulation of moisture over the long term and it takes only one season to release the assumed high level of built-in moisture. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

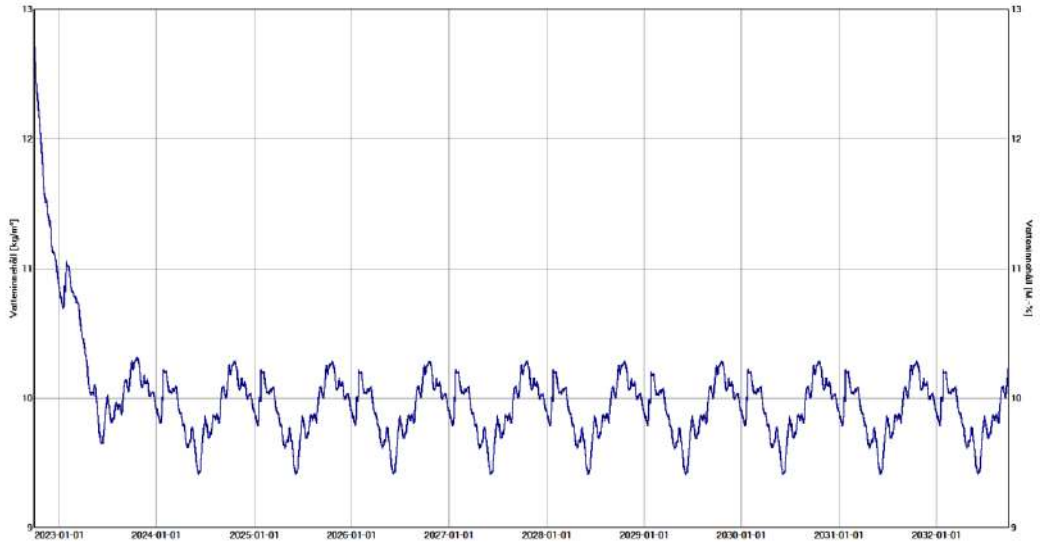
Individual layers

Fermacell board:



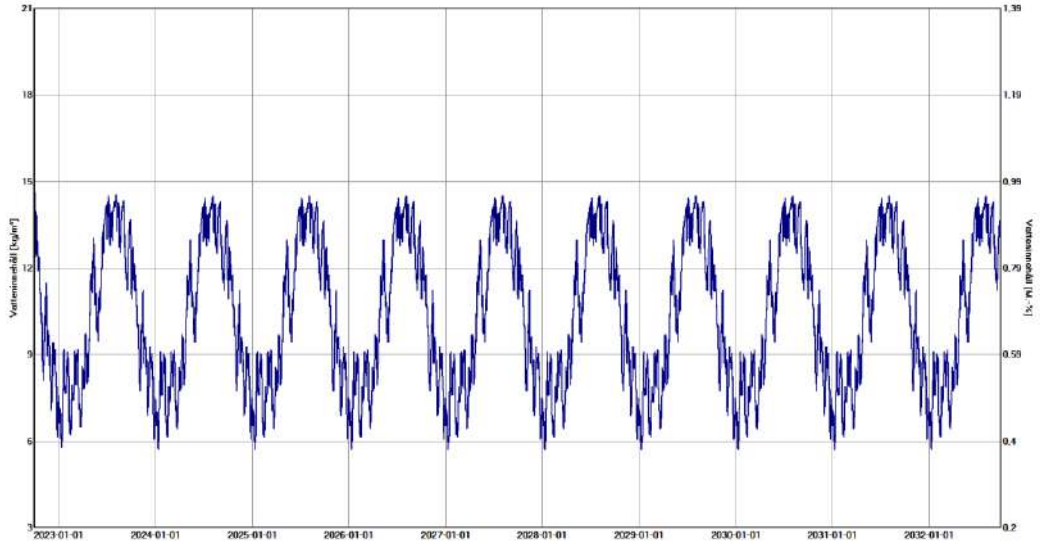
The disc will maintain a low moisture level at all times.

EcoCocon panel (straw):



It takes a season to stay at a low level, but even after the deliberately high value at the beginning, the water content drops below 10.5 M.-% and stays there all the time.

Interior plaster:



The moisture content does not take any harmful forms here.

Summary

The simulation shows that all investigated wall types with an intentionally high moisture content at the construction stage dry out. Of course, there is a periodic accumulation and reduction of moisture in the individual layers, but this never reaches alarming proportions.

A simulation is only as good as its input data, including boundary conditions. The calculation was made with extra safety margins, but each case and situation are special. Therefore, when applying the results in the report, certain aspects have to be taken into account:

1. The calculations are only related to the defined and specified boundary conditions and the named object and substructures and cannot be transferred without further verification, even if the design is the same or similar.
2. For the calculation to be representative, accurate production is required and the contractor is responsible for ensuring that the specifications are consistently maintained.
3. Airtightness and, if possible, airtightness testing, are a prerequisite.
4. The specified moisture contents for the materials, specific to wood or wood-based products, must not be exceeded. Careful, clean and dry storage must be ensured.

Tvärred, 23rd March 2023

Ingo Theoboldt

Building physicist, accredited certifier and designer for passive houses

Passivhusbyrån Ingo Theoboldt

Tel: 0762-874024

Address: Vasared 301, 523 94 Tvärred

E-mail: info@passivhusbyran.se

Report

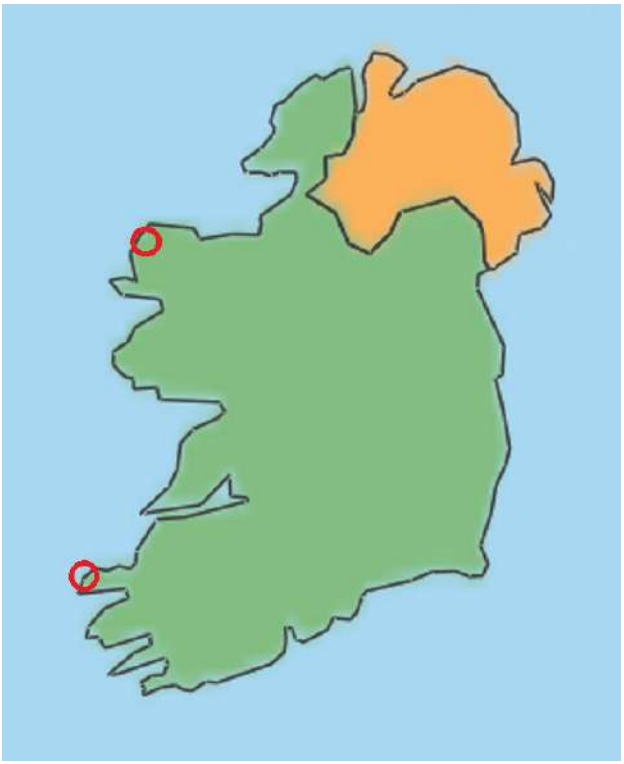
Ireland
Hygrothermal Analysis (WUFI)

Version 1.0 - Updated 02.02.2023

eco cocon

Hygrothermal analysis of the EcoCocon building system for Belmullet and Valentia, Ireland

(as per 2nd February 2023)



Passivhusbyrån Ingo Theoboldt

Tel: +46 (0) 762 874 024

Adress: Vasared 301, 523 94 Tvärred, Sverige

E-post: info@passivhusbyran.se

Contents

Background and assignment

Passivhusbyrån has been commissioned to produce a hygrothermal analysis of *EcoCocon's* building system for two locations on the west coast of Ireland, namely Belmullet and Valentia, with four different wall types (from outside to inside):

1. Façade panels (wood), airgap, 60 mm woodfibre board, EC panel, plasterboard
2. Façade panels (wood), airgap, 60 mm woodfibre board, EC panel, interior plaster
3. Exterior render, 60 mm woodfibre board, EC panel, plasterboard
4. Exterior render, 60 mm woodfibre board, EC panel, interior plaster

The aim of the analysis is to obtain results with the following input data and to examine the long-term performance as regards to moisture safety.

Reservations

The calculations and simulations for this project are based on the submitted input data received between 17th and 31st January 2023. For the simulation, climate data sets containing all necessary parameters have been used, in this case from the *Belmullet* and *Valentia* weather stations, both located on the west coast of Ireland. For additional stress testing, according to ANSI/ASHRAE standard 160, a 1 % fraction of the rain load has been included as seeping into the construction, namely into the straw panel directly behind the weather resistive barrier, which EcoCocon is delivering with their straw panels.

Hygrothermal analysis

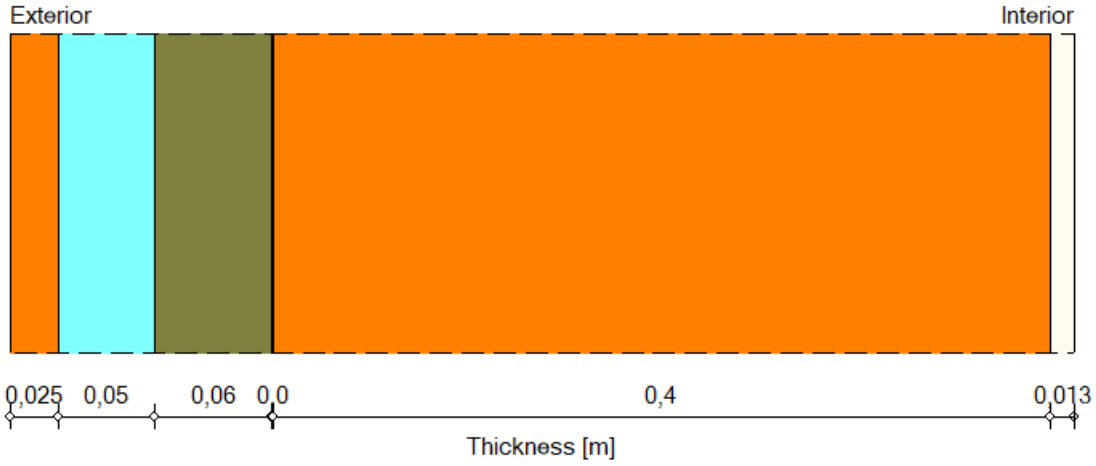
The simulation was done with WUFI 6.5 Pro, which allows for an hourly dynamic simulation for an unlimited number of years to come. During the process, the following parameters are considered, among others:

Material properties: these quantities describe the hygrothermal behaviour of the materials to be examined: bulk density [kg/m³], porosity [m³/m³], specific heat capacity [J/(kg·K)], dry thermal conductivity [W/(m·K)], dry water vapour diffusion resistance, moisture storage function [kg/m³], and liquid transport coefficient suction and redistribution [m²/s] (w-value). If applicable, moisture-dependent thermal conductivity [W/(m·K)] and water vapour diffusion resistance number are also included.

Climate data: these quantities describe the boundary conditions acting on the internal or external surface of the building component: rainfall load on the surface [l/(m²·h)], depending on the slope and orientation of the component, shortwave radiant flux density (solar) [W/m²], depending on the slope and orientation of the component, outdoor air temperature [°C], outdoor air relative humidity [0...100%], indoor air temperature [°C], indoor air relative humidity [0...100%] and average air pressure [hPa] during the calculation period.

Input data

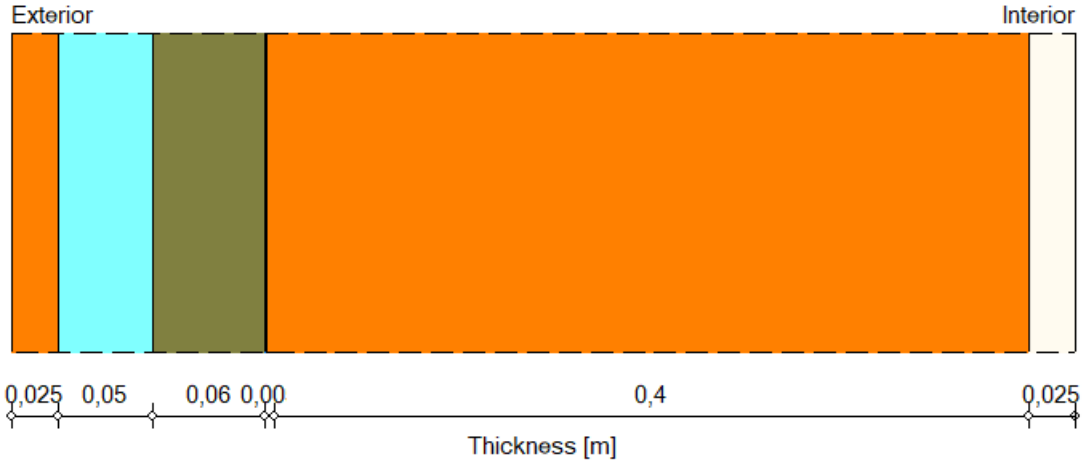
Construction - wall type A:



Materials:

	- Scandinavian spruce transverse direction	0,025 m
	- Air Layer 50 mm	0,05 m
	- wood fibre board 60mm	0,06 m
	- weather resistive barrier (sd=0,05m)	0,0 m
	- *EcoCocon straw bales	0,4 m
	- plasterboard	0,013 m

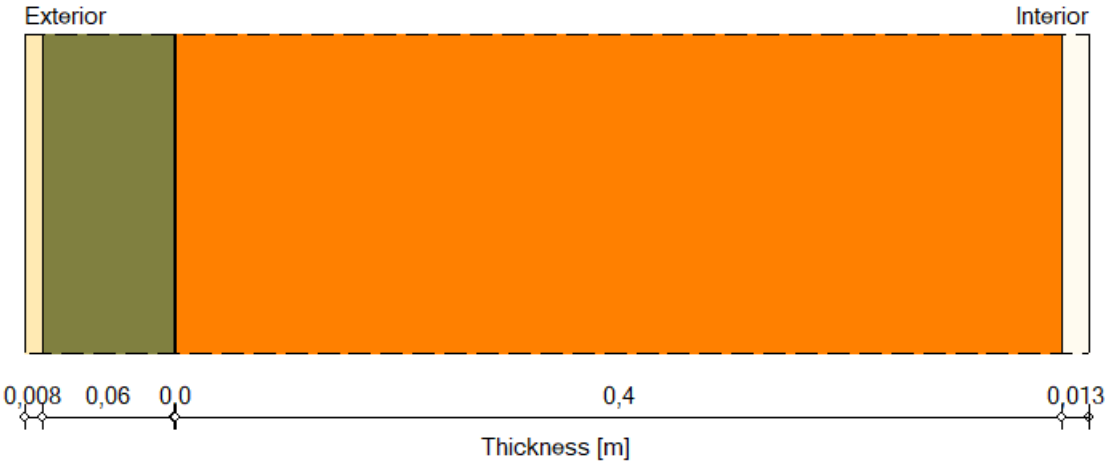
Construction - wall type B:



Materials:

	- Scandinavian spruce transverse direction	0,025 m
	- Air Layer 50 mm	0,05 m
	- wood fibre board 60mm	0,06 m
	- weather resistive barrier (sd=0,05m)	0,0 m
	- *EcoCocon straw bales	0,4 m
	- *Clay Plaster	0,025 m

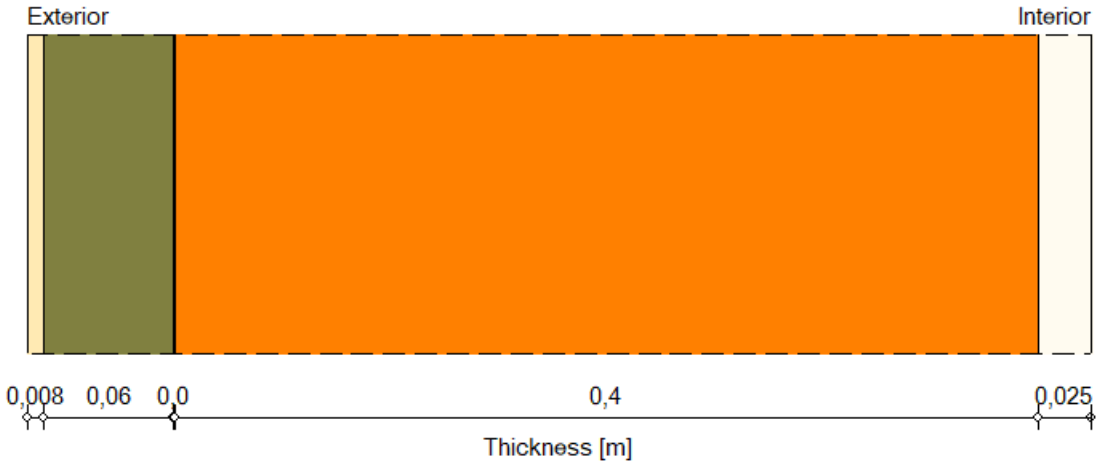
Construction - wall type C:



Materials:

	- Mineral Plaster (stucco, A-value: 0.1 kg/m2h0.5)	0,008 m
	- wood fibre board 60mm	0,06 m
	- weather resistive barrier (sd=0,05m)	0,0 m
	- *EcoCocon straw bales	0,4 m
	- plasterboard	0,013 m

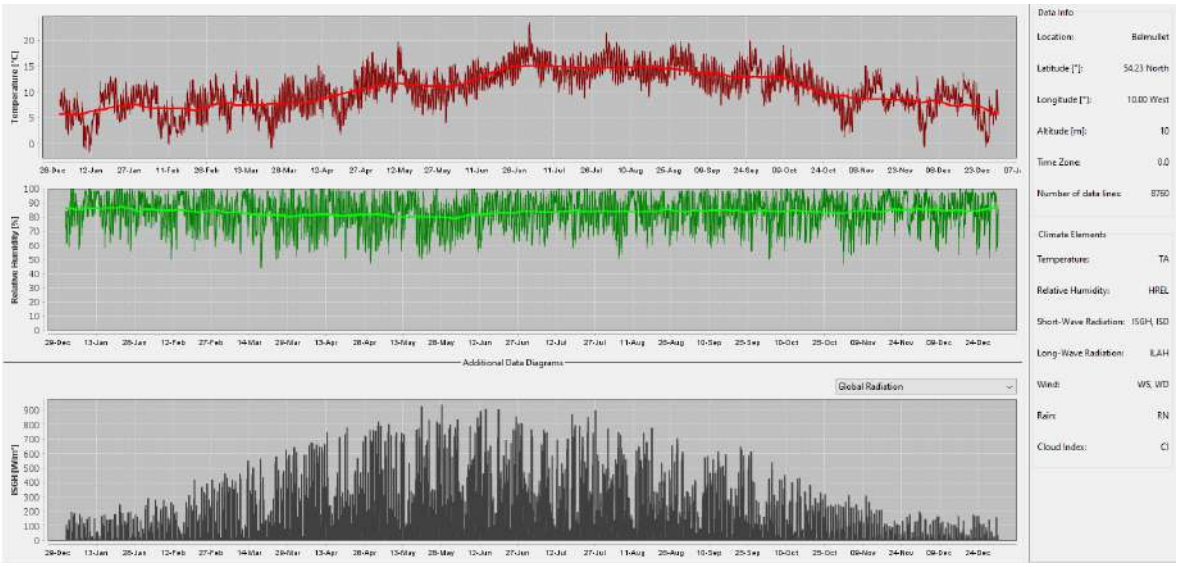
Construction - wall type D:

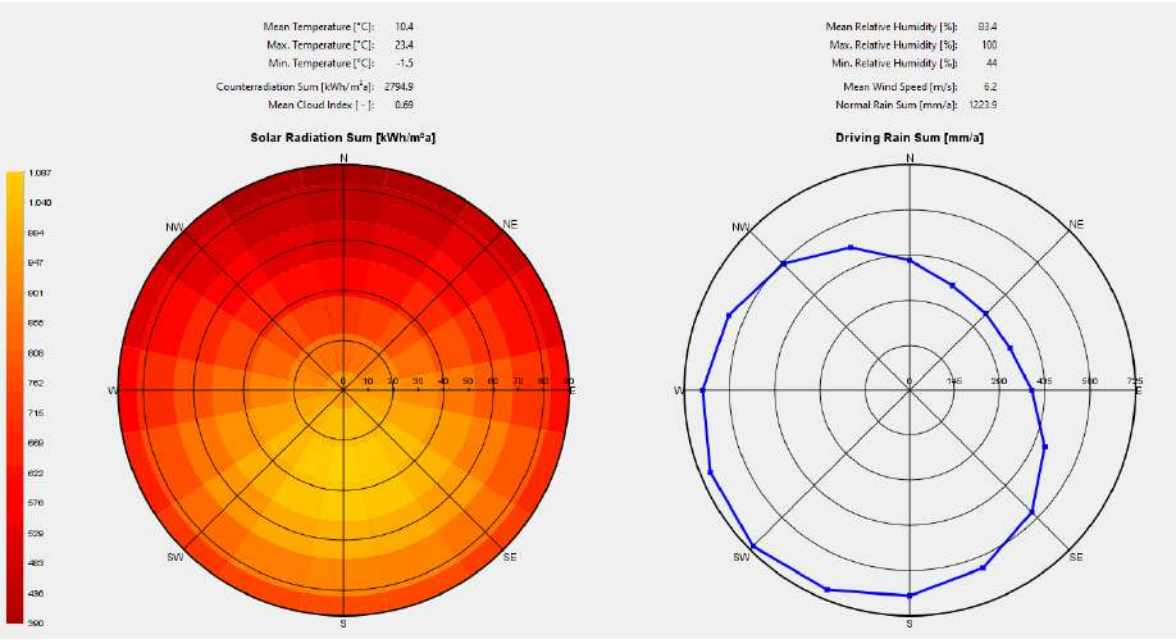


Materials:

	- Mineral Plaster (stucco, A-value: 0.1 kg/m2h0.5)	0,008 m
	- wood fibre board 60mm	0,06 m
	- weather resistive barrier (sd=0,05m)	0,0 m
	- *EcoCocon straw bales	0,4 m
	- *Clay Plaster	0,025 m

Outdoor climate Belmullet (Ireland)





The direction of the strongest driving rain is Southwest, but for ventilated facades, the northward orientation is decisive for these simulations and therefore has been applied. For stress-testing, 1% of the driving rain for an additional moisture source *behind* the weather membrane has been added in order to simulate water possibly seeping into the structure via small leaks, e.g., around the window installations. For rendered façades, the Southwest orientation has been applied.

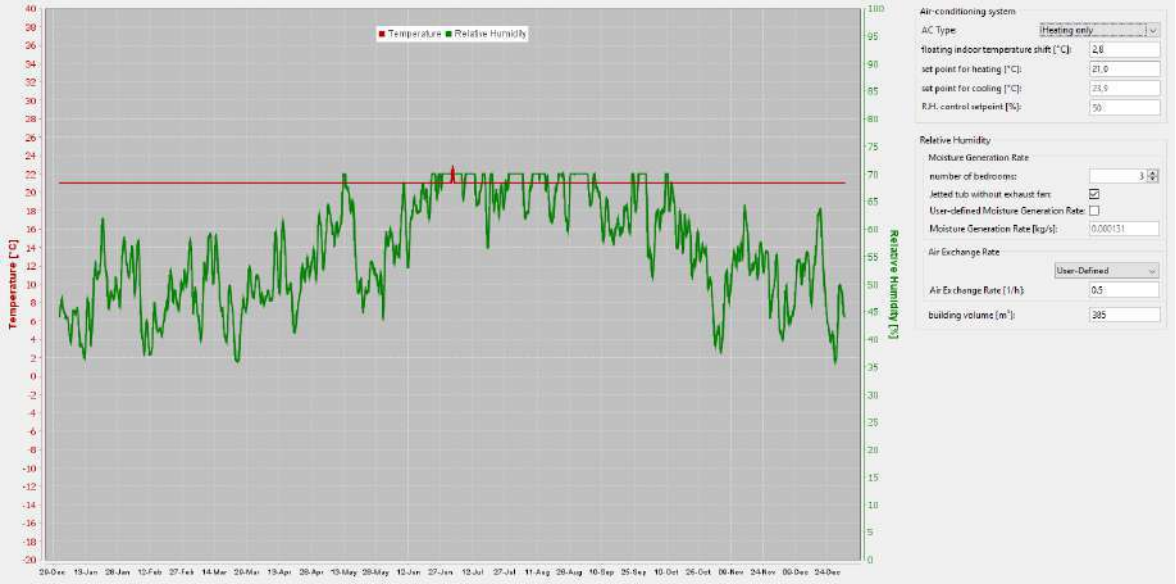
Indoor climate Belmullet (Ireland)

The same model building was used for all simulations: a three-bedroom villa with 385 m³ interior volume.

A whirlpool bath without exhaust fan was added for possible additional moisture production - just to be on the safe side. An MVHR unit delivers 0.5 air changes per hour.

Airconditioning is only available as heating, no active cooling. The set point for heating is 21°C (typical value for SFH).

The indoor climate model was based on ASHRAE 160-2021 as this provided the possibilities to represent the above conditions. For Belmullet, it looks like this:

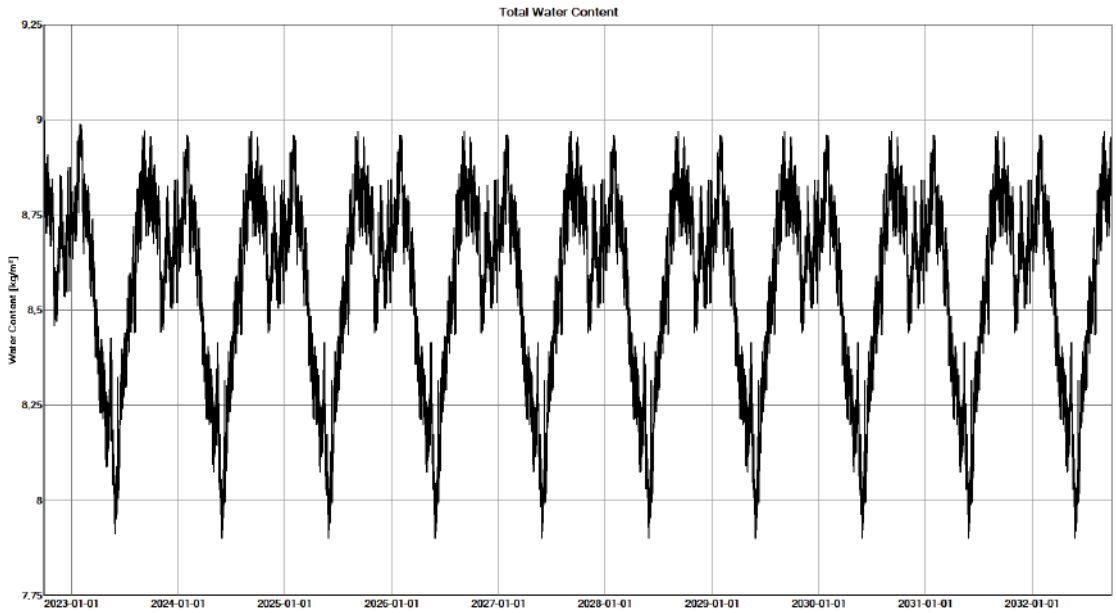


Results

The following diagrams show the water contents of the individual layers.

Wall type A

Entire wall

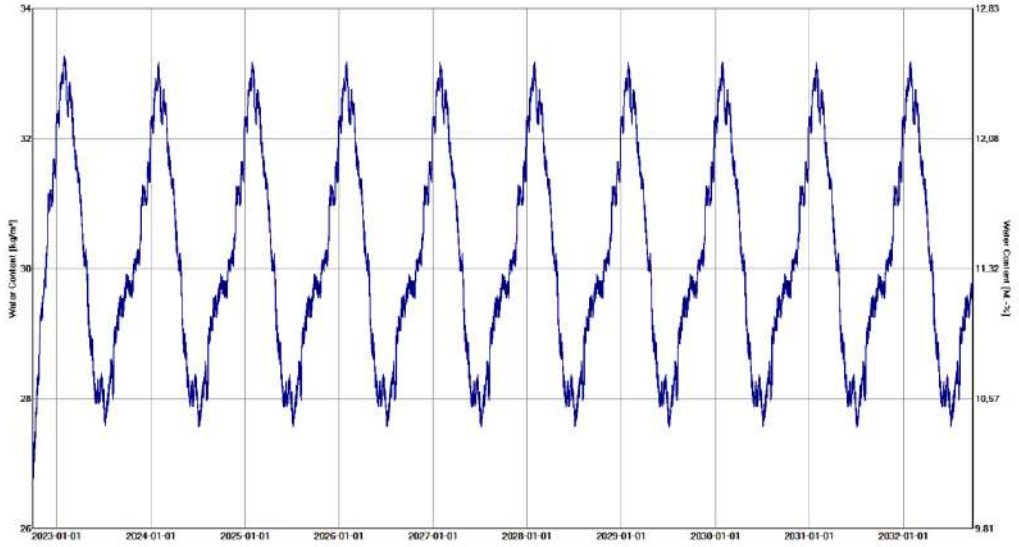


The simulation over 10 years shows that there is no accumulation of moisture over the long term (apart from the usual seasonal fluctuation). No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

For the simulation, 80 % relative humidity has been assumed for the materials built into the construction. As the house consists of prefabricated modules, there is even less risk of built-in moisture or leakage. For additional stress testing, the air exchange rate in the ventilation gap has been set to be very low, i.e., 10/h. This goes for all other ventilated façade simulations in this report as well.

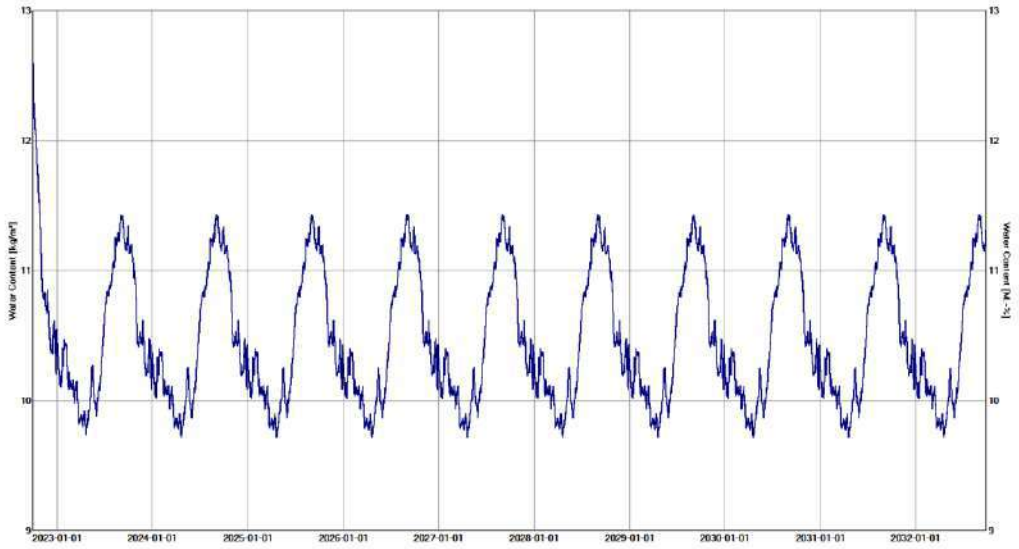
Individual layers

Woodfibre board behind the air gap:



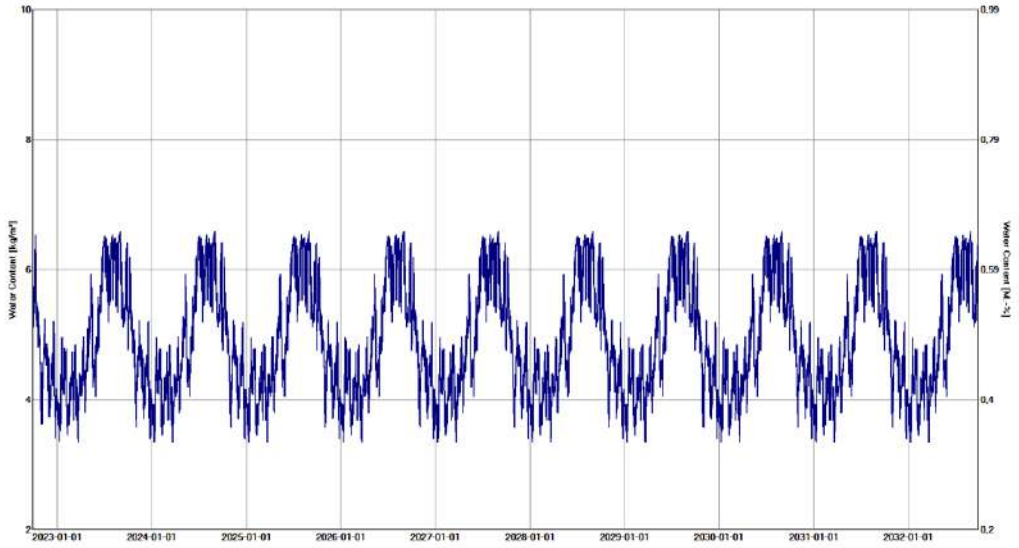
The woodfibre board has the ability to dry out and the relative humidity remains below 13 %, which is significantly below the critical limit.

EcoCocon straw panel:



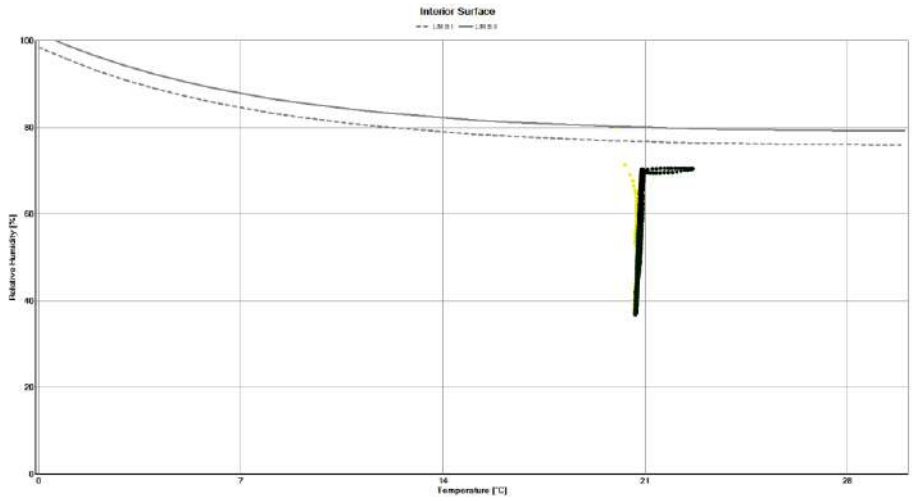
After the deliberately high setting at the beginning, the relative humidity drops immediately and continuously stays below 11.5 M.-%.

Plasterboard layer:



The moisture content does not take harmful forms.

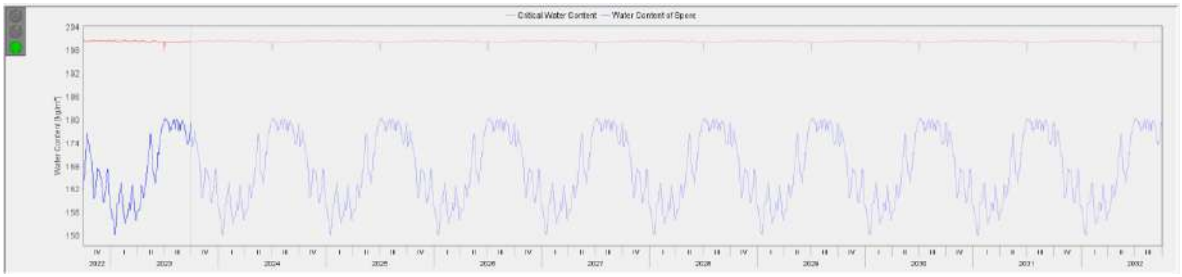
Isoplet on inner surface:



*) "LIM" stands for lowest isoplet for mould, "B" for construction.
The two scenarios I & II mean:
I = substrates that are readily biodegradable (e.g. wallpaper, dirt).
II = Substrates that are hardly biodegradable (e.g. mineral building materials).
Here, the interior surface examined is made of mineral plaster, i.e. No. II is relevant.

Each point represents one of the 87,600 calculations performed with respect to the combination of humidity and temperature and its potential to promote mould growth on the inside of the investigated exterior wall over a 10-year period. All are well below the two LIM threshold lines that represent two different scenarios for mould growth.

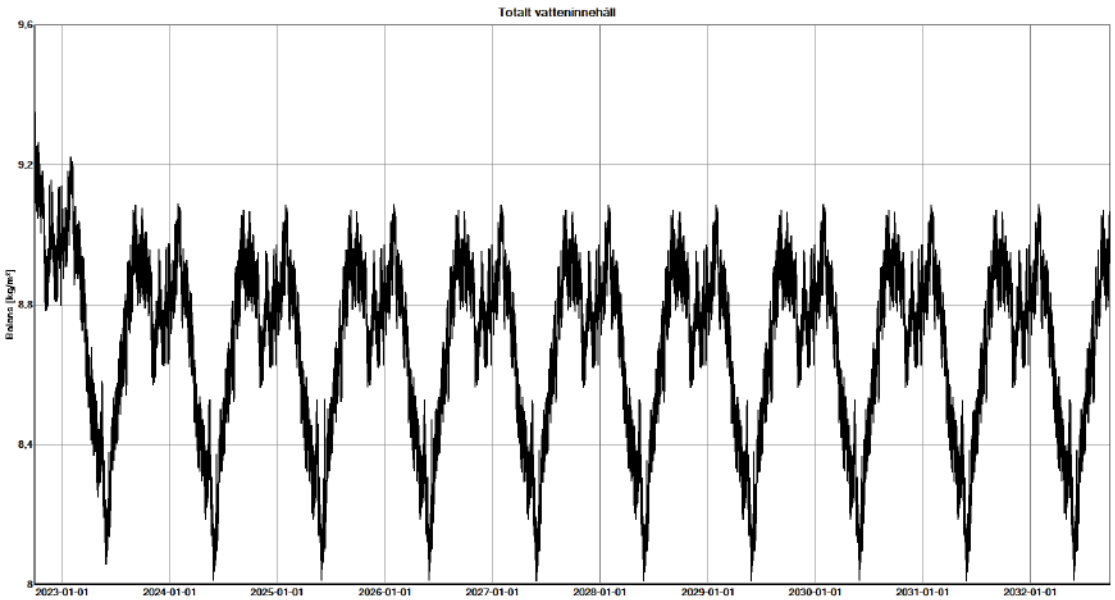
In addition to that, a study was carried out using *WUFI Bio 4.0*, a tool that examines spore formation by calculating their water content required for growth. The results show that the spores never reach a critical level - the traffic light shows *green*, i.e. approved, no problem:



Since the results regarding mould growth on the interior surface are basically identical for all four wall types, the above graphs and comments are not included again for the remaining three wall types.

Wall type B

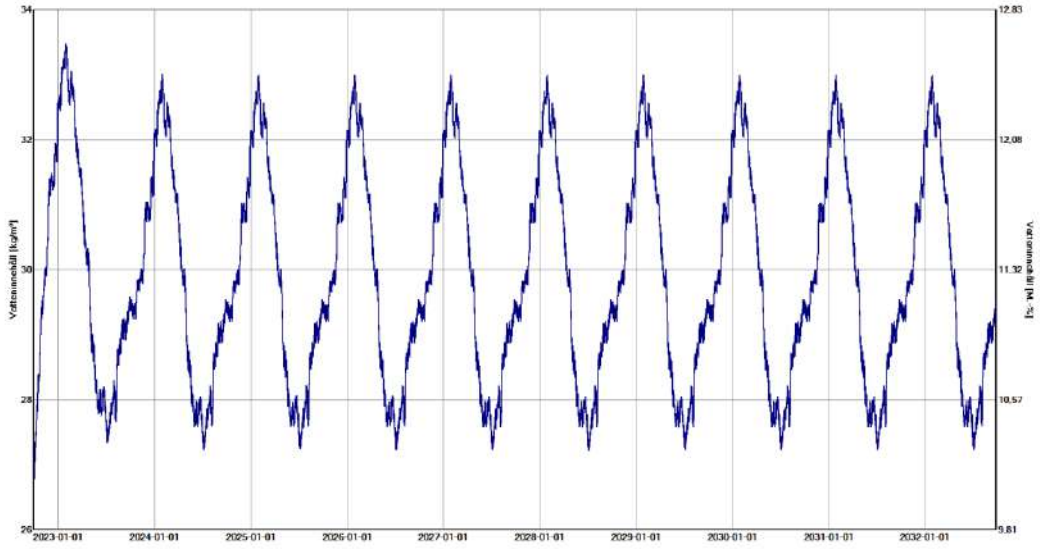
Entire wall



Even with built-in moisture content (80%), the entire wall structure dries out quite quickly. The simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

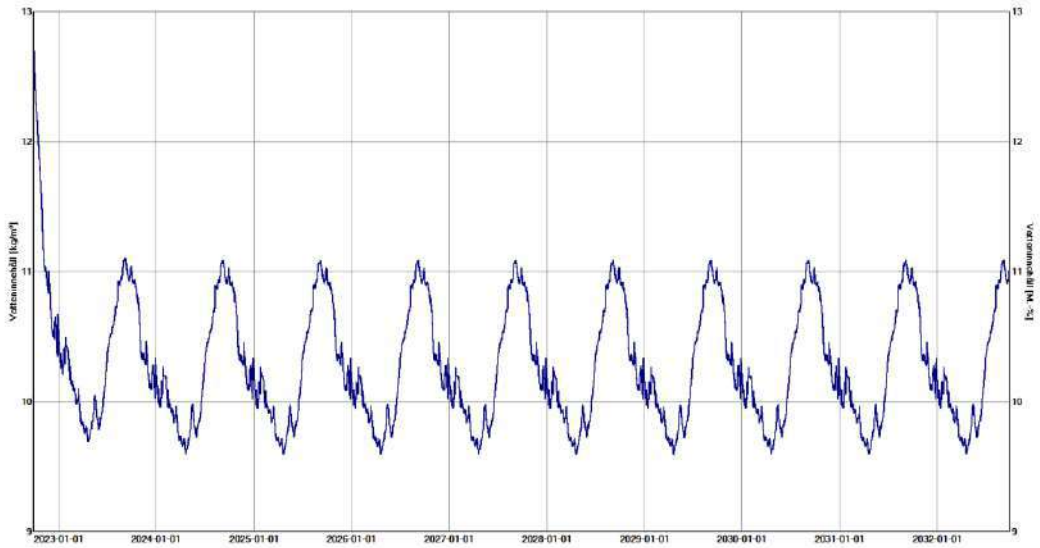
Individual layers

Woodfibre board behind the air gap:



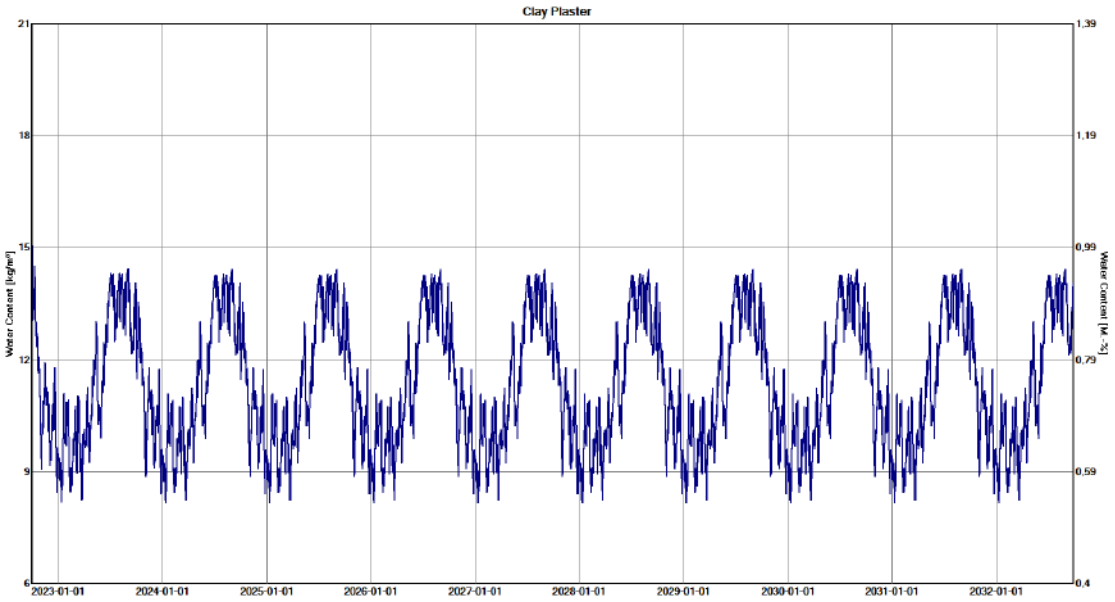
The woodfibre board has the ability to dry out and the relative humidity remains below 13 %, which is significantly below the critical limit.

EcoCocon straw panel



Even if an 80 % moisture content is assuemed for the construction phase, the straw panel dries out quickly and the water content remains below 12 M.-% all year round. It does not exceed this value over the course of the examined years either. After the initial steadying, the periodic variation remains the same.

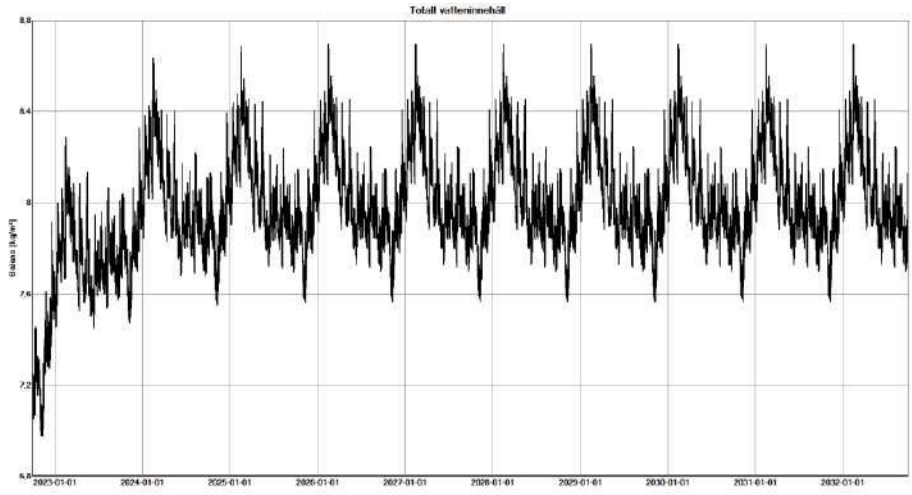
Interior clay paster:



The moisture content here does not take on any harmful forms. Rather does the clay render layer help to improve the indoor climate by buffering the humidity.

Wall type C

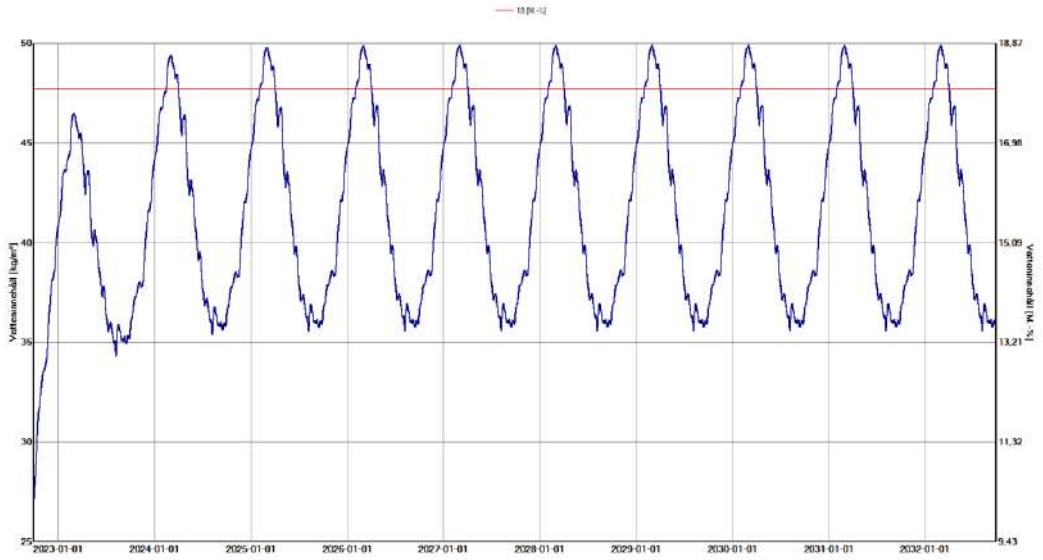
Entire wall



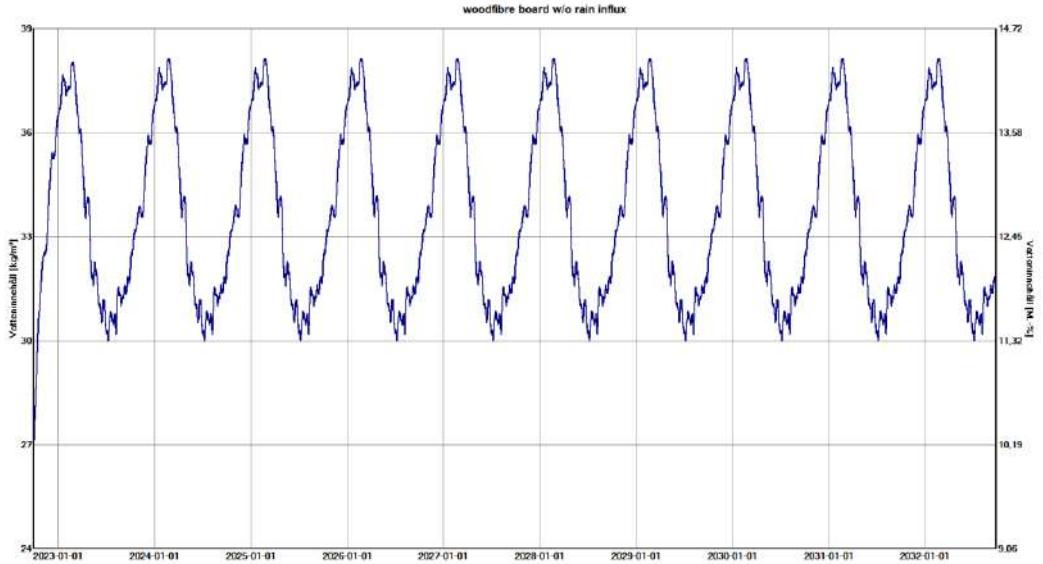
The simulation over 10 years shows that there is no further accumulation of moisture over the long term after the initial stabilisation period. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

Individual layers

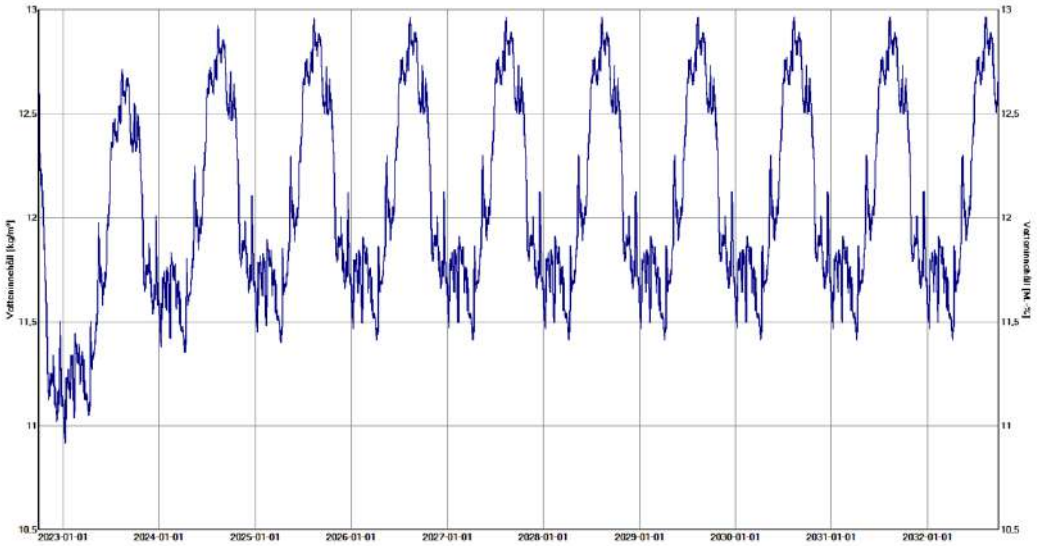
Woodfibre board behind the external render layer:



The woodfibre board including the 1% influx of rain partially reaches over the critical limit of 18 M.-%. Particular focus on watertightness during construction would therefore be required. Below, the results for woodfibre board *without* the additional "stress" of rainwater influx is shown – the water content there remains well below the critical limit:

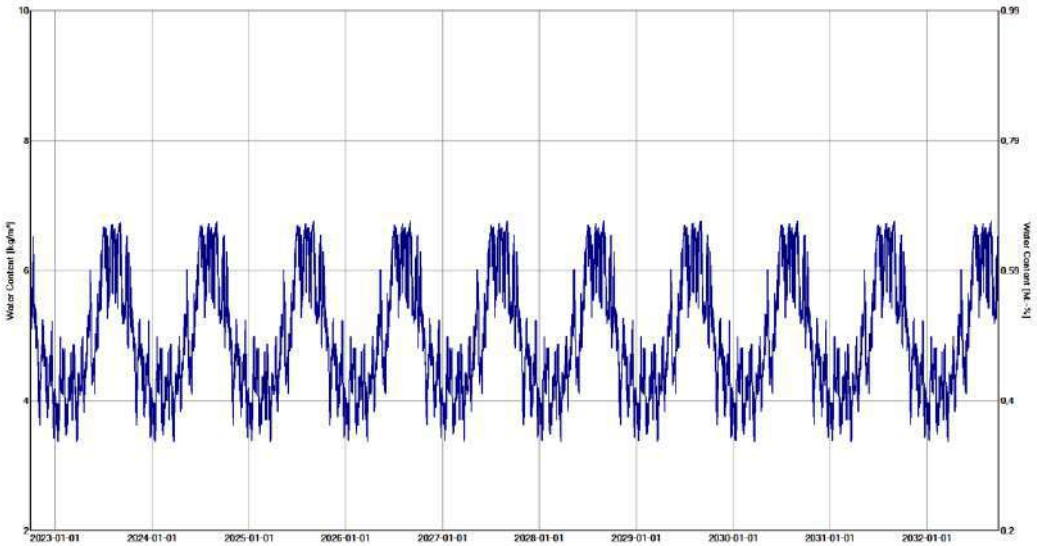


EcoCocon straw panel:



Even with a high moisture content assuemed for the construction phase, the straw panel dries out quickly and the water content remains below 13 M.-% all year round. It does not exceed this value over the course of the examined years either.

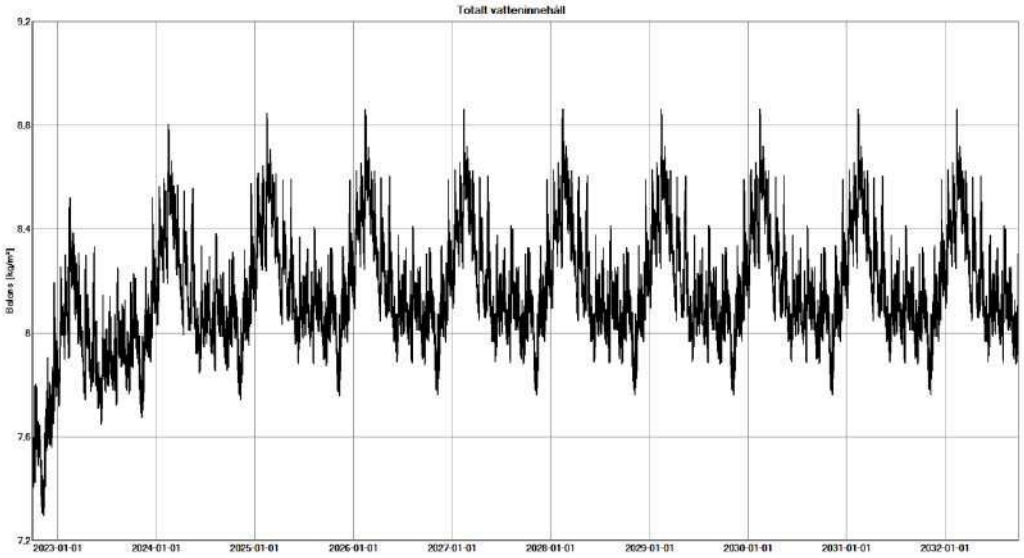
Plasterboard layer:



The moisture content here does not take on any harmful forms.

Wall type D

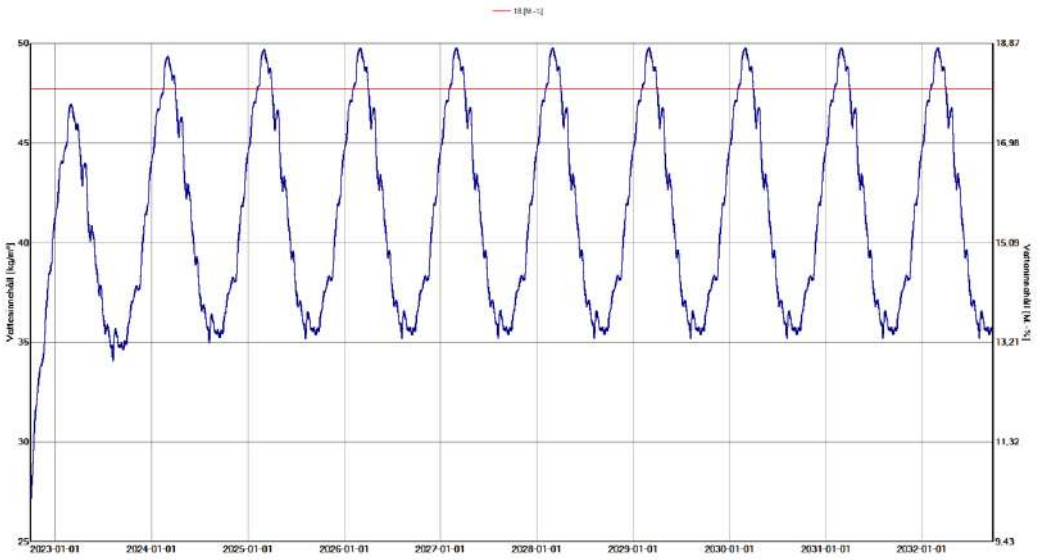
Entire wall



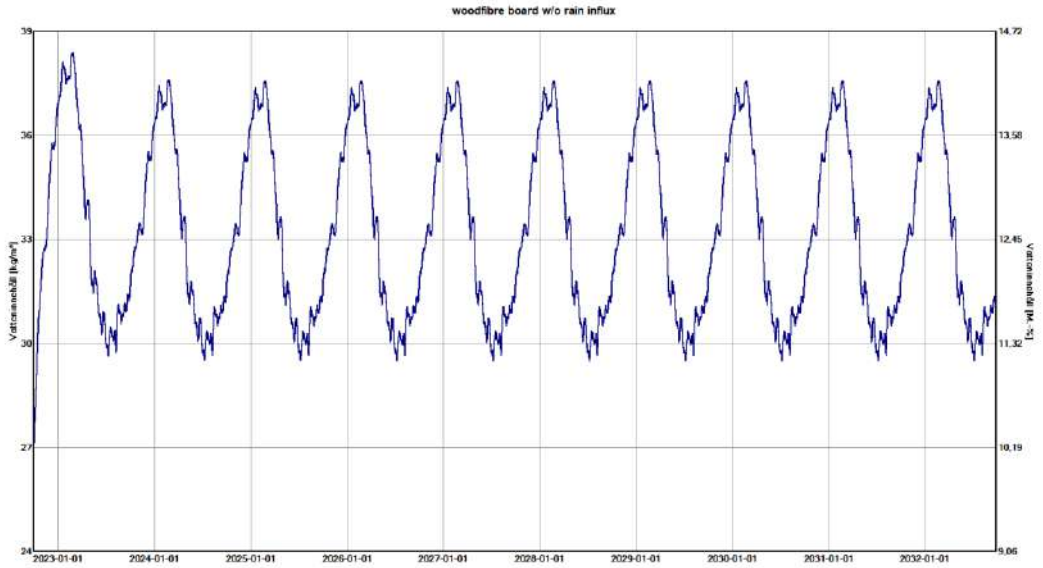
The simulation over 10 years shows that there is no further accumulation of moisture over the long term after the initial stabilisation period. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

Individual layers

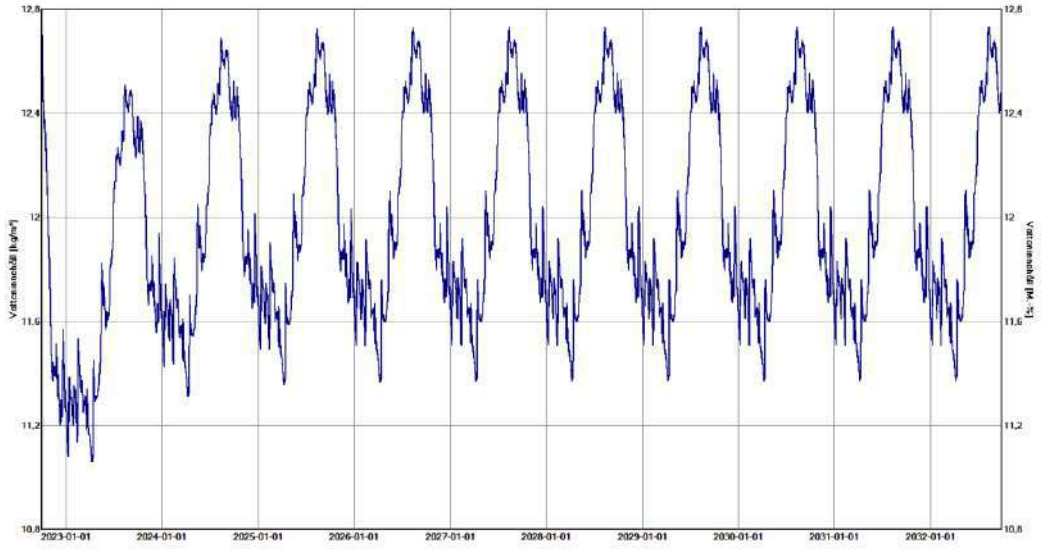
Wood fibre board behind the external render layer:



The woodfibre board including the 1% influx of rain partially reaches over the critical limit of 18 M.-%. Particular focus on watertightness would be required. Below, the results for woodfibre board *without* the additional "stress" of rainwater influx is shown – the water contents there remains well below the critical limit:

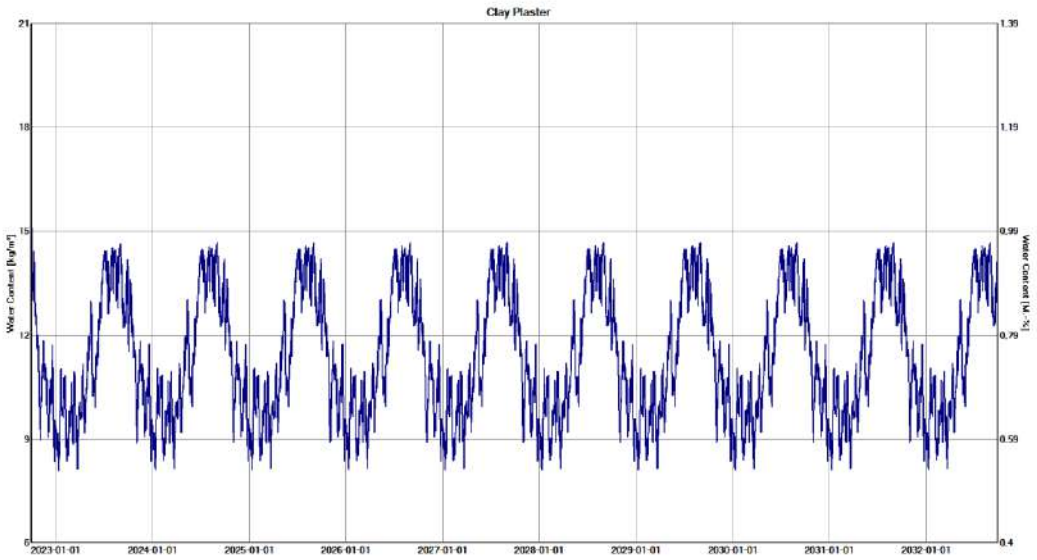


EcoCocon straw panel:



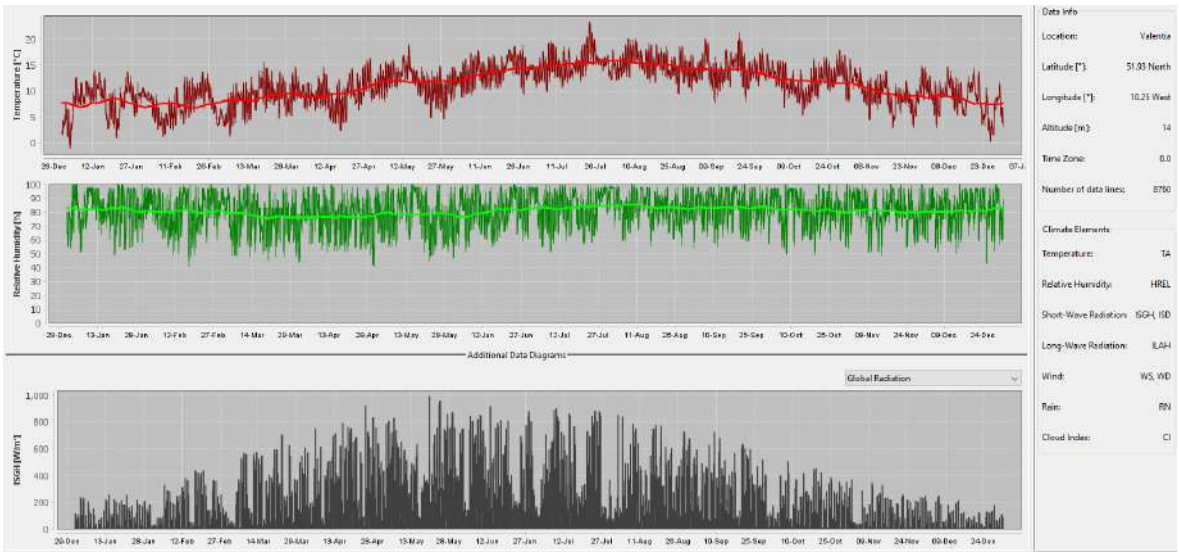
Even with a high moisture content assuemed for the construction phase, the straw panel dries out quickly and the water content remains below 13 M.-% all year round. It does not exceed this value over the course of the examined years either.

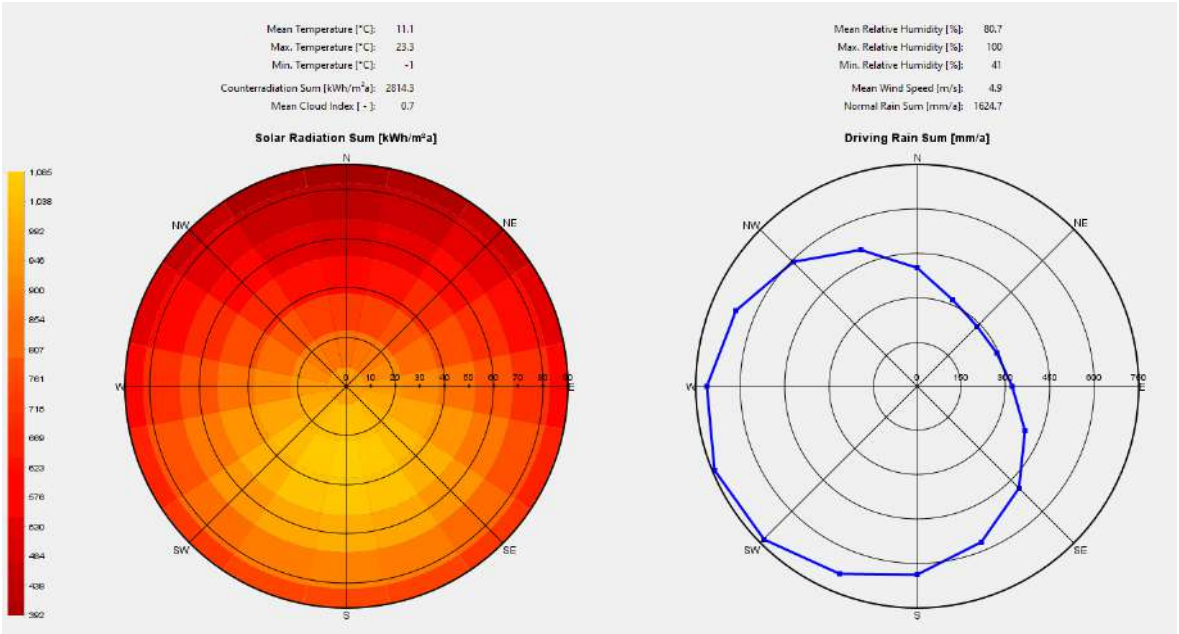
Interior clay plaster:



The moisture content here does not take on any harmful forms. As for wall types 1 and 2, the clay render layer rather helps to improve the indoor climate by buffering the humidity.

Outdoor climate Valentia (Ireland)





The direction of the strongest driving rain is West-southwest, but for ventilated facades, the northward orientation is decisive for these simulations and therefore has been applied. For stress-testing, 1% of the driving rain for an additional moisture source *behind* the weather membrane has been added in order to simulate water possibly seeping into the structure via small leaks, e.g., around the window installations. For rendered façades, West orientation has been applied. The driving rain is almost the same as for West-southwest, but there is less solar radiation – and therefore less drying potential. This will make the results even more on the safe side.

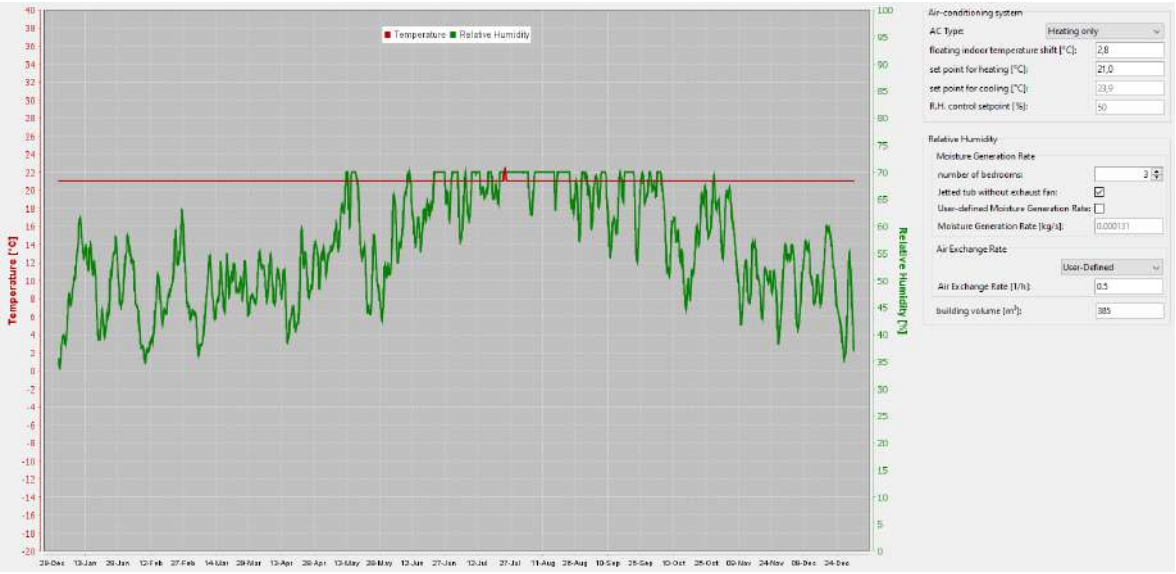
Indoor climate Valentia (Ireland)

The same model building was used for all simulations: a three-bedroom villa with 385 m³ interior volume.

A whirlpool bath without exhaust fan was added for possible additional moisture production - just to be on the safe side. An MVHR unit delivers 0.5 air changes per hour.

Airconditioning is only available as heating, no active cooling. The set point for heating is 21°C (typical value for SFH).

The indoor climate model was based on ASHRAE 160-2021 as this provided the possibilities to represent the above conditions. For Belmullet, it looks like this:

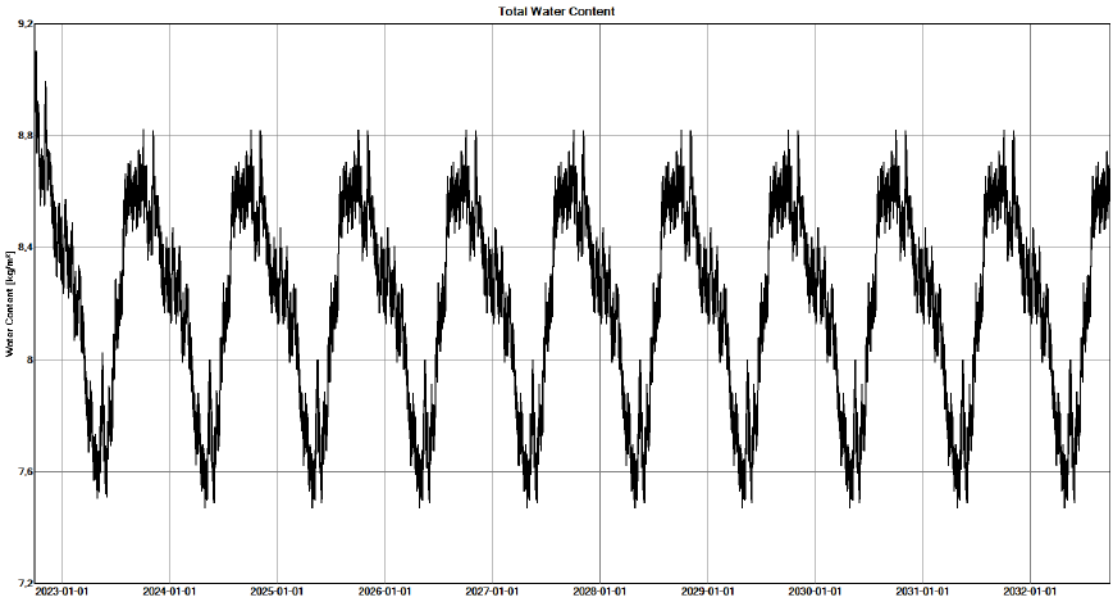


Results

The following diagrams show the water contents of the individual layers.

Wall type A

Entire wall

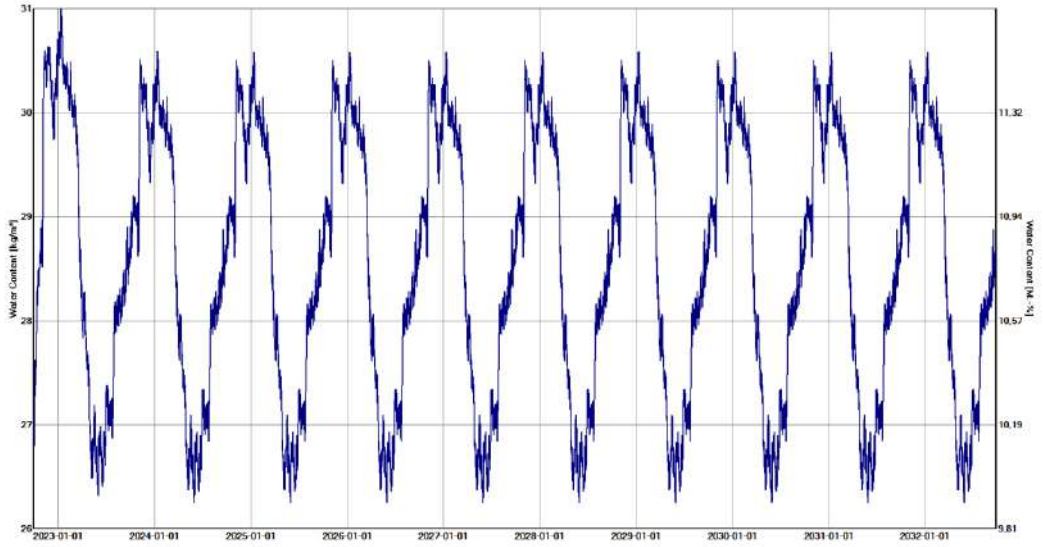


The simulation over 10 years shows that there is no accumulation of moisture over the long term (apart from the usual seasonal fluctuation). No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

For the simulation, 80 % relative humidity has been assumed for the materials built into the construction. As the house consists of prefabricated modules, there is even less risk of built-in moisture or leakage.

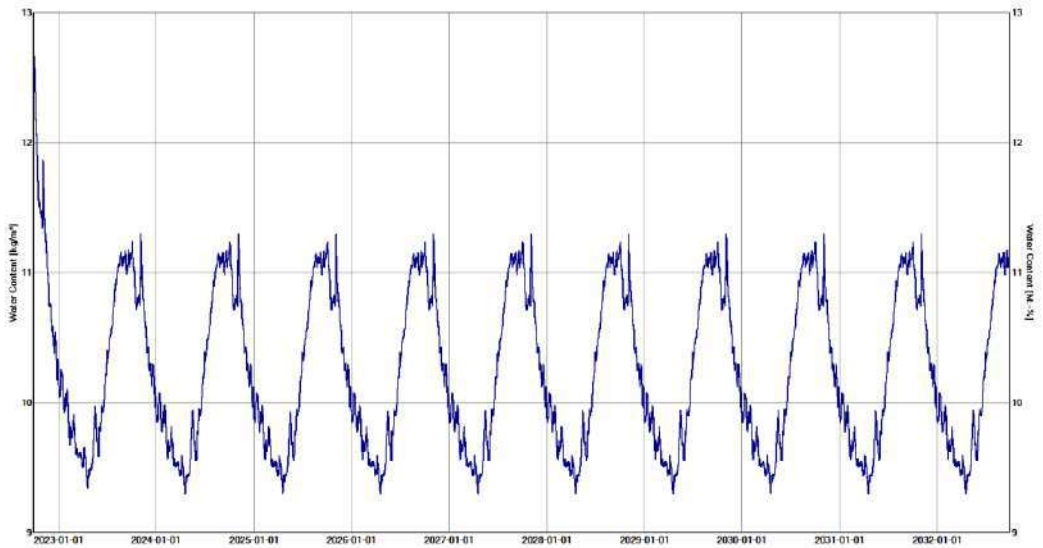
Individual layers

Woodfibre board behind the air gap:



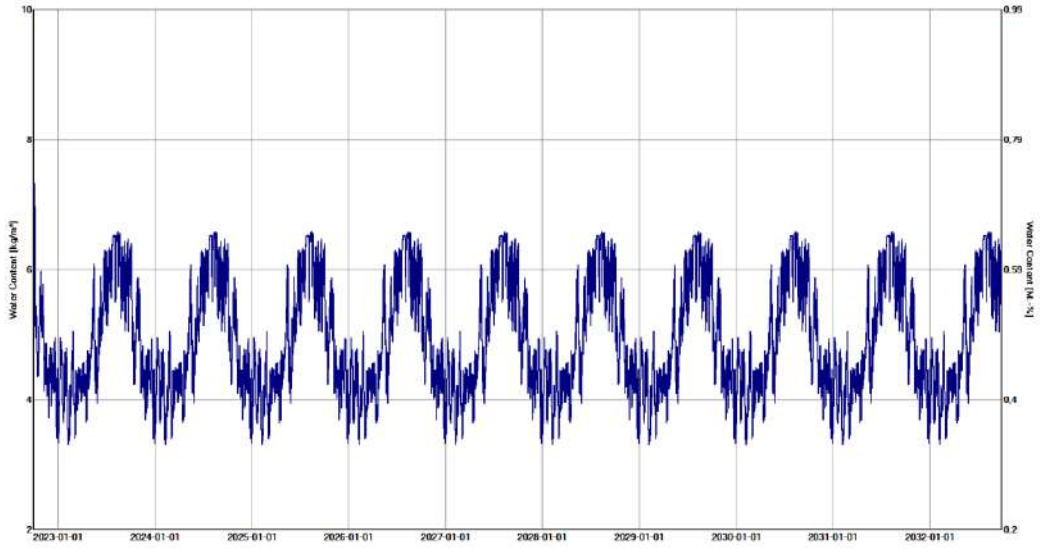
The woodfibre board has the ability to dry out and the relative humidity remains below 12 %, which is significantly below the critical limit.

EcoCocon straw panel:



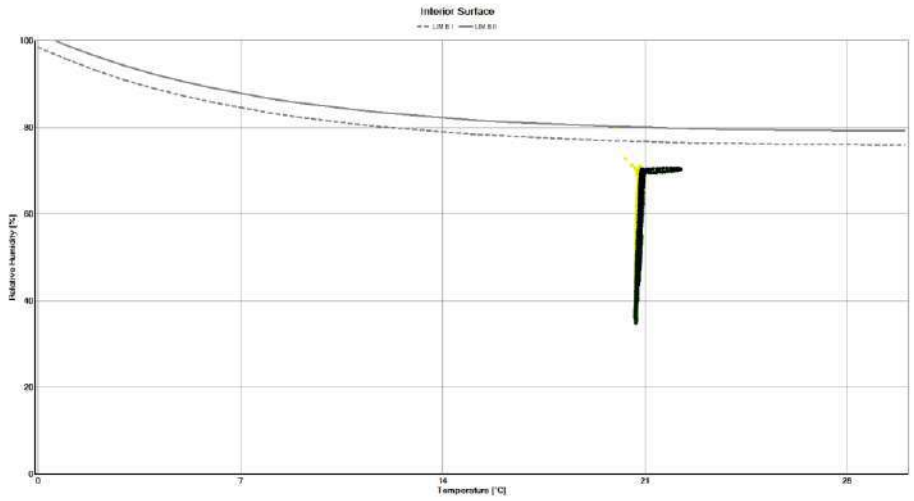
After the deliberately high setting at the beginning, the relative humidity drops immediately and continuously stays below 12 M.-%.

Plasterboard layer:



The moisture content does not take harmful forms here.

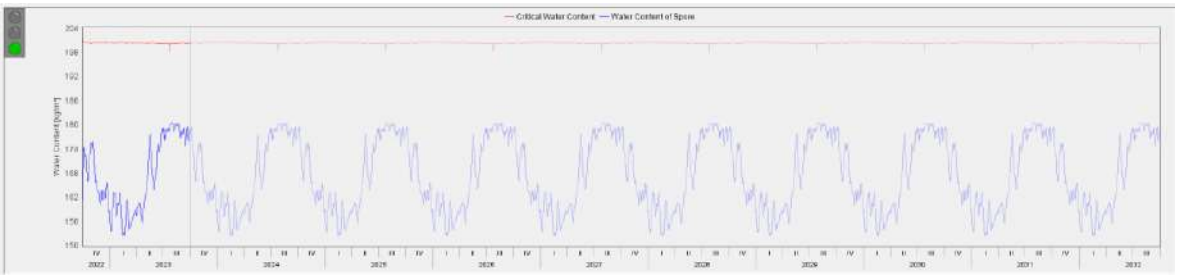
Isoplet on inner surface:



*) "LIM" stands for lowest isoplet for mould, "B" for construction.
The two scenarios I & II mean:
I = substrates that are readily biodegradable (e.g. wallpaper, dirt).
II = Substrates that are hardly biodegradable (e.g. mineral building materials).
Here, the interior surface examined is made of mineral plaster, i.e. No. II is relevant.

Each point represents one of the 87,600 calculations performed with respect to the combination of humidity and temperature and its potential to promote mould growth on the inside of the investigated exterior wall over a 10-year period. All are well below the two LIM threshold lines that represent two different scenarios for mould growth.

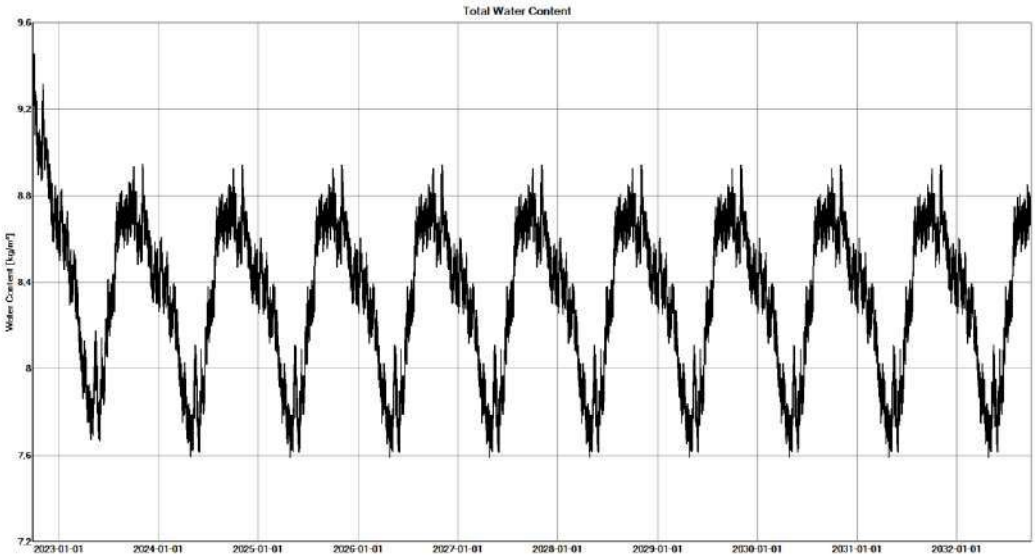
In addition to that, a study was carried out using *WUFI Bio 4.0*, a tool that examines spore formation by calculating their water content required for growth. The results show that the spores never reach a critical level - the traffic light shows *green*, i.e. approved, no problem:



Since the results regarding mould growth on the interior clay render surface are basically identical for all four wall types, the above graphs and comments are not included again for the remaining three wall types.

Wall type B

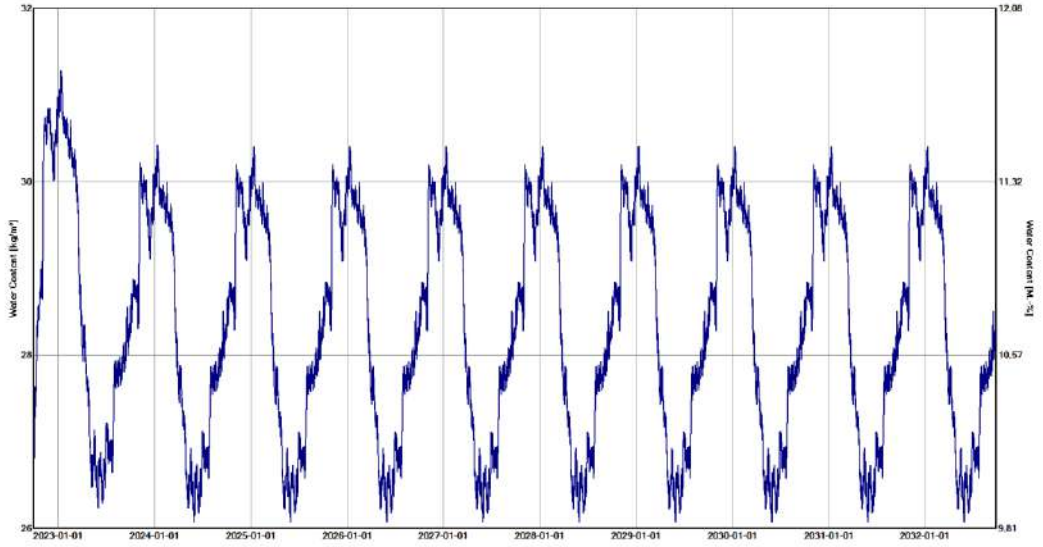
Entire wall



Even with built-in moisture content (80%), the entire wall structure dries out quite quickly. The simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

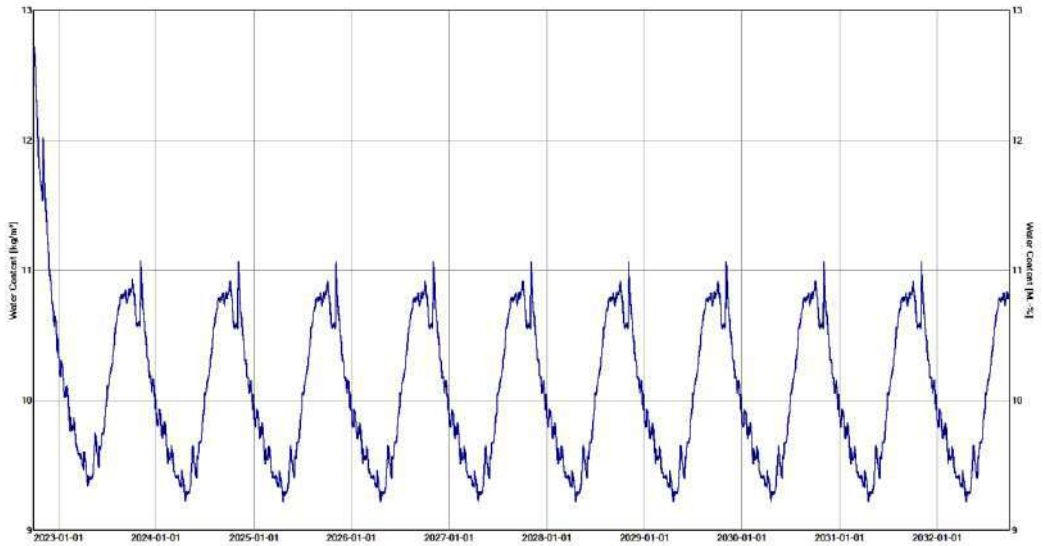
Individual layers

Woodfibre board behind the air gap:



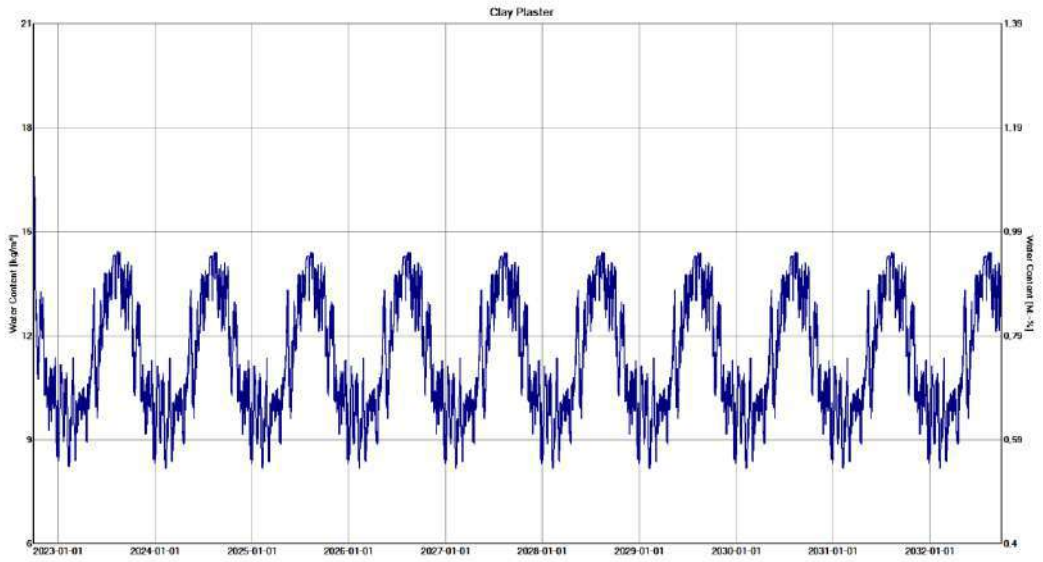
The woodfibre board has the ability to dry out and the relative humidity remains below 11 %, which is significantly below the critical limit.

EcoCocon straw panel



Even if an 80 % moisture content is assuemed for the construction phase, the straw panel dries out quickly and the water content remains below 12 M.-% all year round. It does not exceed this value over the course of the examined years either. After the initial steadying, the periodic variation remains the same.

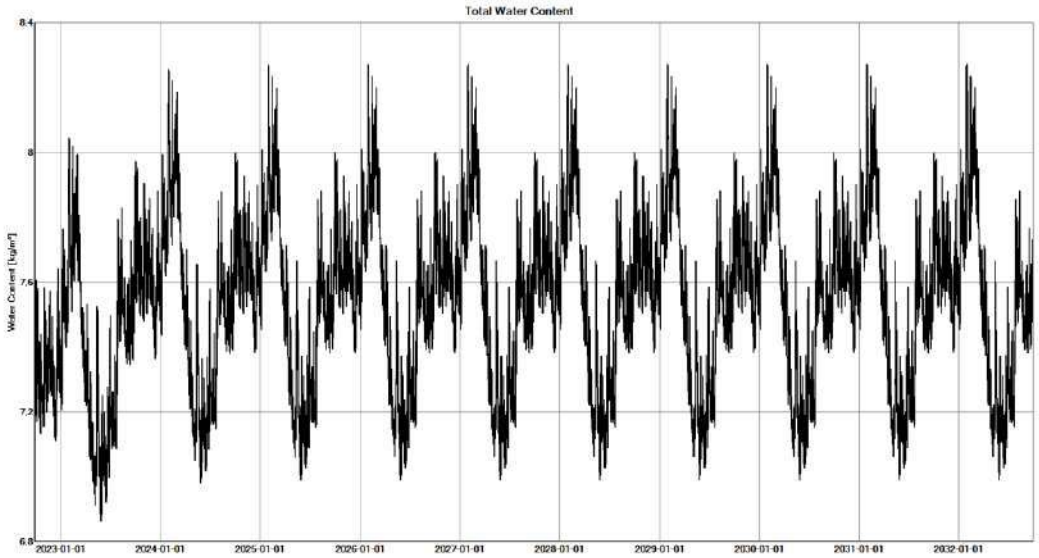
Interior clay paster:



The moisture content here does not take on any harmful forms. On the contrary: the clay render layer rather helps to improve the indoor climate by buffering the humidity.

Wall type C

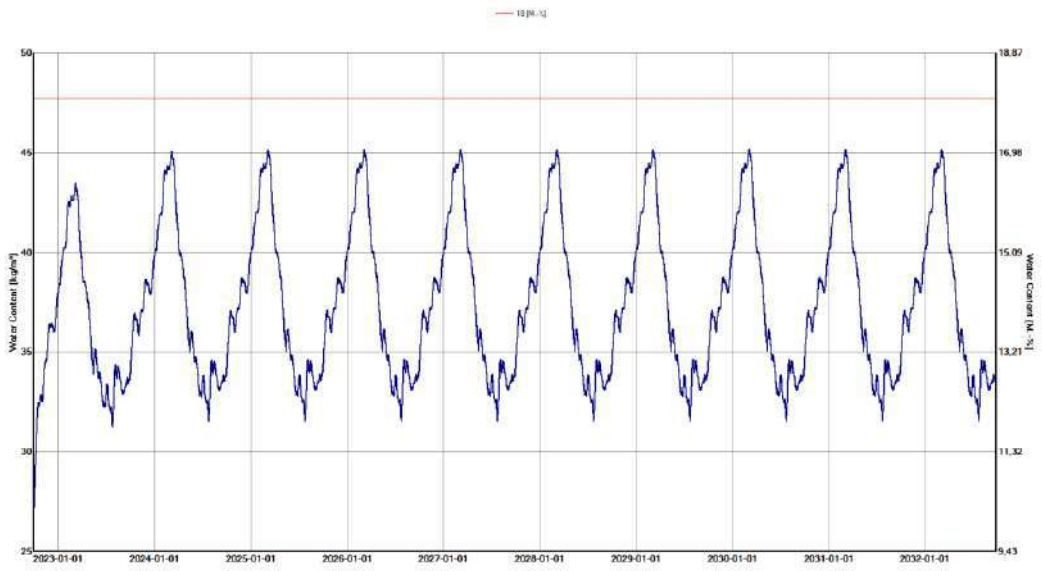
Entire wall



The simulation over 10 years shows that – after the initial stabilisation period - there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, would be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

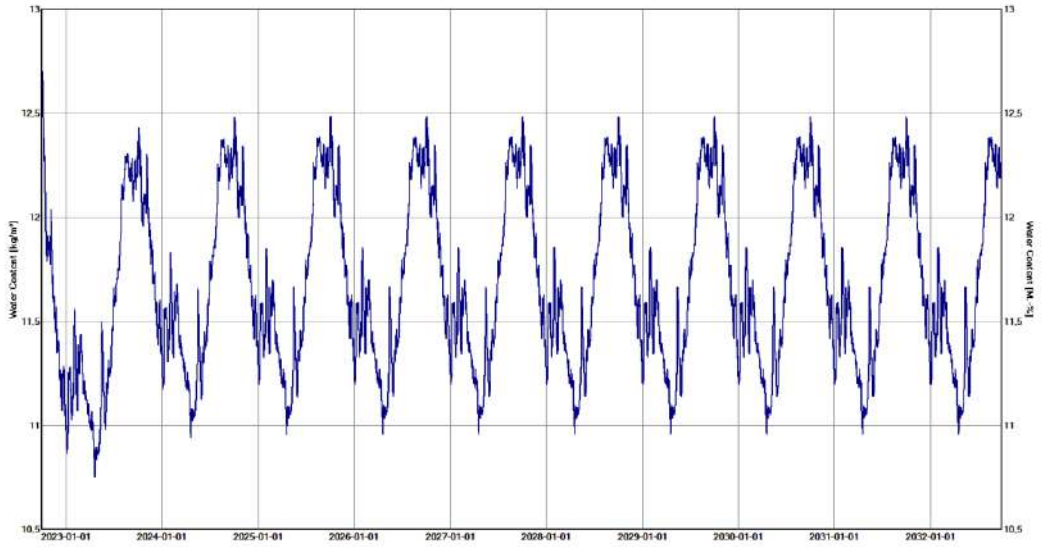
Individual layers

Wood fibre board behind the external render layer:



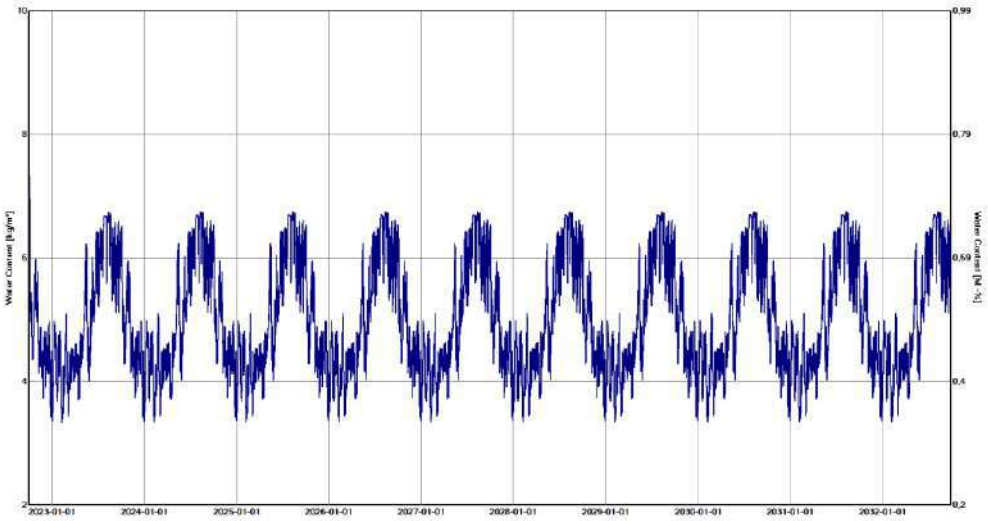
The relative humidity in the woodfibre board remains below 17 % - even with the additional stress through driving rain.

EcoCocon straw panel:



Even with a high moisture content assuemed for the construction phase, the straw panel dries out quickly and the water content remains below 12.5 M.-% all year round. It does not exceed this value over the course of the examined years either.

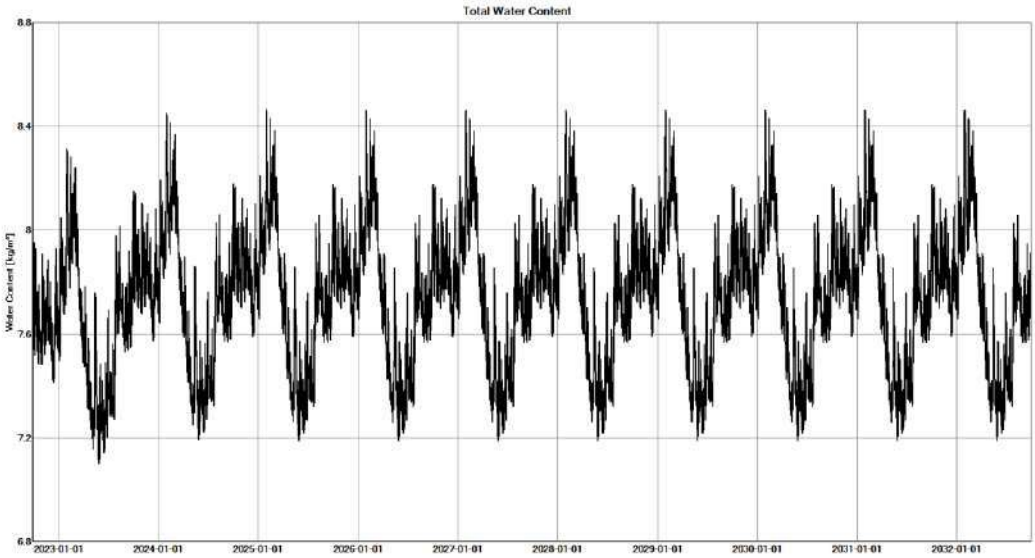
Plasterboard layer:



The moisture content here does not take on any harmful forms. As for wall types 1 and 2, the clay render layer rather helps to improve the indoor climate by buffering the humidity.

Wall type D

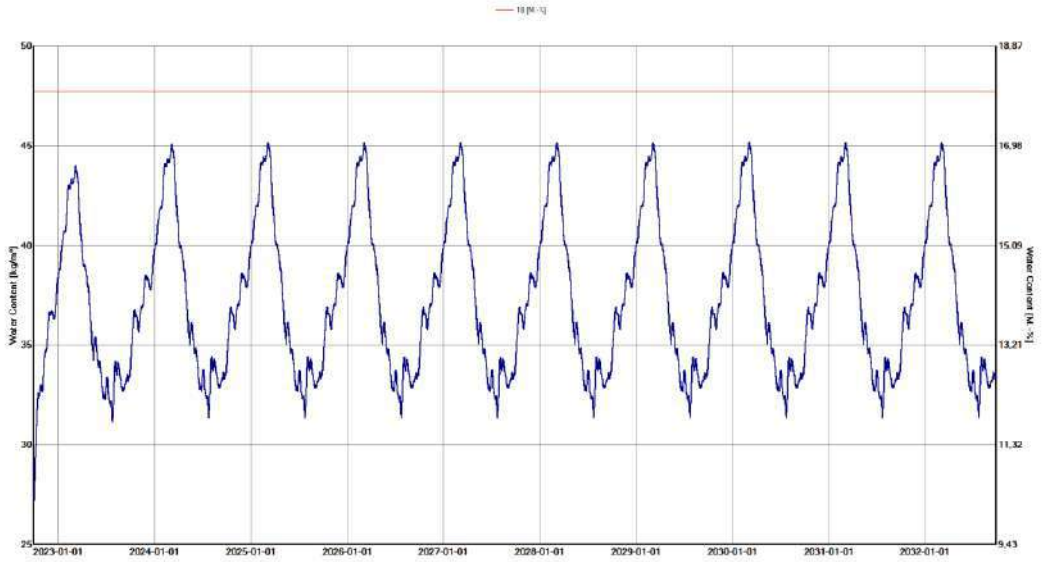
Entire wall



The simulation over 10 years shows that there is no accumulation of moisture over the long term – after the initial stabilisation period. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

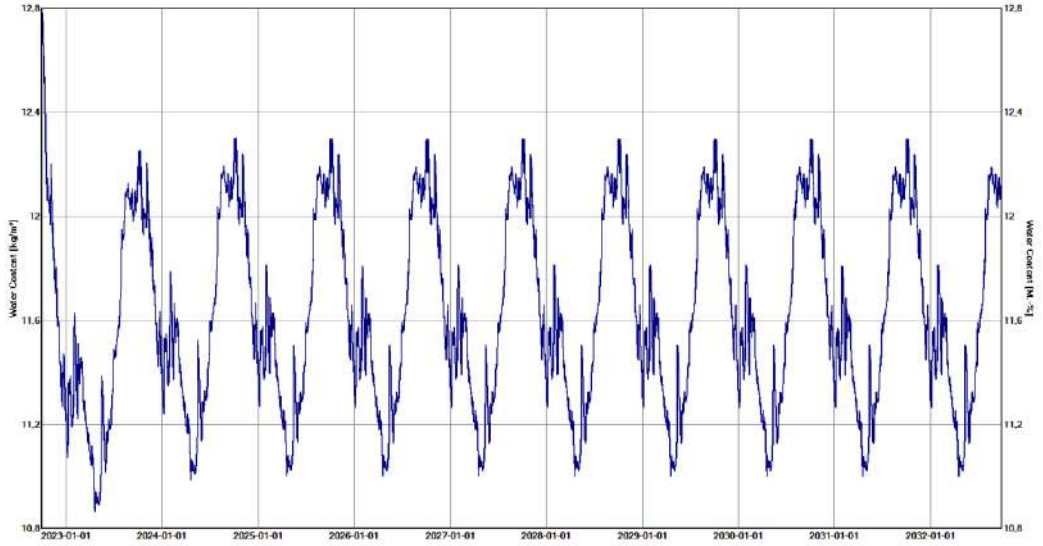
Individual layers

Woodfibre board behind the external render layer:



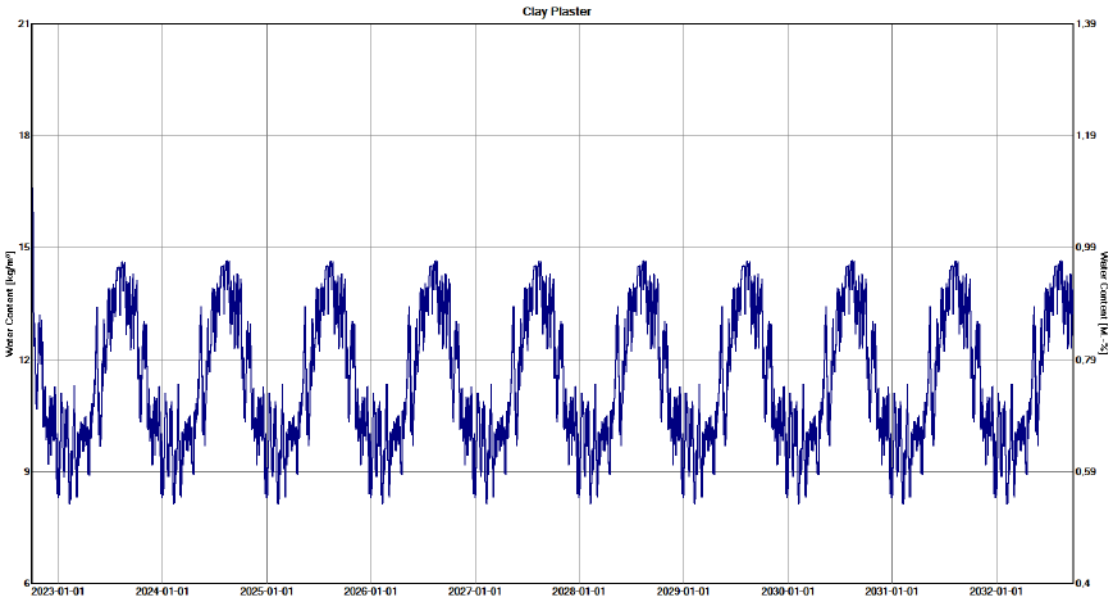
The woodfibre board - including the 1% influx of rain – never exceeds the critical limit of 18 M.-%.

EcoCocon straw panel:



Even with a high moisture content assuemed for the construction phase, the straw panel dries out quickly and the water content remains below 12.5 M.-% all year round. It does not exceed this value over the course of the examined years either.

Interior clay plaster:



The moisture content here does not take on any harmful forms. As for wall types B, the clay render layer rather helps to improve the indoor climate by buffering the humidity.

Summary

A simulation is only as good as its input data, including boundary conditions. The calculations were made with additional safety margins, namely an additional source of moisture indoors, 1% of driving rain was considered to leak into the structure - which can be prevented by proper construction – and a very low air exchange rate in the ventilation gap of the façade.

The simulation shows that the structure dries out quickly, even if it had 80 % humidity at the start of construction, or – depending on the wall type – at least remains stable in a safe state after an initial (slight) infiltration of moisture. There is a periodic accumulation and reduction of moisture in the individual layers, but this never reaches alarming proportions.

However, when applying these results, certain aspects must be taken into account:

1) The calculations are only related to the defined and specified boundary conditions and the named object and substructures and are not transferable, even if the structure is the same or similar.
2) In order for the calculation to be representative, accurate production is required and the contractor is responsible for consistently maintaining the specifications.
3) Airtightness and, ideally, airtightness testing, is a prerequisite.
4) The specified moisture contents for the materials, specifically for wood or wood-based products, must not be exceeded. Careful, clean and dry storage must be ensured.
5) The render on the rendered façades has been included with an A-value (coefficient of water absorption) of 0.1 kg/(m²·h$^{0.5}$), which needed for the appropriate control of the water contents in the woodfibre board behind it. This A-value needs to be maintained.

Tvärred, 2nd February 2023

Ingo Theoboldt
Building physicist, accredited certifier and designer for Passive Houses

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Passivhusbyrån Ingo Theoboldt

Tel: 0762-874024

Adress: Vasared 301, 523 94 Tvärred

E-post: info@passivhusbyran.se

Report

Miami
Hygrothermal Analysis (WUFI)

Version 1.0 - Updated 28.08.2013

eco cocon

Schäden an Gebäuden
Euro Zert Certification
Überwacht durch: SVG office GmbH
Alfred-Herrhausen-Straße 44 in 58455 Witten
Jörg Brandhorst
Sachverständiger
DIN EN ISO/IEC 17024:2012
Zertifizierungs-Nr.:
ZN - 20120928 - 0262
Gültig bis 10/2017
Personen-zertifizierter Sachverständiger

Bjorn Kierulf
Createrra s.r.o.
Hruby Sur 15

90301 Senec
Slovak Republic

Zertifizierter Sachverständiger
nach DIN EN ISO/ISC 17024:2012,
Zertif.-Nr : ZN – 20120928-0262
für Schäden an Gebäuden,
Innenraumschadstoffen,
Bauphysik, Fenstermontagen,
energetische Bewertung von
Gebäuden und Energieeffizienz

Bonn, den 28.08.2013

Straw Bale House

Dear Mr. Bjorn Kierulf,

The calculations with WUFI have been done under the following conditions:

- **climate data: Miami, cold year**
- humidity of the materials: straw < 17%
- indoor climate: high humidity loads (bathrooms or similar as maximal humidity)
- exterior wall: southeast (main wheater side)

1) Wall construction with 4mm plaster

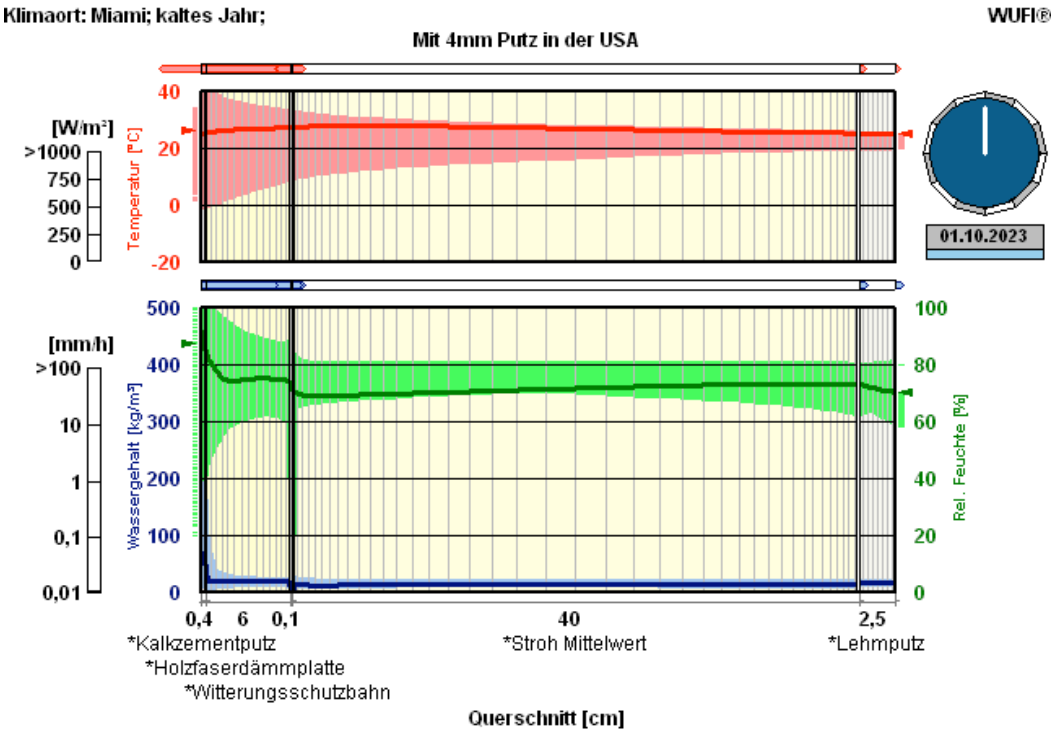
Construction from inside to outside:

clay plaster 25mm
straw 400mm
roofing membrane SD: 0.2 m
wood fibre insulation board 040 60mm
exterior plaster 4mm

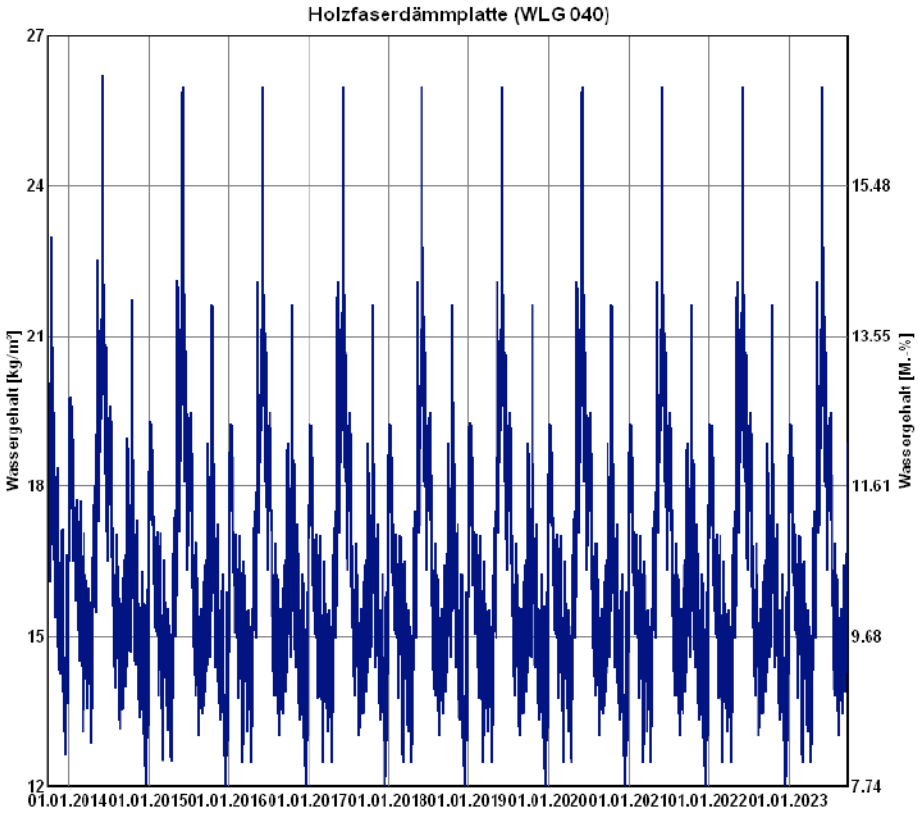
The exterior plaster with a w-value (coefficient of water absorption) of <0.1 kg/m2 * h.

Under these conditions, the calculations for the relevant components have revealed the following:

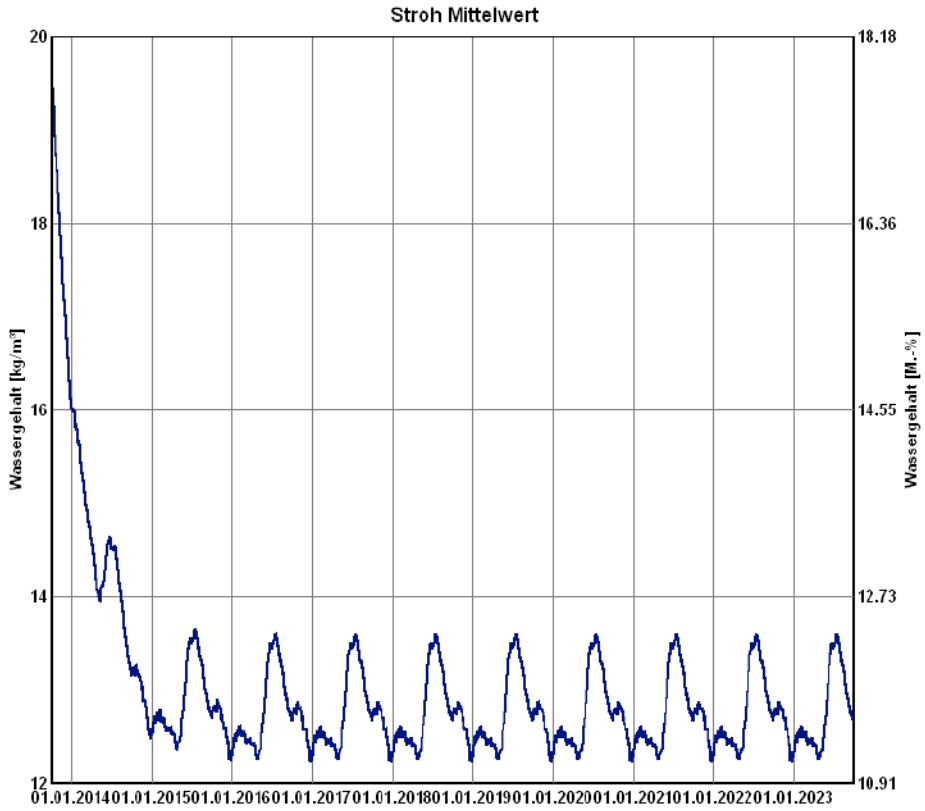
Whole construction:



Wood fibre insulation board:



Straw bale:



This construction can be realiseded under the following conditions:

- The exterior plaster must have permanently a w-value of <0.1 kg/m2 * h.
- The w-value must be frequently controlled. If the value increases over 0.15 kg/m2 *h the construction is not longer realisable.

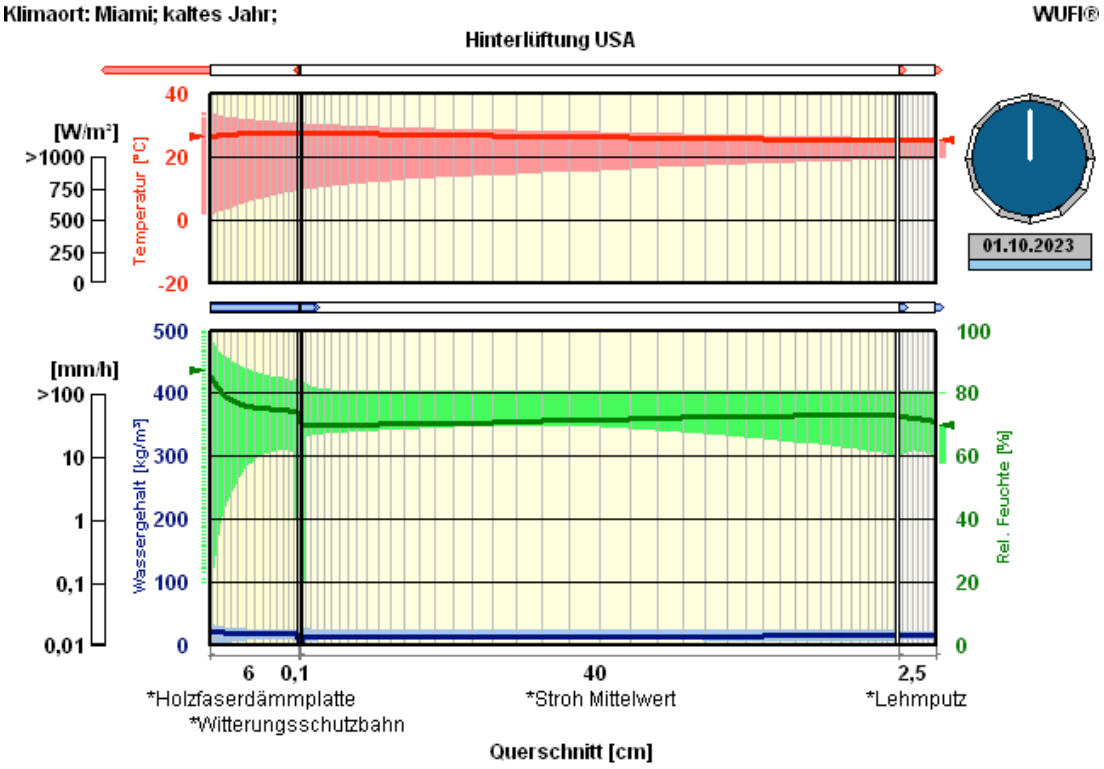
2) Construction with ventilated facade:

The construction with the ventilated facade, without rainfall on the wood fibre insulation board, has the following results:

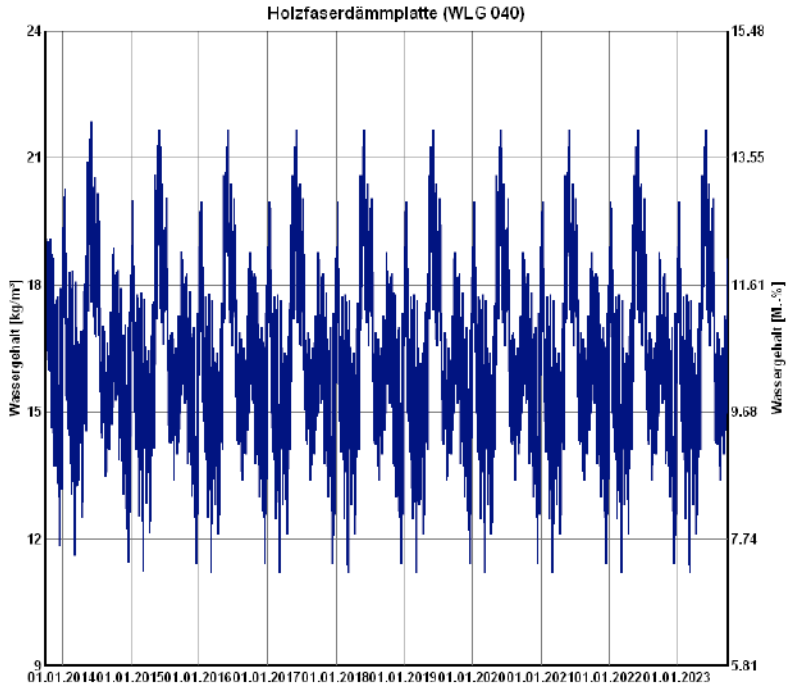
Construction from inside to outside:

clay plaster 25mm
straw 400mm
roofing Membrane SD: 0.2 m
wood fibre insulation board 040 60mm
ventilated facade

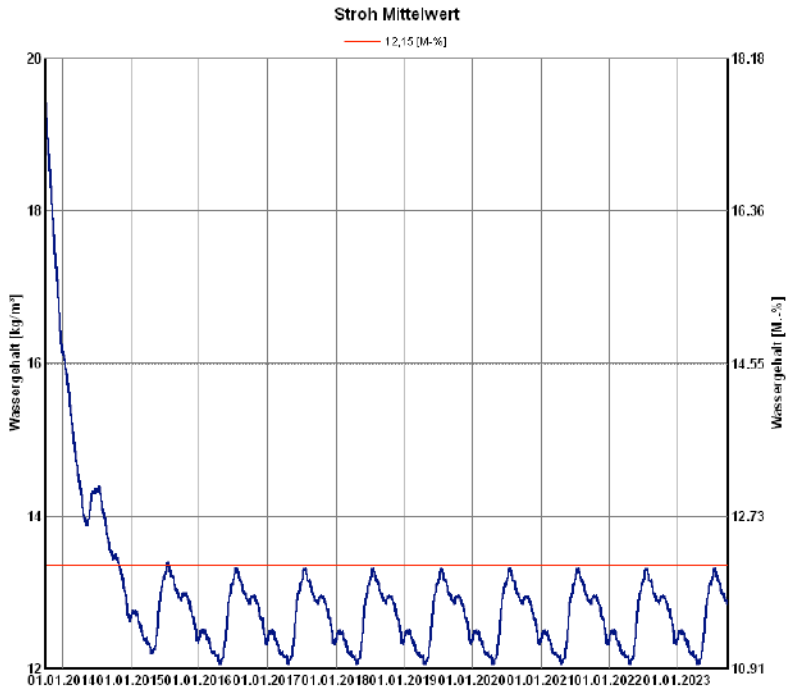
Whole construction:



Wood fibre insulation board:



Straw bale:



The construction can be realised.

The same construction could also be realised without the roofing membrane, if the vapor tightness is ensured on the inside.

Kind regards

Michael Brandhorst

Annotation:

The values for the straw bale are average values, of all existent analysis. The following values has been used for he calculations:

raw density	100,0	kg/m^3
porosity	0,9	m^3/m^3
thermal Capacity	2000	J/kgK
thermal Conductivity	0,045	W/mK
diffusion resistance coefficent	1,3	-

Due to their inhomogeneity, exacte values for straw bales are not definable. The above-mentioned calculations present only refenrence values.

Report

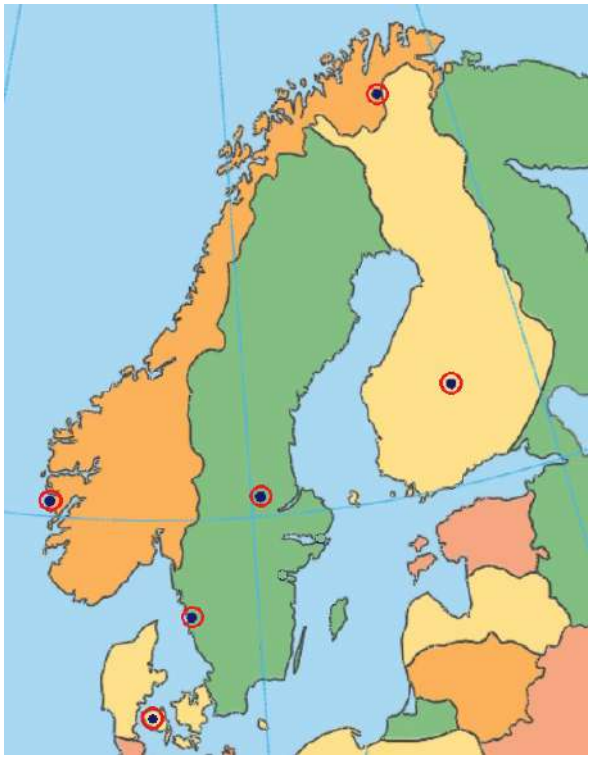
Scandinavia
Hygrothermal Analysis (WUFI)

Version 1.0 - Updated 14.02.2023

eco cocon

Hygrothermal analysis of the *EcoCocon* wall system in different Scandinavian climatic conditions

(as of 14 February 2023)



Passivhusbyrån Ingo Theoboldt

Tel: +46 (0) 762 874 024

Address: Vasared 301, 523 94 Tvärred, Sweden

E-mail: info@passivhusbyran.se

Content

Background and mission

Passivhusbyrån has been commissioned to produce a hygrothermal analysis of *EcoCocon's* building systems for six different Scandinavian locations (climates) and eleven different wall types. The locations are Borlänge (Sweden), Gothenburg (Sweden), Bergen (Norway), Karasjok (Norway), Jyväskylä (Finland) and Aarslev (Denmark).

Climatic conditions and the different types of walls are described below (input data).

The aim of the analysis is to obtain results, based on the input data, and to examine the performance and long-term moisture safety. In order to get a good overview of the effects under the different Scandinavian climatic conditions, the locations were chosen with a wide spread (see map on the front page).

Reservations

The calculations and simulations for this project are based on the submitted sketches and input data received between 2022-06-09 and 2023-02-03.
Climate data needed for the simulations are obtained from the following sources: the Lund University of Technology (Borlänge and Gothenburg), the Norwegian University of Science and Technology (Bergen and Karasjok), the Finnish Meteorological Institute (Jyväskylä), and the Meteonorm-8 programme for Aarslev.

Hygrothermal analysis

The simulation was done with *WUFI 6.5 Pro*, which allows hourly dynamic simulation for an unlimited number of years. During the process, the following parameters are considered, among others:

Material properties - these quantities describe the hygrothermal behaviour of the materials to be examined: bulk density [kg/m³], porosity [m³/m³], specific heat capacity [J/kg·K], dry thermal conductivity [W/m·K], dry water vapour diffusion resistance, moisture storage function [kg/m³], and liquid transport coefficient of suction and redistribution [m²/s] (w-value). If applicable, moisture-dependent thermal conductivity [W/m·K] and water vapour diffusion resistance number are also included. The weatherproofing membrane used in all simulations has a sd-value of 0.05 m, and wall type M has an additional vapour retarder with a sd-value of 6.45 m.

Climate data - these quantities describe the boundary conditions acting on the internal or external surface of the building component: rainfall load on the surface [ltr/m²·h], depending on the slope and orientation of the component, shortwave radiant flux density (solar) [W/m²], depending on the slope and orientation of the component, outdoor air temperature [°C], outdoor air relative humidity [0...100 %], indoor air temperature [°C], indoor air relative humidity [0...100 %] and average air pressure [hPa] during the calculation period.

Input data

Construction of wall type A (used in all places except Karasjok):

Materials:

	- Scandinavian spruce transverse direction	0.025 m
	- Air Layer	0.05 m
	- wood fibre board	0.06 m
	- weather resistive barrier (sd=0,05m)	0.00 m
	- EcoCocon straw bales	0.4 m
	- Clay Plaster	0.025 m

Construction of wall type B (used in all places except Karasjok):

Materials:

	- Scandinavian spruce transverse direction	0.025 m
	- Air Layer	0.05 m
	- wood fibre board	0.06 m
	- weather resistive barrier (sd=0,05m)	0.0 m
	- EcoCocon straw bales	0.4 m
	- plasterboard	0.013 m

Construction of wall type C (used in all locations except Karasjok):

Materials:

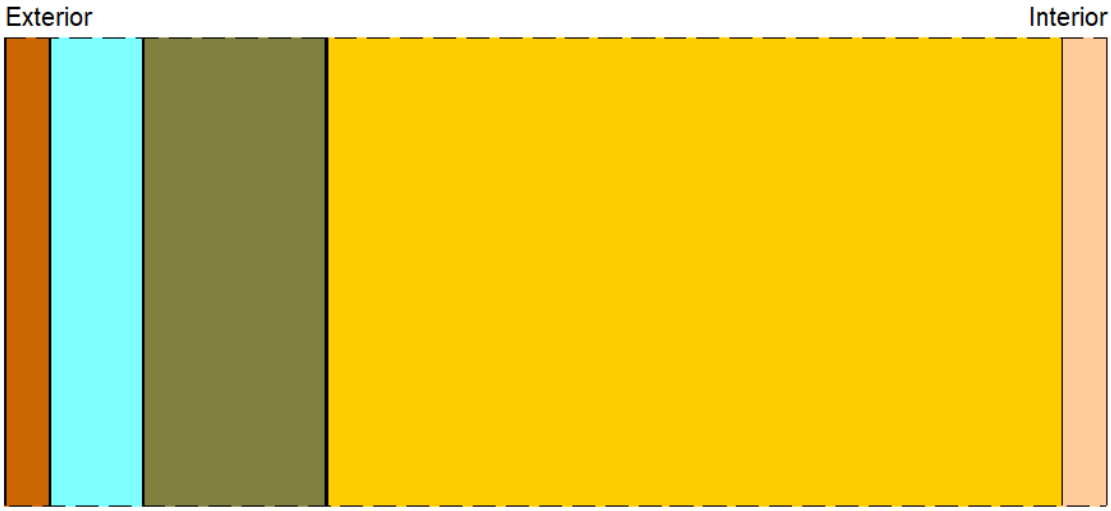
	- Mineral Plaster	0.008 m
	- wood fibre board	0.06 m
	- weather resistive barrier (sd=0,05m)	0.0 m
	- EcoCocon straw bales	0.4 m
	- Clay Plaster	0.025 m

Construction of wall type D (used in all locations except Karasjok):

Materials:

- Mineral Plaster	0.008 m
- wood fibre board 60mm	0.06 m
- weather resistive barrier (sd=0,05m)	0.0 m
- EcoCocon straw bales	0.4 m
- plasterboard	0.013 m

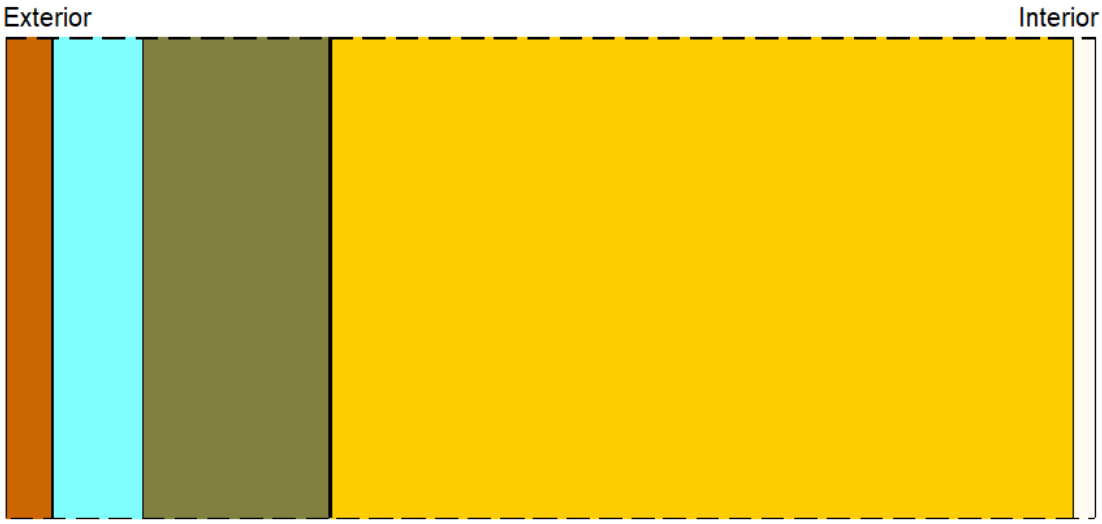
Construction of wall type E (used only in Karasjok calculations):



Material:

- Scandinavian spruce, tranverse direction	0.025 m
- Air layer	0.05 m
- Wood fibre board	0.1 m
- Weather resistive barrier (sd = 0.05 m)	0.001 m
- EcoCocon straw panel	0.4 m
- Clay plaster	0.025 m

Construction of wall type F (used only in Karasjok calculations):



Material:

- Scandinavian spruce, tranverse direction	0.025 m
- Air layer	0.05 m
- Wood fibre board	0.1 m
- Weather resistive barrier (sd = 0.05 m)	0.001 m
- EcoCocon straw panel	0.4 m
- Plaster board	0.013 m

Construction of wall type G (used only in Karasjok calculations):

Materials:

	- Mineral Plaster	0.008 m
	- wood fibre board	0.1 m
	- weather resistive barrier (sd=0,05m)	0.0 m
	- EcoCocon straw bales	0.4 m
	- Clay Plaster	0.025 m

Construction of wall type H (used only for Karasjok calculations):

Materials:

	- Mineral Plaster	0,008 m
	- wood fibre board	0,1 m
	- weather resistive barrier (sd=0,05m)	0,0 m
	- EcoCocon straw bales	0,4 m
	- plasterboard	0,013 m

Construction of wall type J (only used in Aarslev's calculations):

Materials:

- Scandinavian spruce transverse direction	0.025 m
- Air Layer	0.05 m
- wood fibre board	0.025 m
- weather resistive barrier (sd=0,05m)	0.00 m
- EcoCocon straw bales	0.4 m
- Clay Plaster	0.025 m

Construction of wall type K (only used in Aarslev's calculations):

Materials:

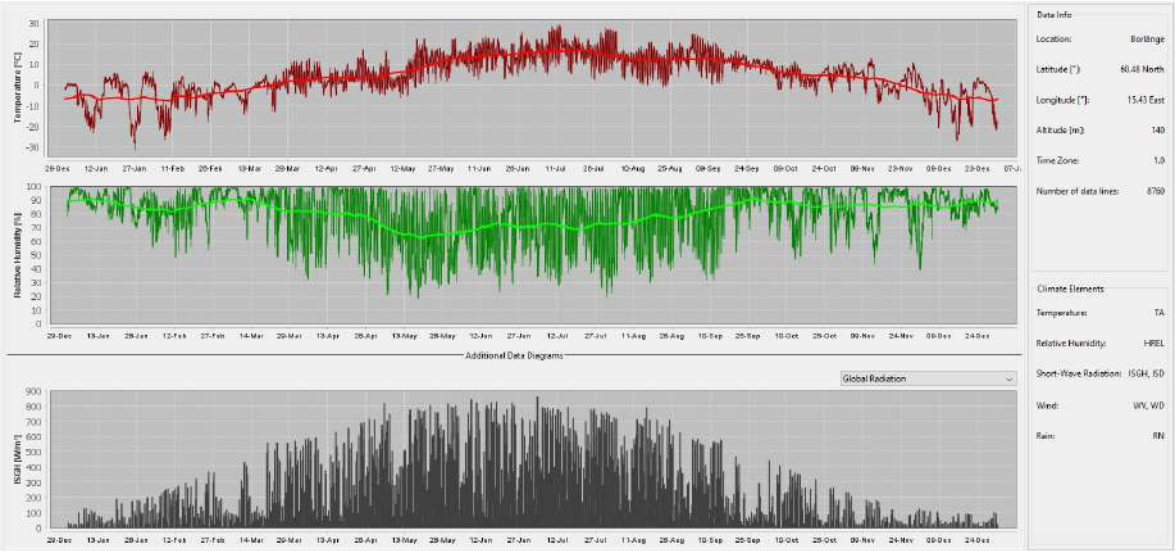
- Scandinavian spruce transverse direction	0.025 m
- Air Layer	0.05 m
- wood fibre board	0.025 m
- weather resistive barrier (sd=0,05m)	0.0 m
- EcoCocon straw bales	0.4 m
- plasterboard	0.013 m

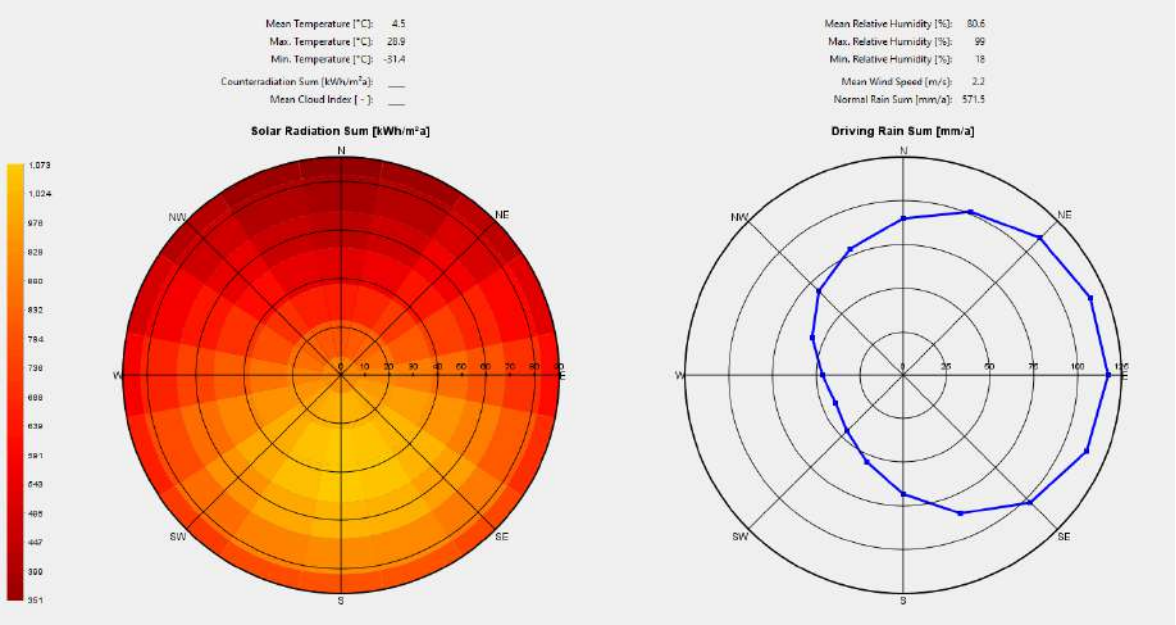
Construction of wall type M (only used in Aarslev's calculations):

Materials:

- Scandinavian spruce transverse direction	0,025 m
- Air Layer	0,052 m
- Weatherboard 365	0,01 m
- OSB	0,012 m
- Weather resistive barrier (sd=0,05m)	0,001 m
- EcoCocon straw panel	0,4 m
- Vapour retarder	0,001 m
- Wood fibre board	0,045 m
- OSB	0,012 m
- Plaster board	0,013 m

Outdoor climate Borlänge (Sweden)





The direction with the most driving rain is east. There is also only moderate solar radiation, with lower drying capacity than that to the south. For analyses of plastered walls, the north-east orientation is used, as there is still a lot of driving rain there and also less drying from solar radiation. For ventilated facades, northward is always the decisive orientation.

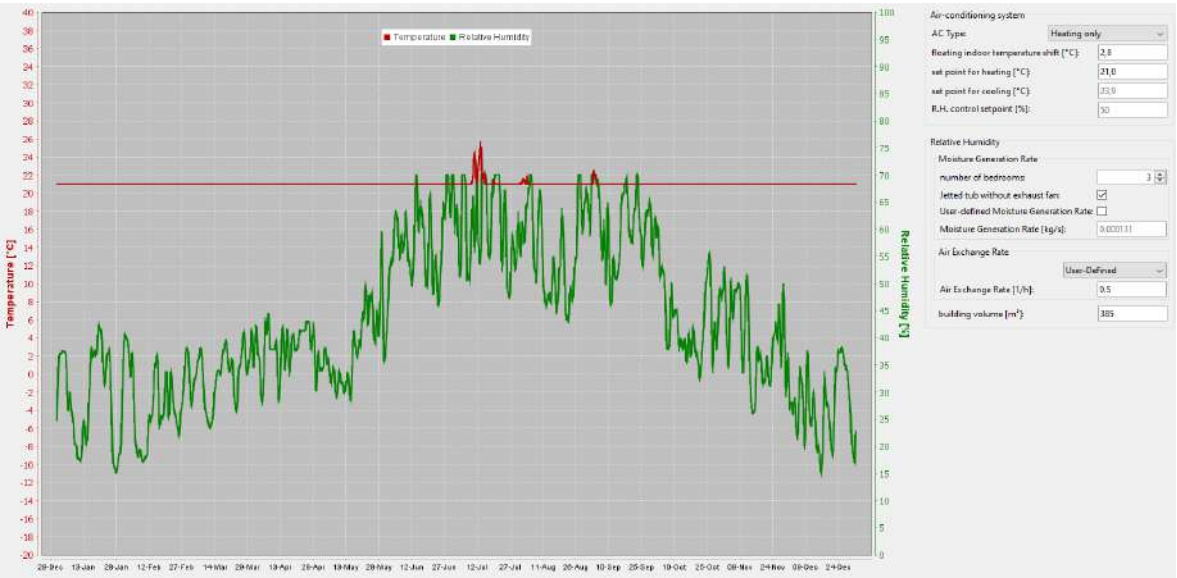
Indoor climate Borlänge

The same model building was used for all simulations: a three-bedroom villa with 385 m³ interior volume.

A ventilation unit delivers 0.5 air exchanges per hour. A whirlpool bath without (additional) exhaust fan was added for slightly higher humidity production - just to be on the safe side.

Airconditioning is only available in the form of heating, no active cooling and dehumidification. The set point for heating is 21°C (standard value according to BEN/BBR).

The indoor climate model was based on *ASHRAE 160-2021* as this provided the means to represent the above conditions. For Borlänge it looks like this:

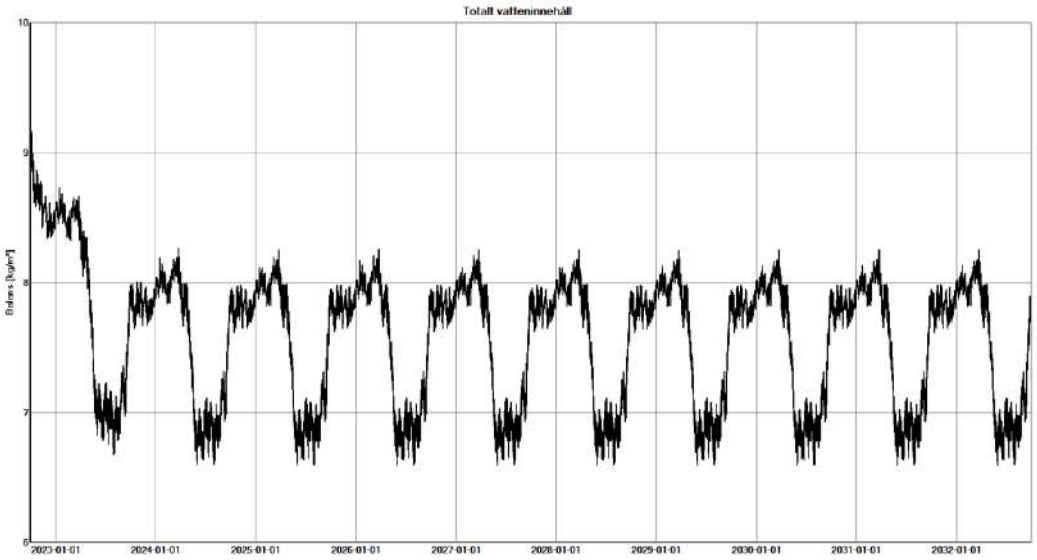


Results Borlänge

The following diagram shows the water content in total and in the individual layers.

Wall type A - ventilated facade, plaster on the inside

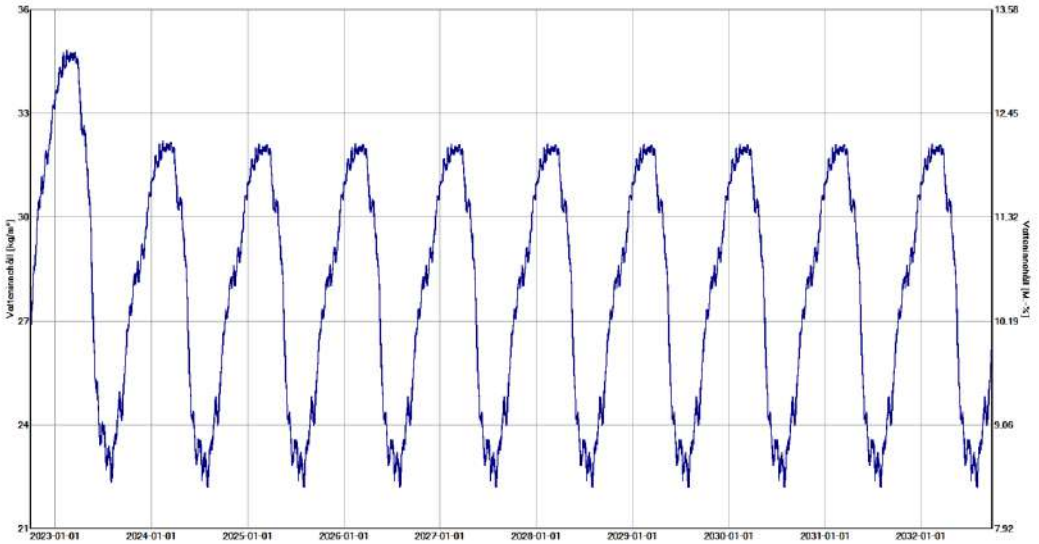
<u>The whole wall</u>



Even with high built-in moisture content (assumed at 80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

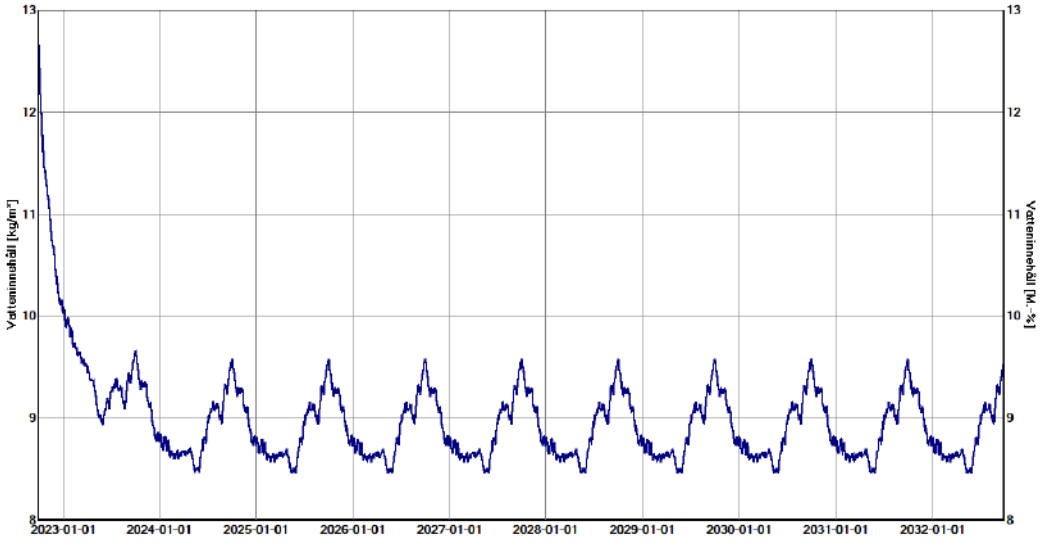
Single layers

Wood fibre behind the air gap:



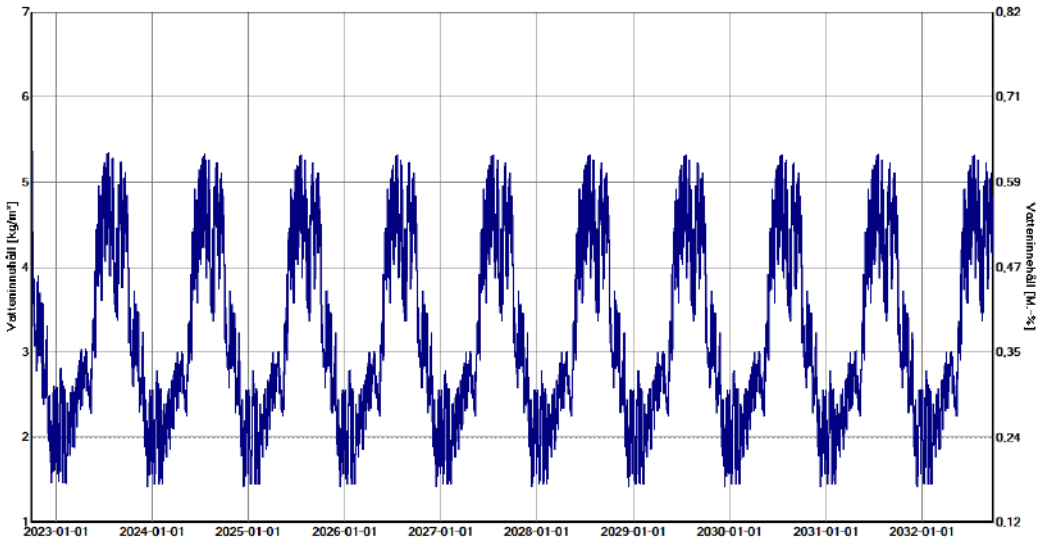
The wood fibreboard has the chance to dry out and the moisture content is always below 13 M.-% and thus far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays well below 10 M.-% all the time.

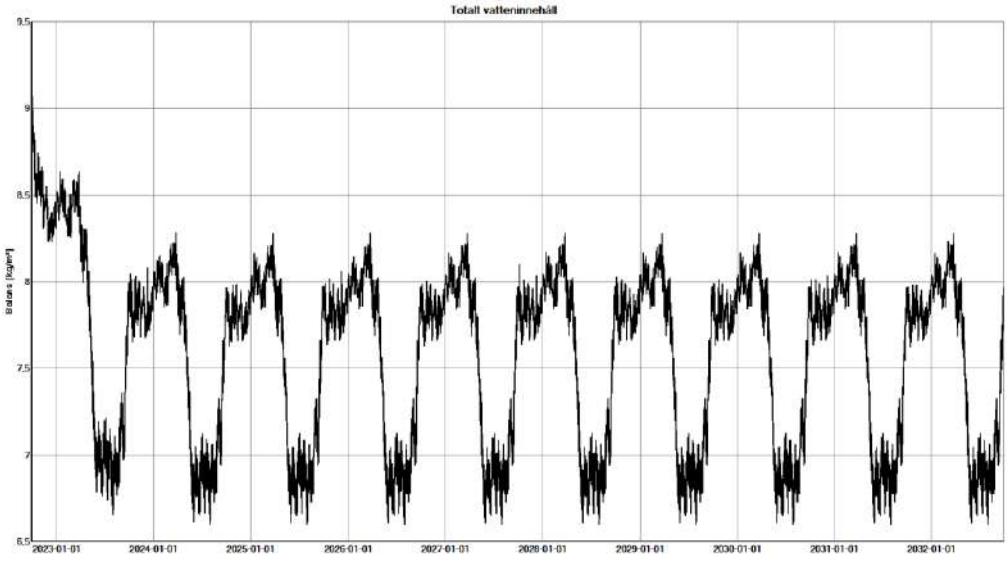
Plaster layer:



The moisture content does not take any harmful forms here. On the contrary: the layer helps to improve the indoor climate by buffering the humidity.

Wall type B - ventilated facade, plasterboard on the inside

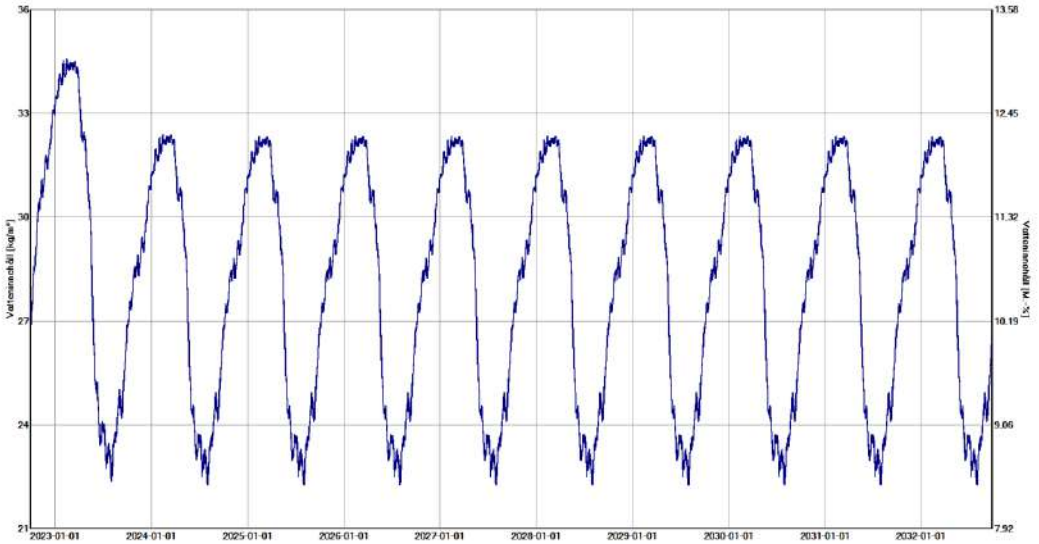
<u>The whole wall</u>



Even with a lot of built-in moisture, the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

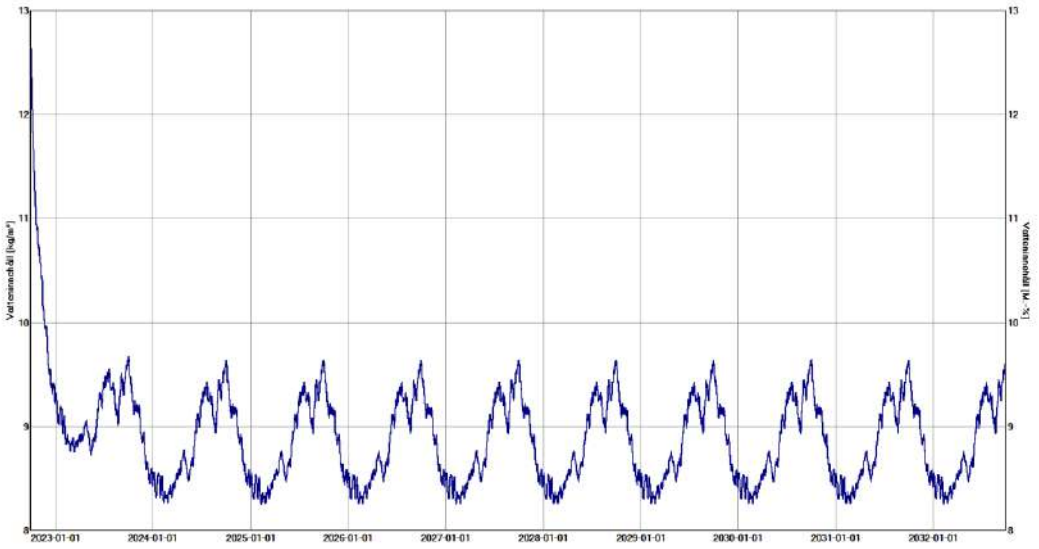
Single layers

Wood fibre behind the air gap:



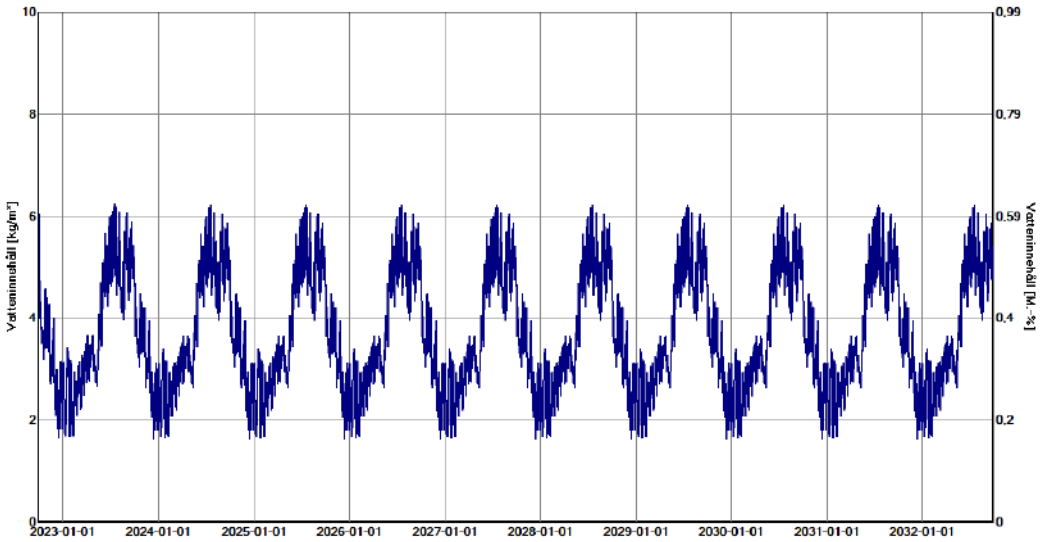
The wood fibreboard has the chance to dry out and the moisture content is always below 13 M.-% and thus far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays well below 10 M.-% all the time.

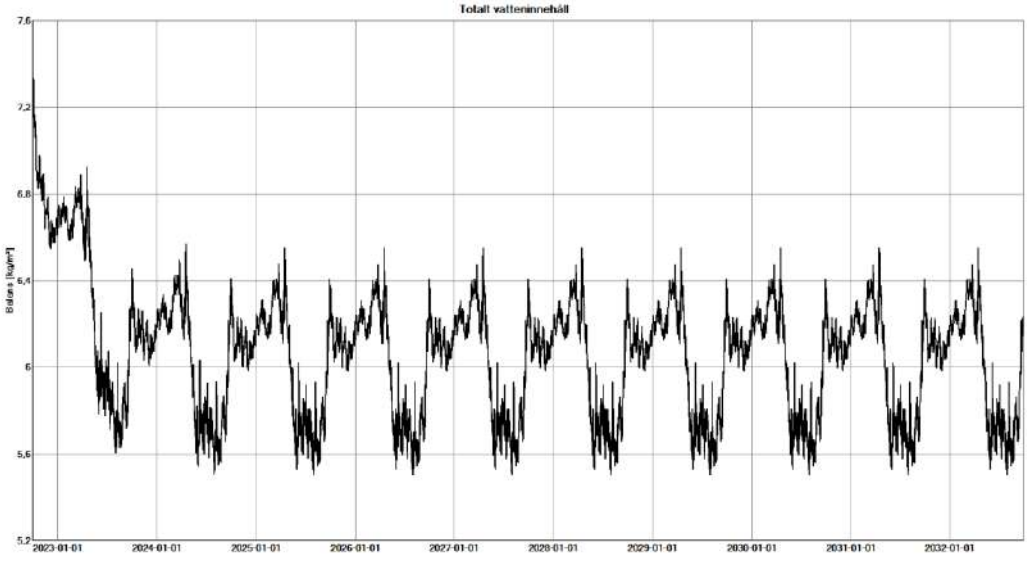
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type C - plastered facade, plaster on the inside

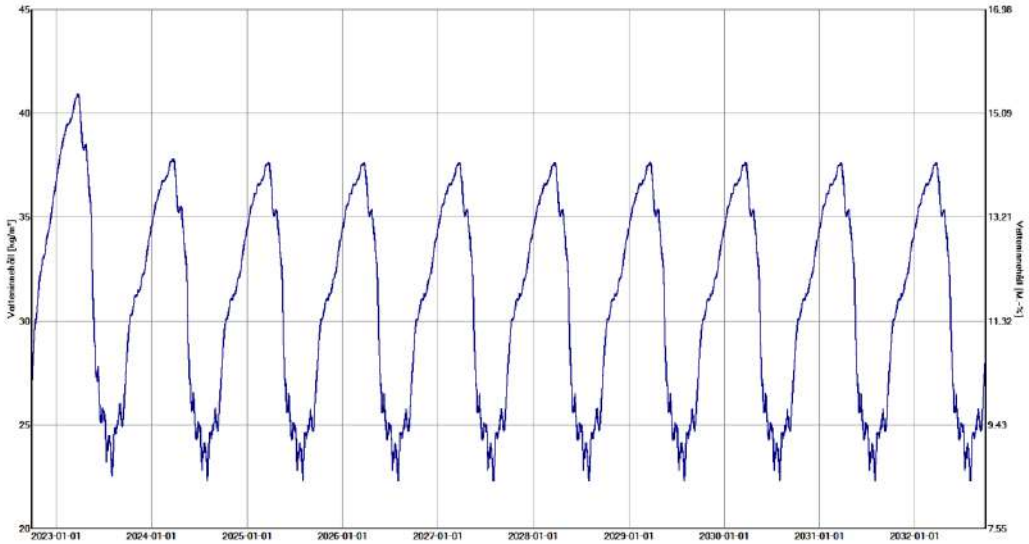
<u>The whole wall</u>



Even with high built-in moisture content (assumed at 80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

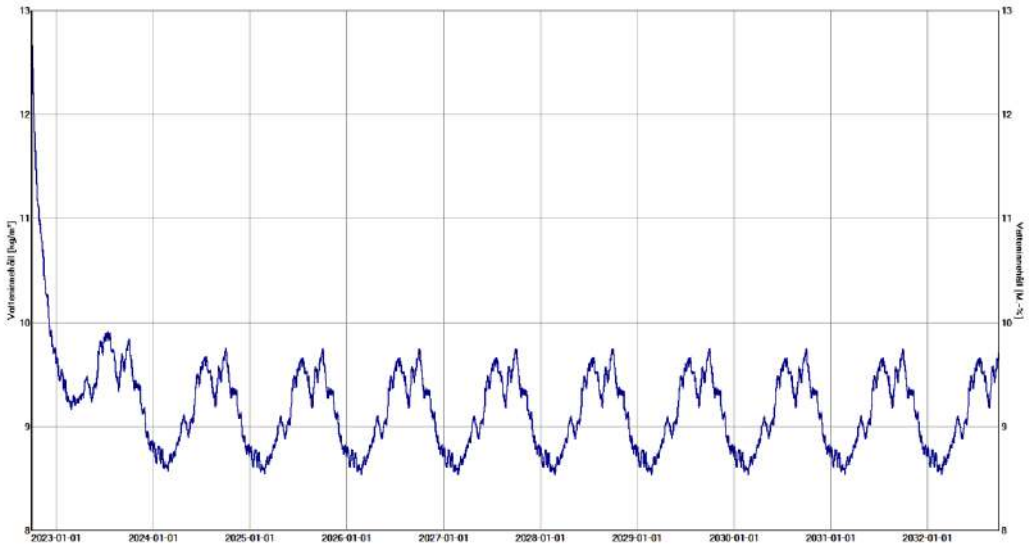
Single layers

Wood fibre behind the plaster:



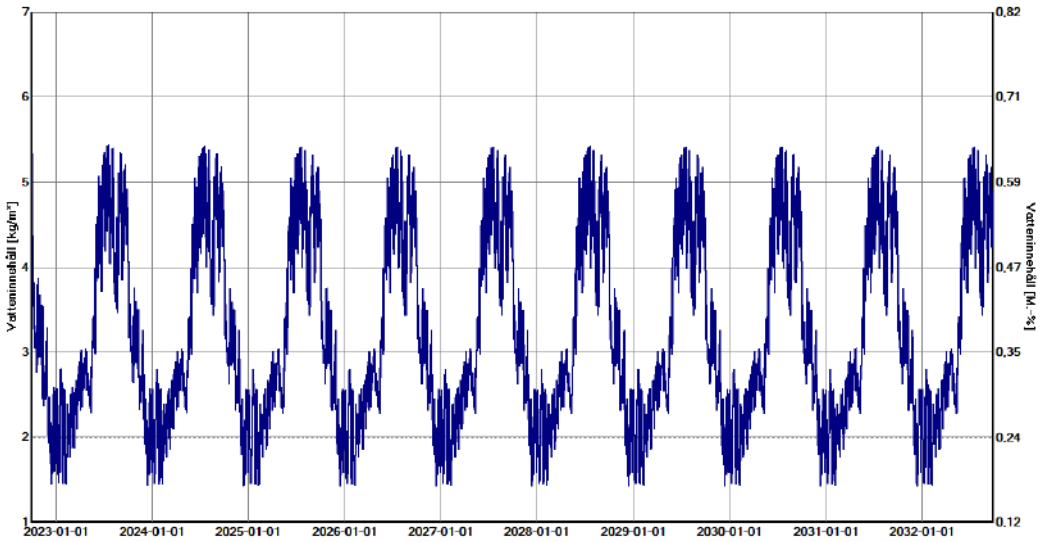
The wood fibreboard has the chance to dry out and the moisture content is always below 15 M.-% and thus below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

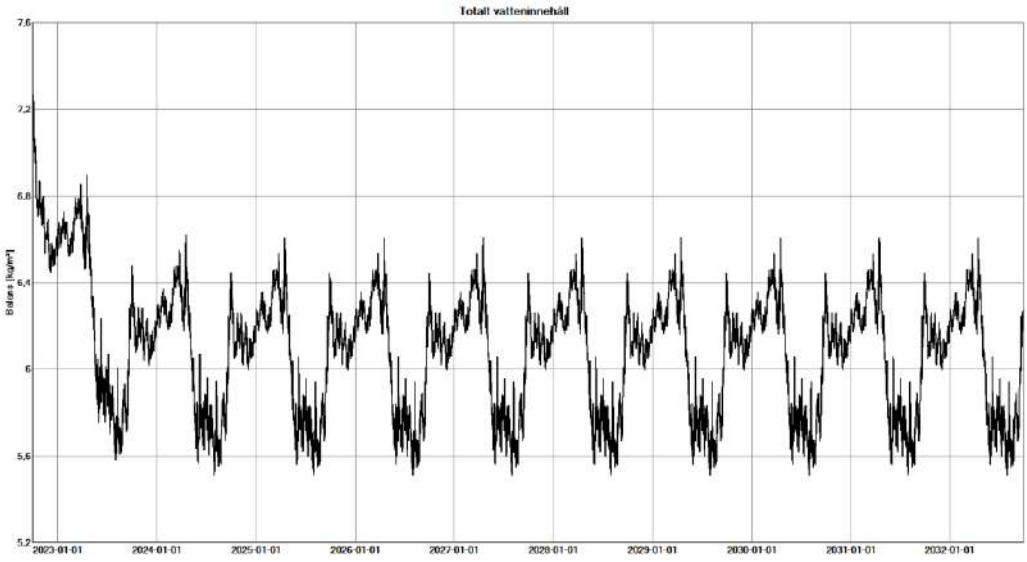
Plaster layer:



The moisture content does not take any harmful forms here.

Wall type D - plastered facade, plasterboard on the inside

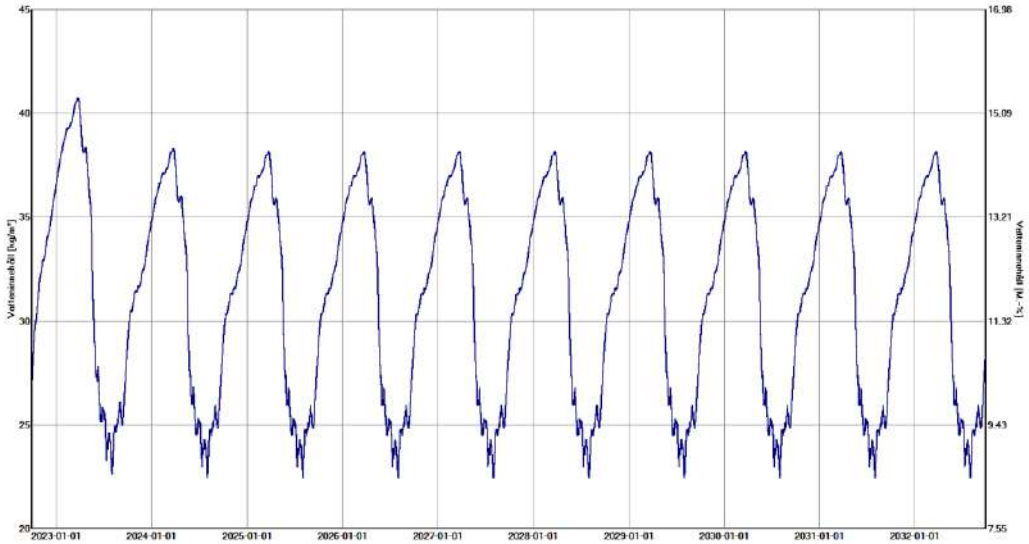
<u>The whole wall</u>



Even with a high built-in moisture content, the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

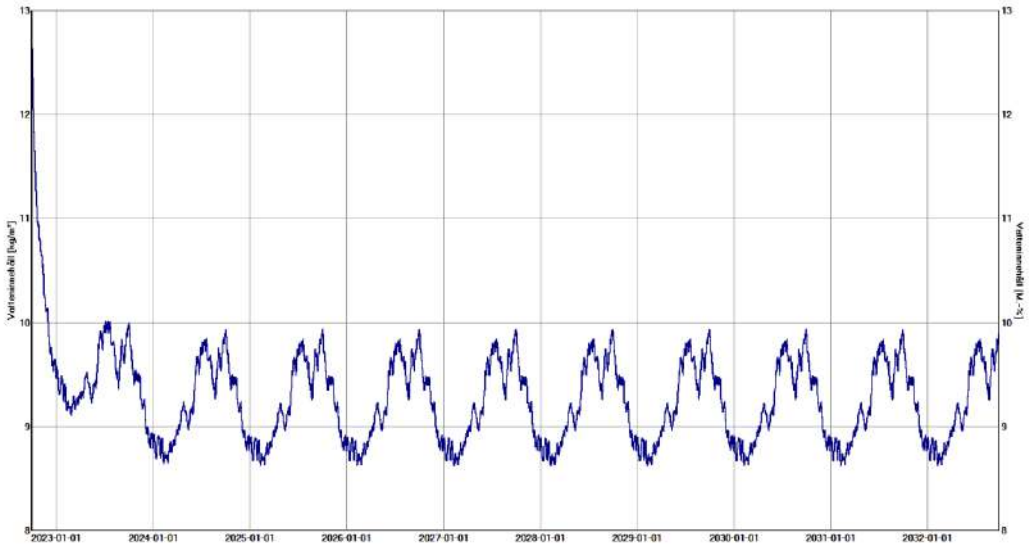
Single layers

Wood fibre behind the plaster:



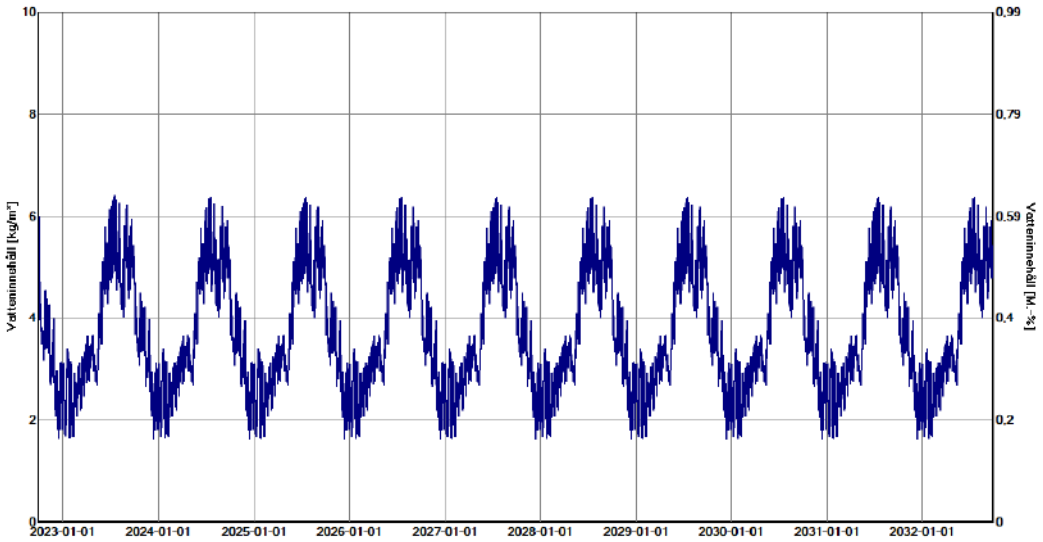
The wood fibreboard has the chance to dry out and the moisture content is always below 15 M.-% and thus below the critical limit.

EcoCocon panel (straw):



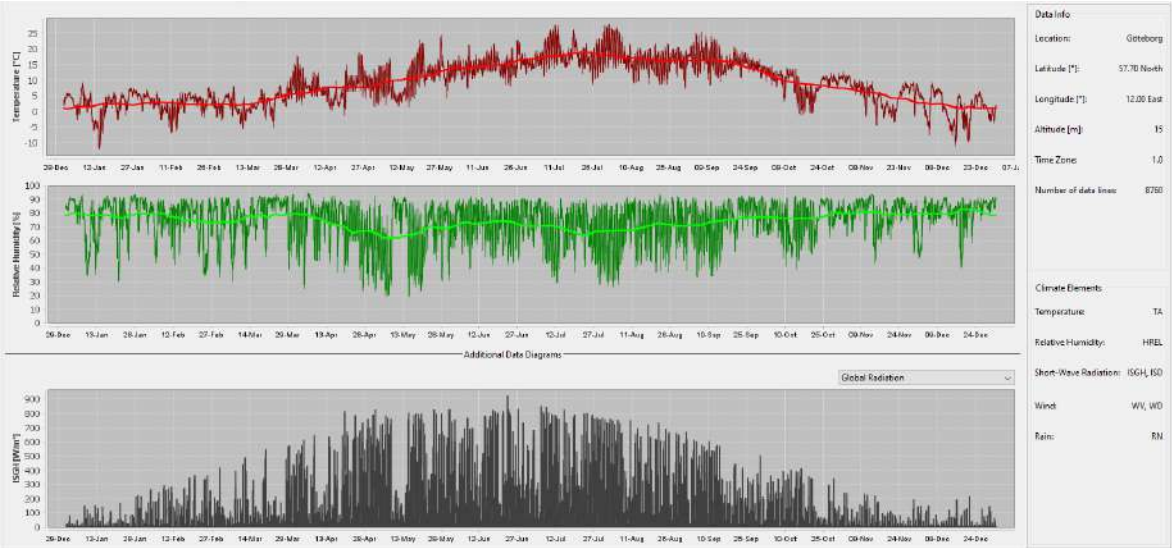
After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

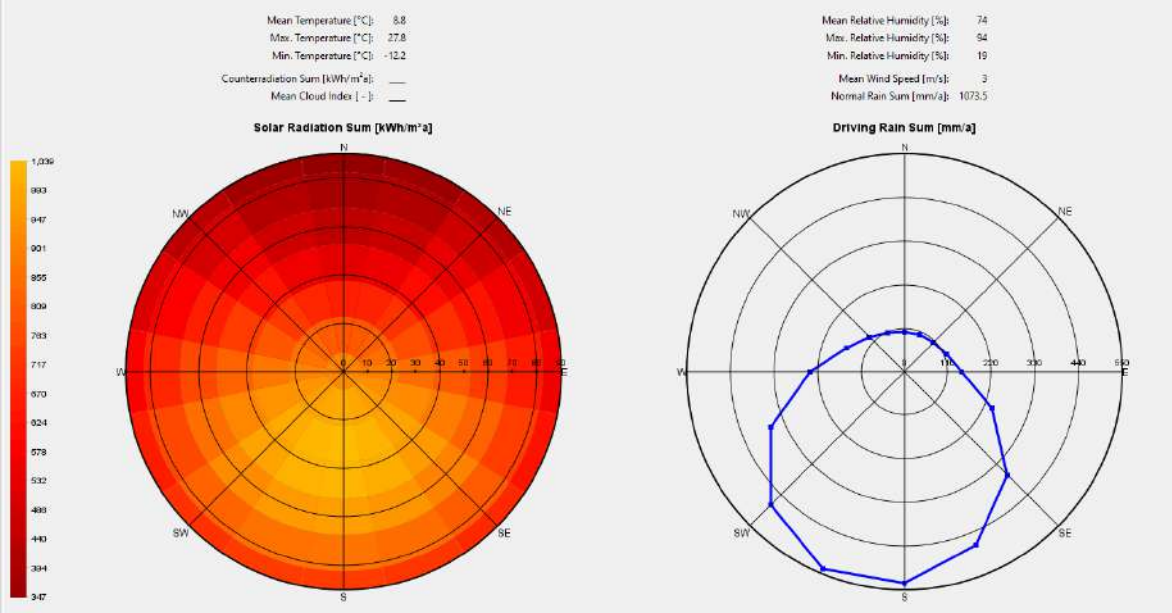
Plasterboard:



The moisture content does not take any harmful forms here.

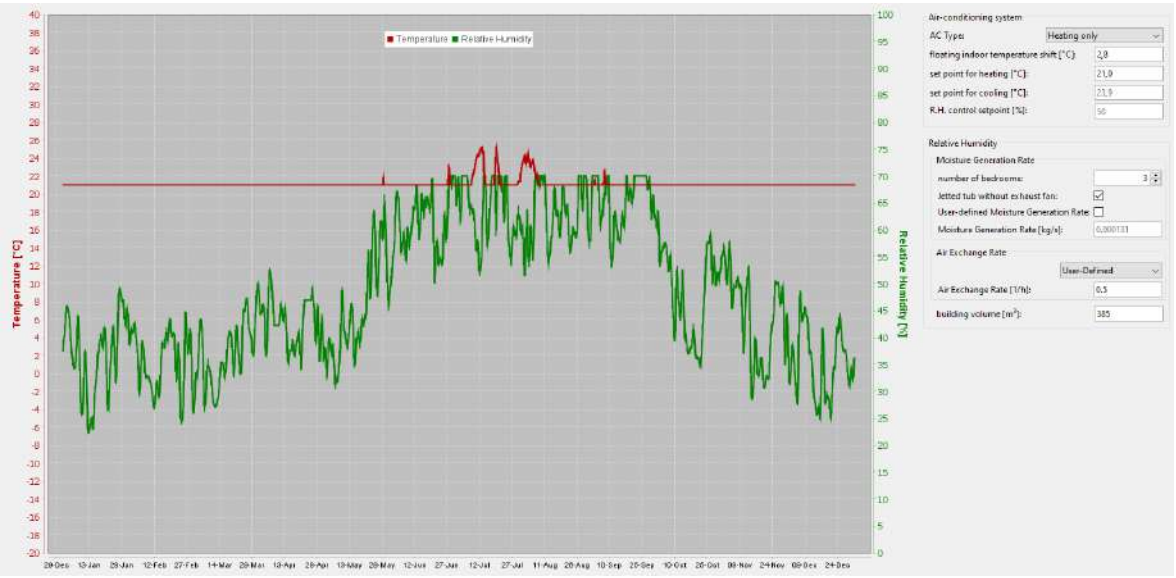
Outdoor climate Gothenburg (Sweden)





The direction with the most driving rain is south-southwest. There is a lot of solar radiation, with higher drying capacity than that towards most other orientations. Therefore, the southwest orientation is used for analyses of plastered walls, still with a lot of driving rain but slightly less drying capacity. For ventilated facades, straight north is always the decisive orientation.

Indoor climate Gothenburg

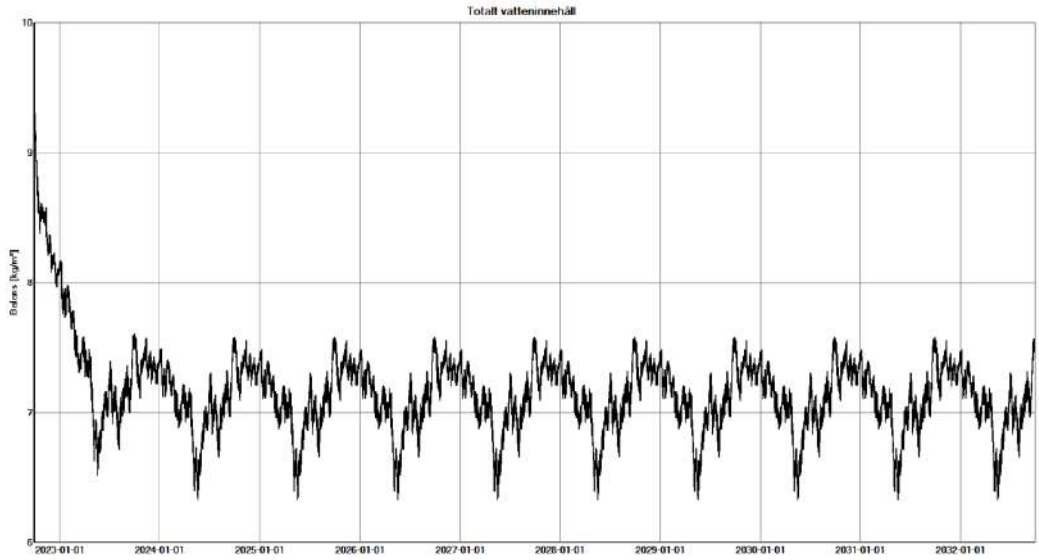


Results Gothenburg

The following diagram shows the water content in total and in the individual layers.

Wall type A - ventilated facade, plaster on the inside

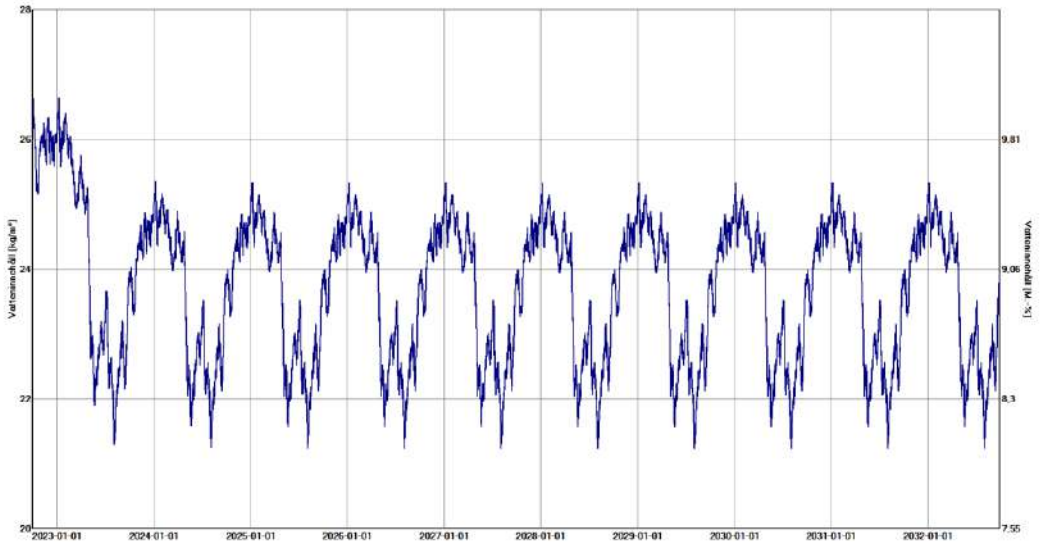
<u>The whole wall</u>



Even with high built-in moisture content (assumed at 80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

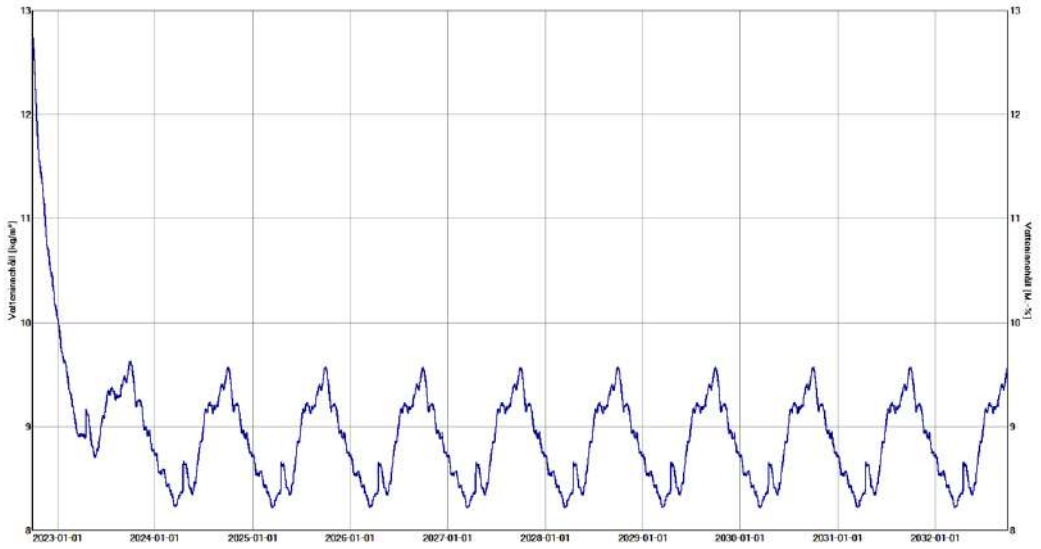
Single layers

Wood fibre behind the air gap:



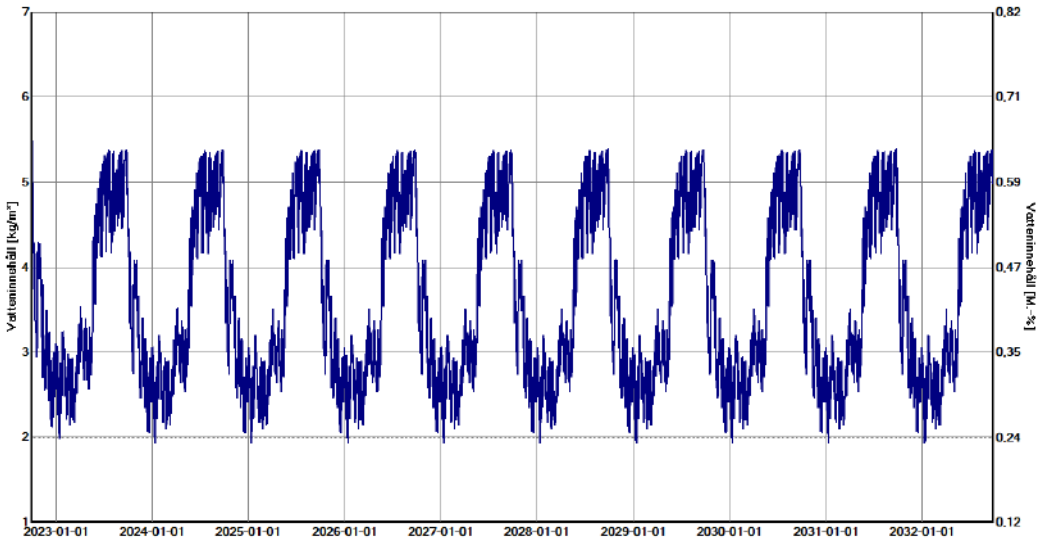
The wood fibreboard has the chance to dry out and the humidity is always below 10 M.-% and thus far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

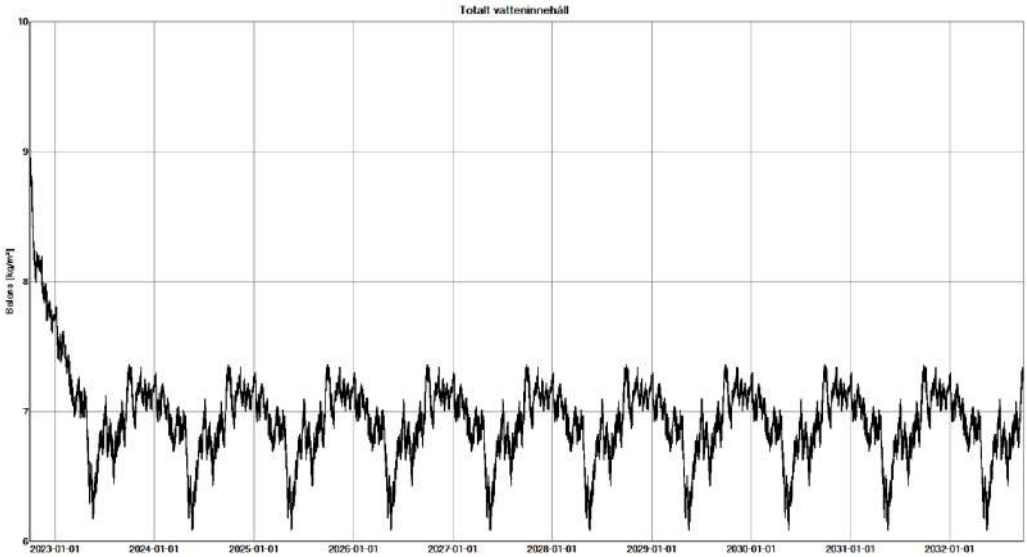
Plaster layer:



The moisture content does not take any harmful forms here. On the contrary: the layer helps to improve the indoor climate by buffering the humidity.

Wall type B - ventilated facade, plasterboard on the inside

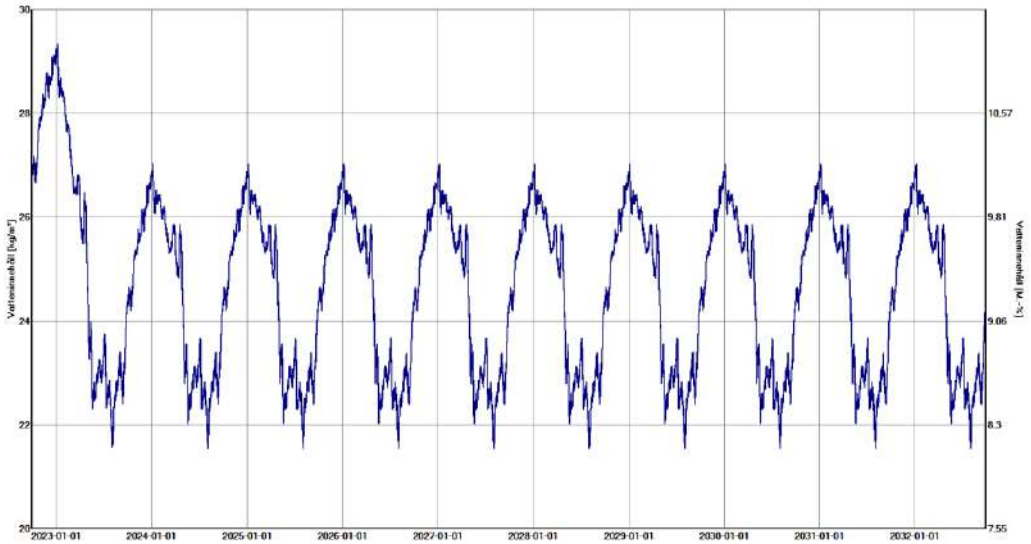
<u>The whole wall</u>



Even with a high built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

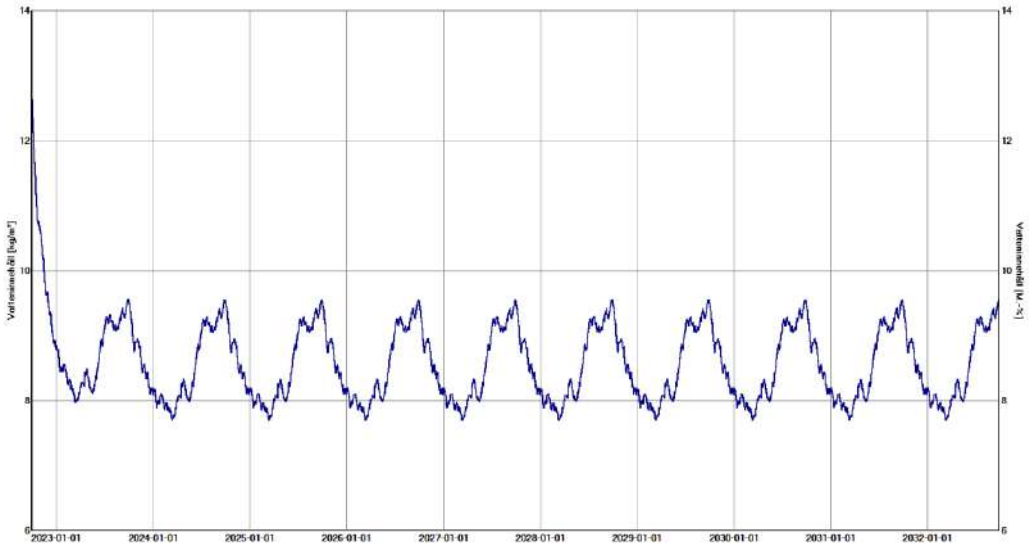
Single layers

Wood fibre behind the air gap:



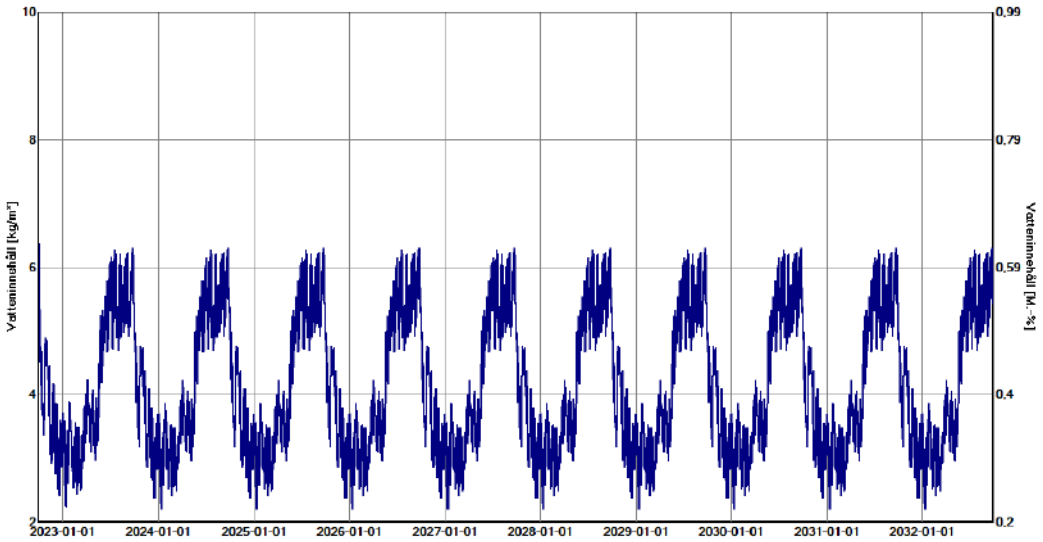
The wood fibreboard has the chance to dry out and the water content is always below the 18 M.-% which is considered to be the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

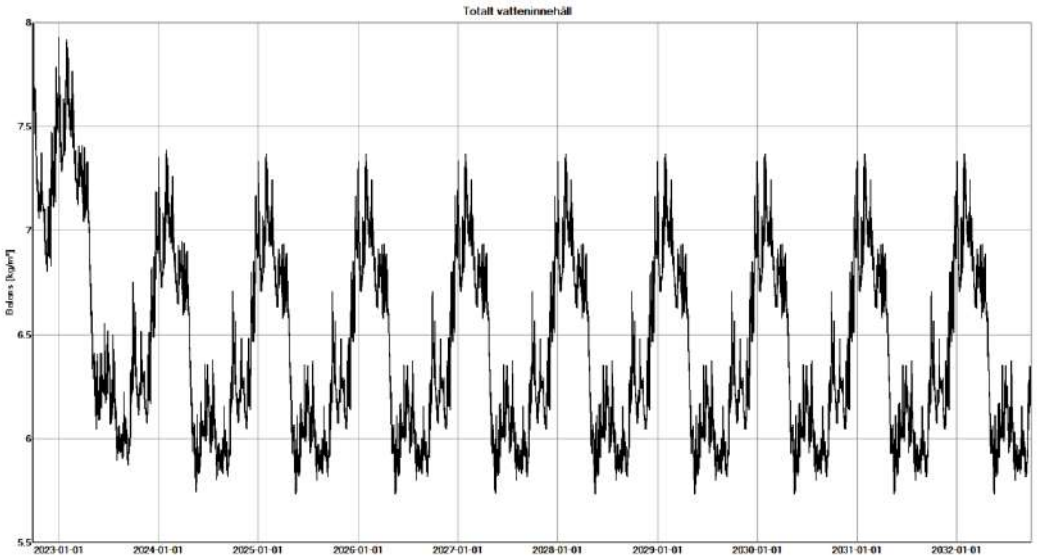
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type C - plastered facade, plaster on the inside

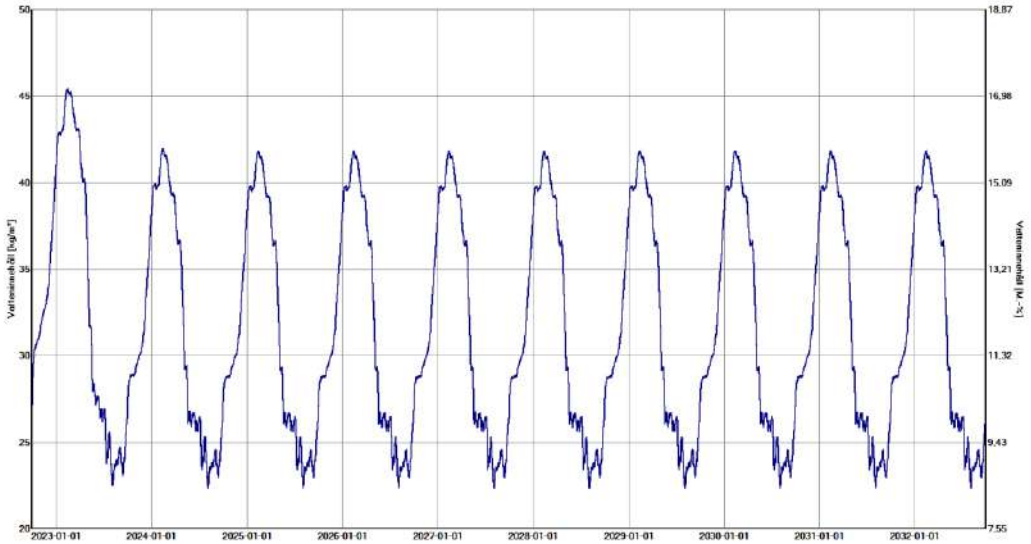
<u>The whole wall</u>



Even with high built-in moisture content (assumed at 80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

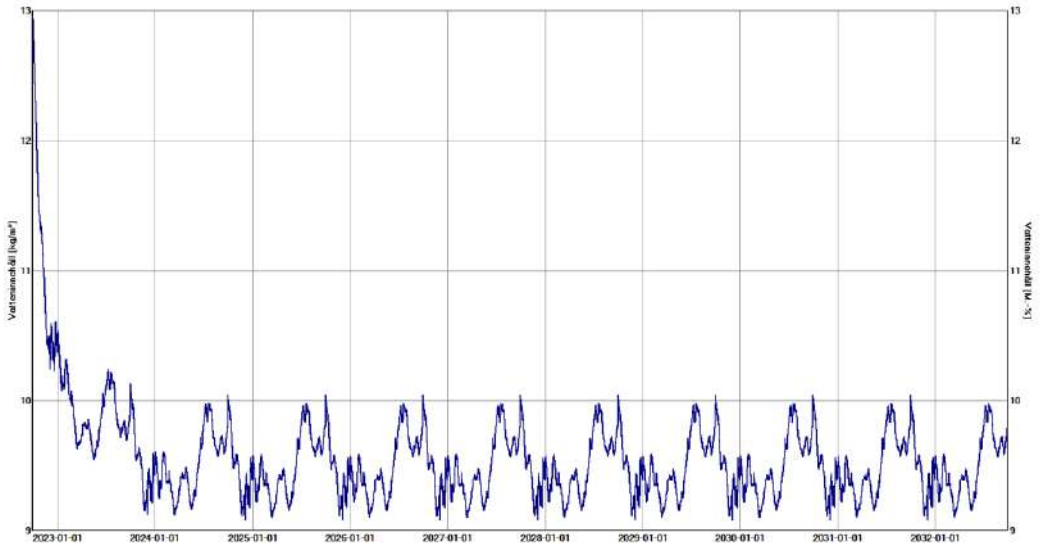
Single layers

Wood fibre behind the plaster:



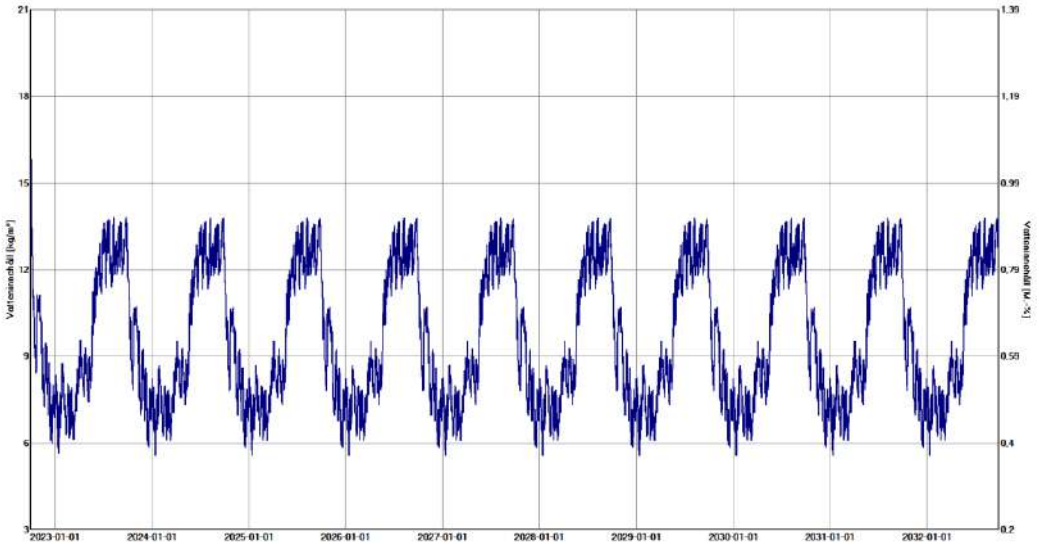
The wood fibreboard has the chance to dry out and the water content is always below 16 M.-% and thus below the lowest critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

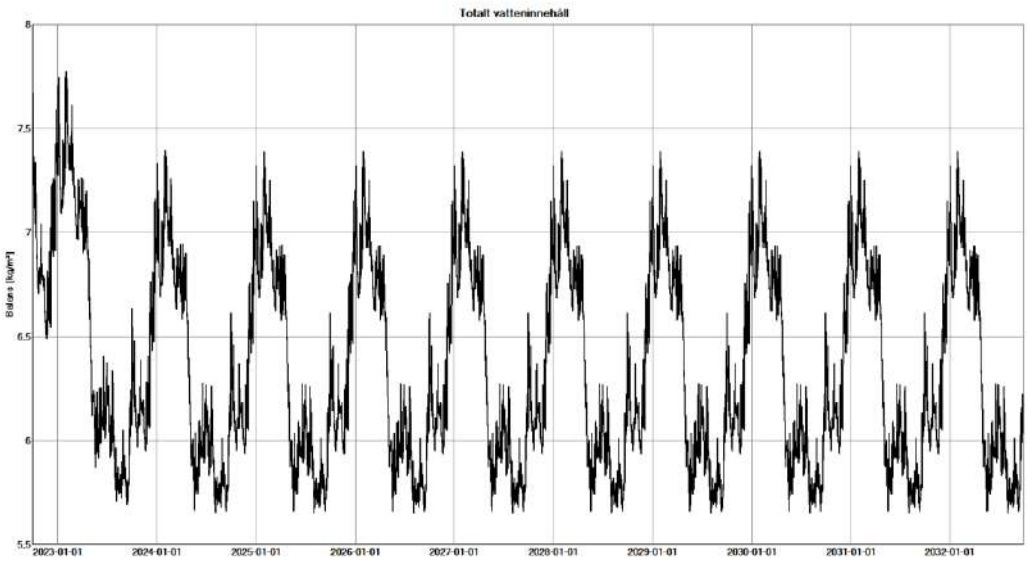
Plaster layer:



The moisture content does not take any harmful forms here.

Wall type D - plastered facade, plasterboard on the inside

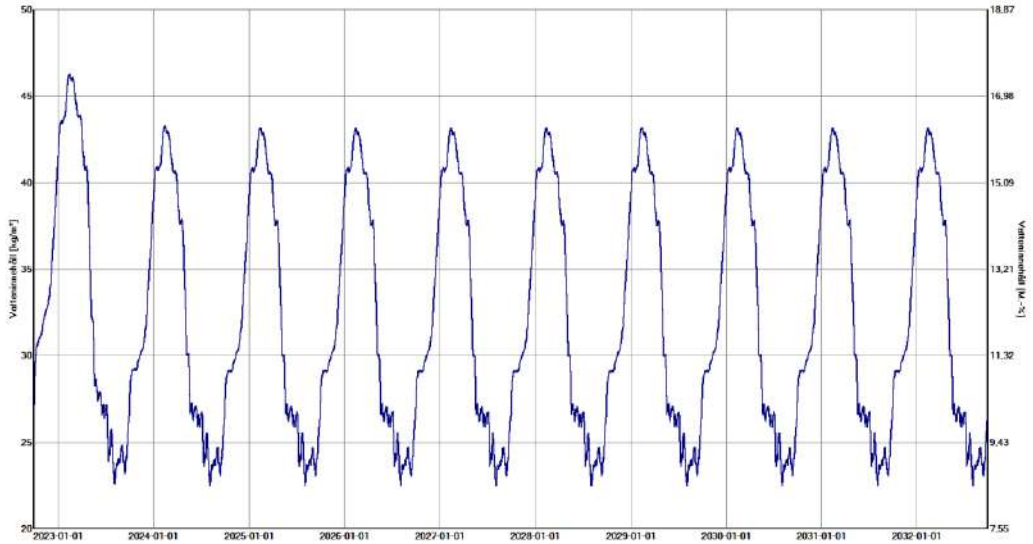
<u>The whole wall</u>



Even with a high built-in moisture content, the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

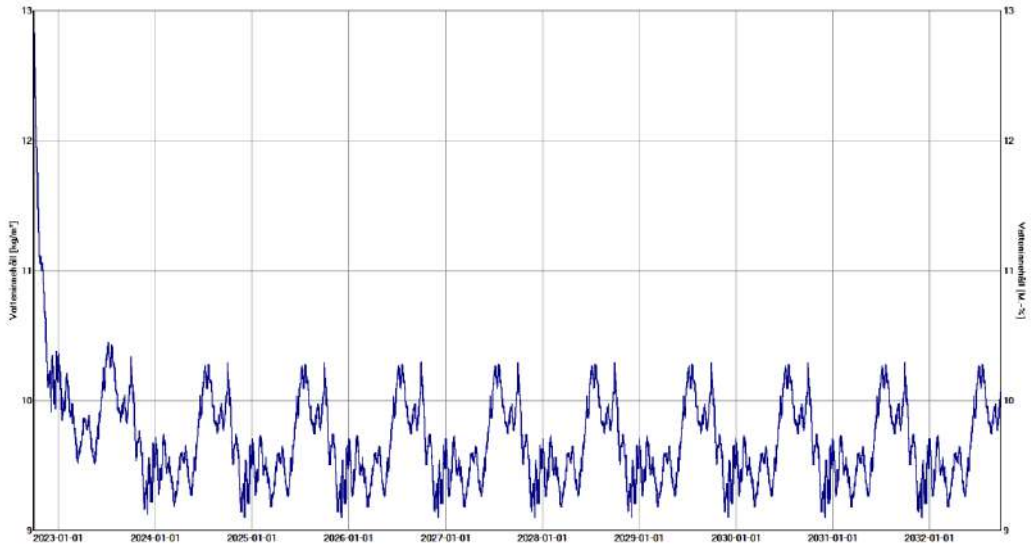
Single layers

Wood fibre behind the plaster:



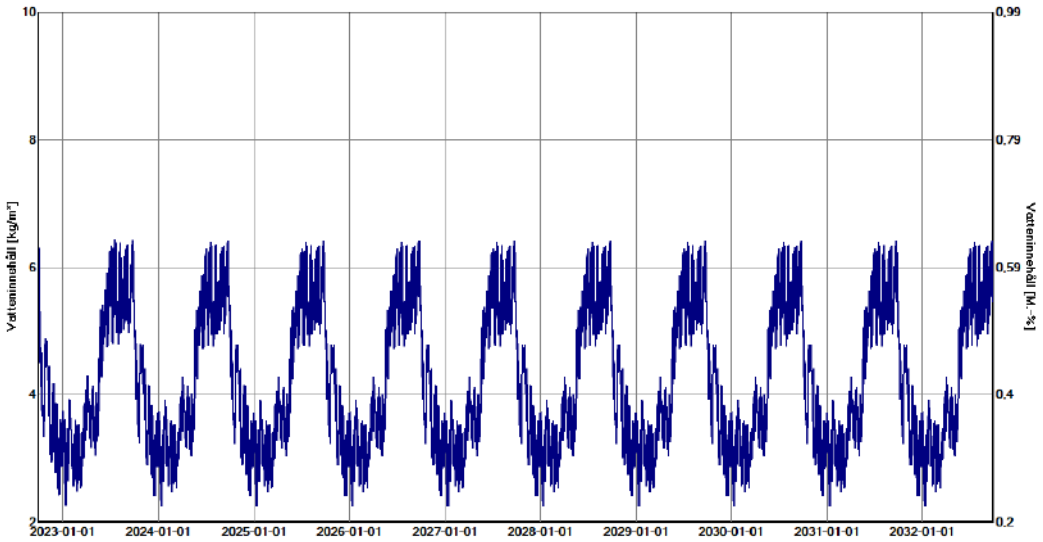
The wood fibreboard has the chance to dry out and the moisture content is always below 17 M.-% and thus below the critical limit.

EcoCocon panel (straw):



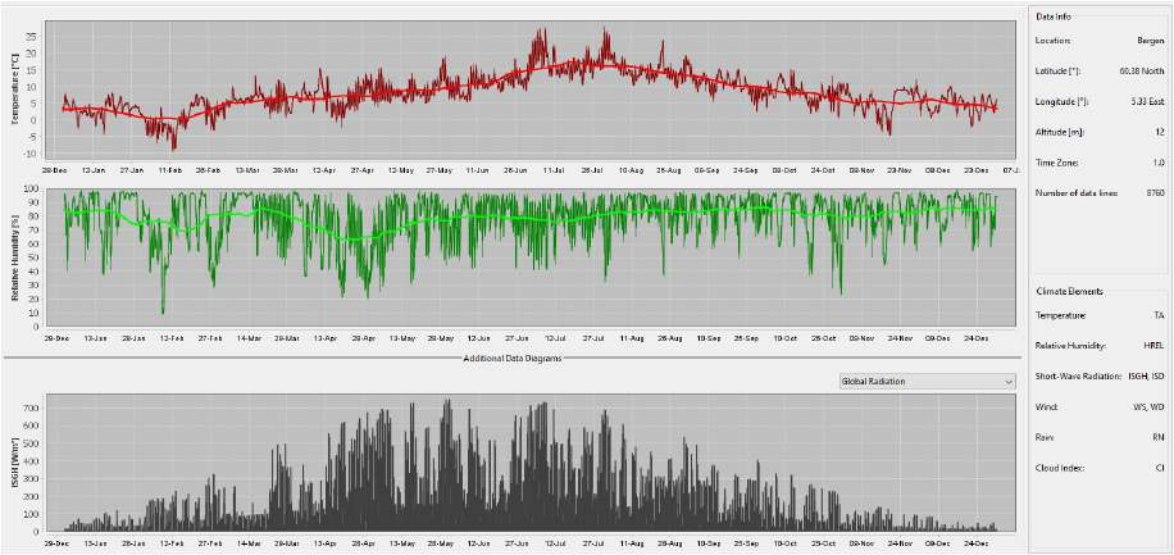
After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

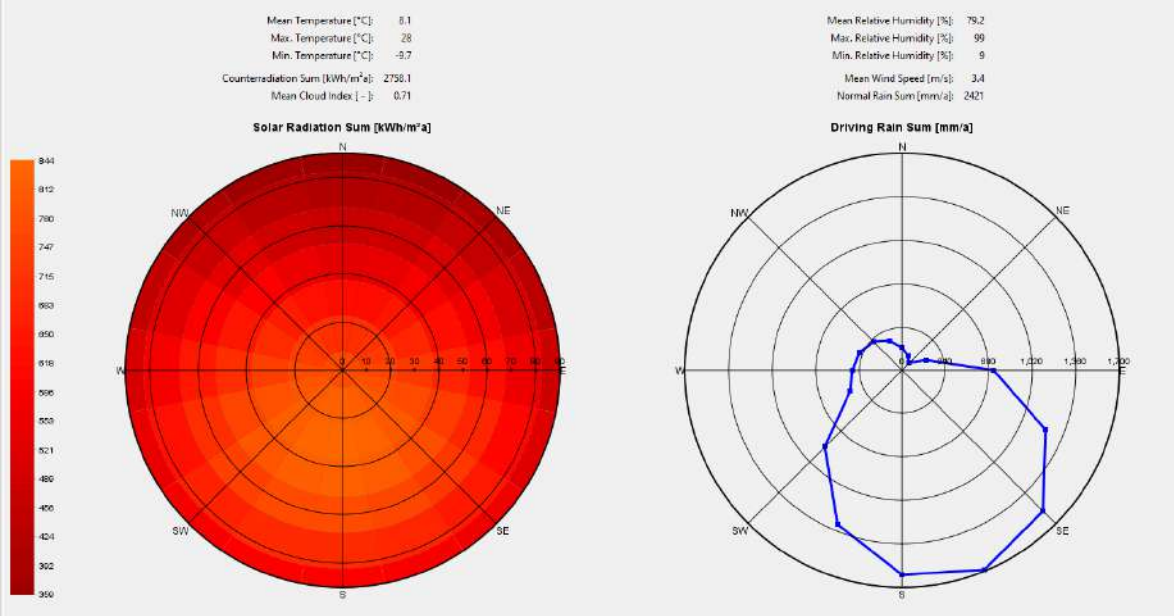
Plasterboard:



The moisture content does not take any harmful forms here.

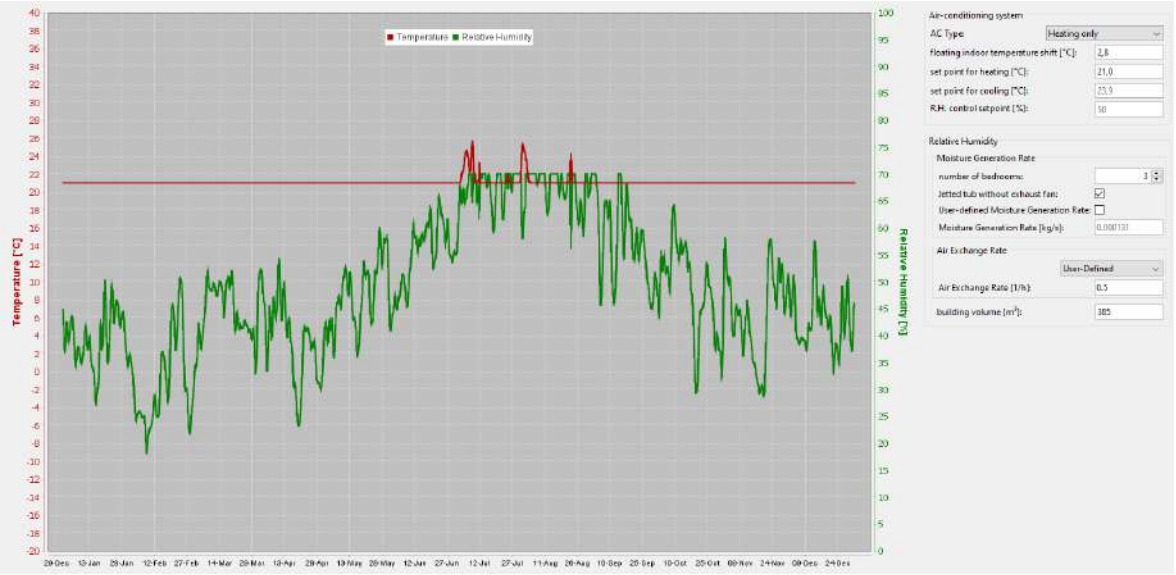
Outdoor climate Bergen (Norway)





The direction with the most driving rain is south-southeast. There is a lot of solar radiation, with higher drying capacity than that towards most other orientations. Therefore, the southeast orientation is used for analyses of plastered walls, with still a lot of driving rain but slightly less drying capacity. For ventilated facades, the north orientation is always the decisive one.

Indoor climate Bergen

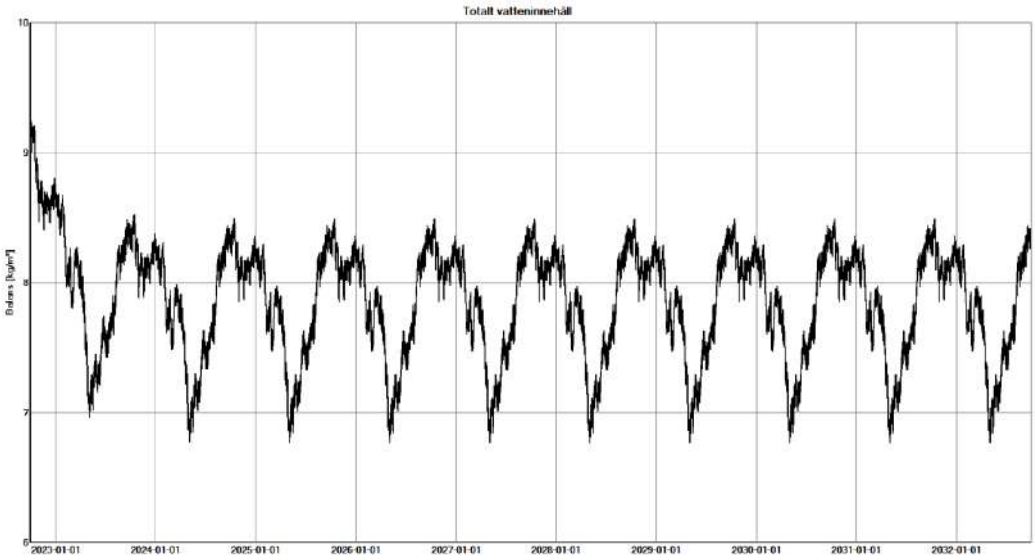


Results Bergen

The following diagram shows the water content in total and in the individual layers.

Wall type A - ventilated facade, plaster on the inside

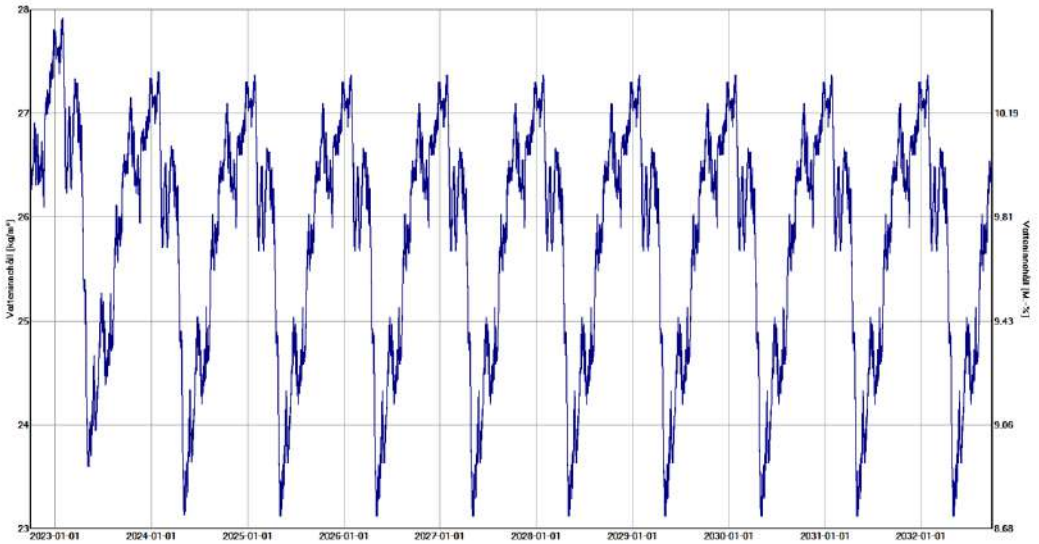
<u>The whole wall</u>



Even with a high built-in moisture content at the beginning, the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

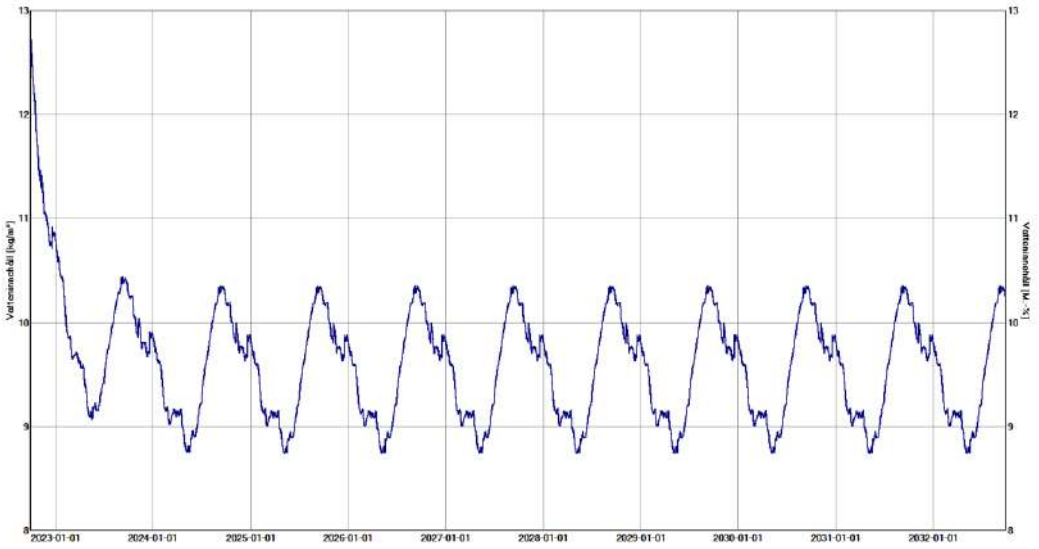
Single layers

Wood fibre behind the air gap:



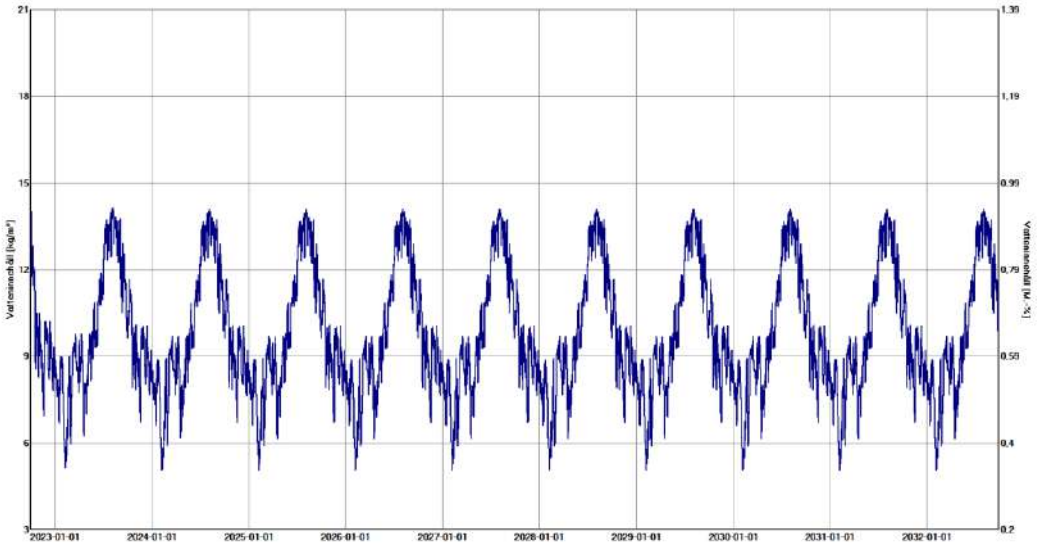
The wood fibreboard has the chance to dry out and the moisture content is always below 11 M.-% and thus far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

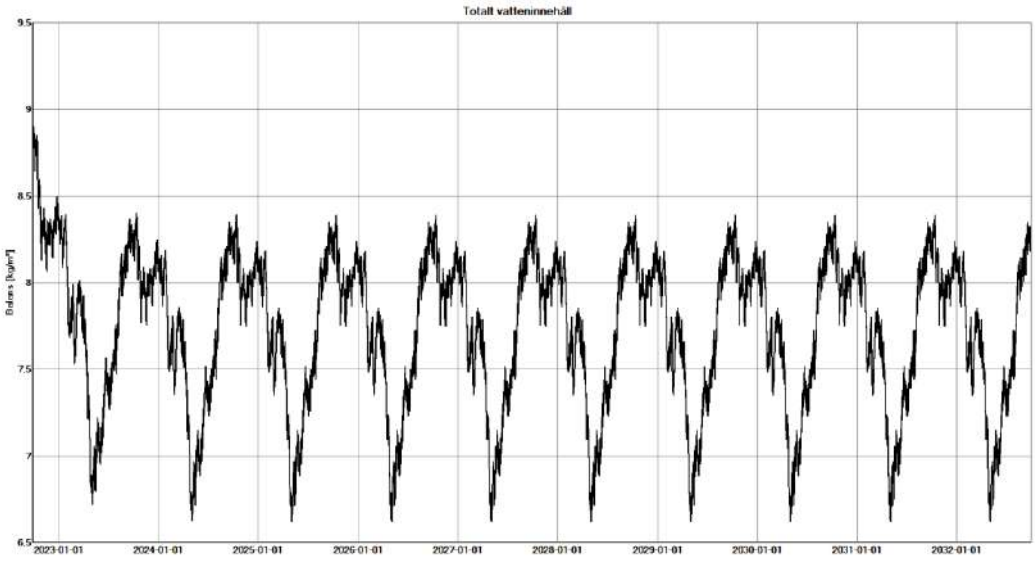
Plaster layer:



The moisture content does not take any harmful forms here - on the contrary: the layer helps to improve the indoor climate by buffering the humidity.

Wall type B - ventilated facade, plasterboard on the inside

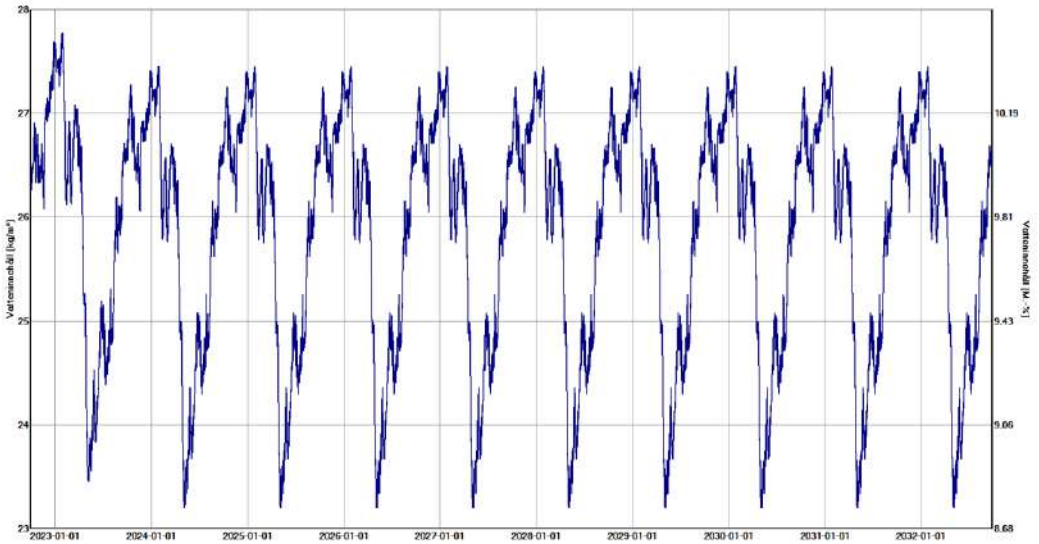
<u>The whole wall</u>



Even with high built-in moisture content (assumed at 80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

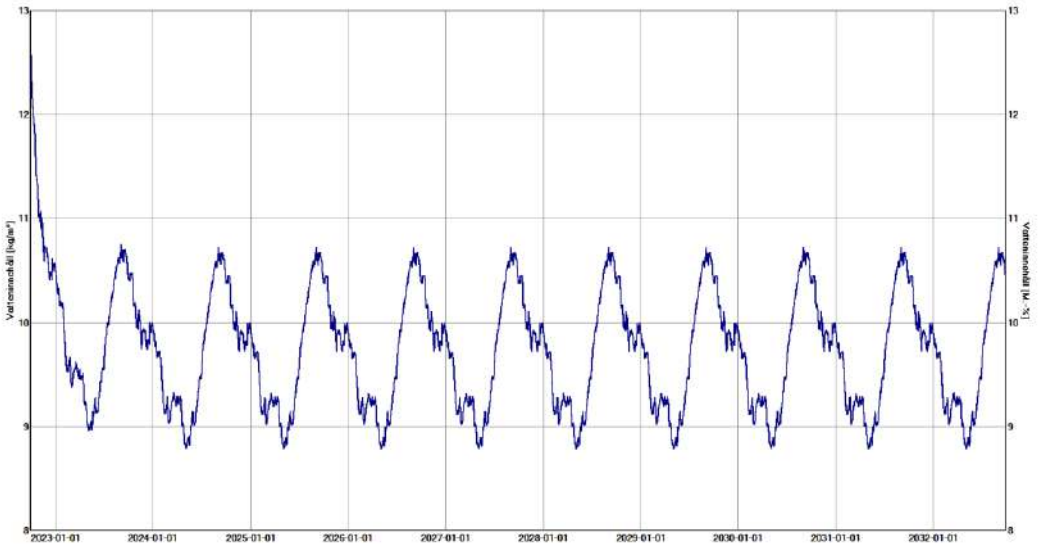
Single layers

Wood fibre behind the air gap:



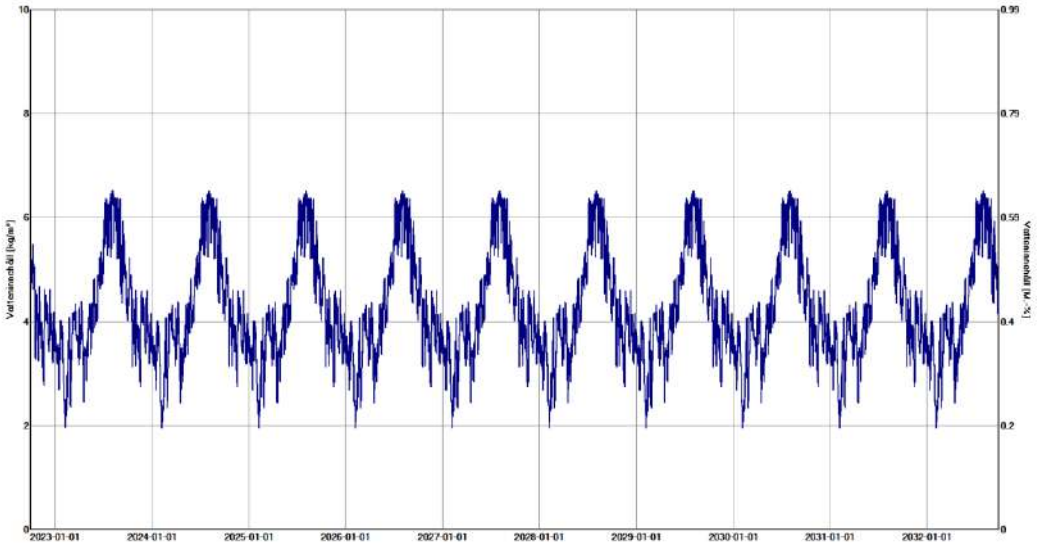
The wood fibreboard has the chance to dry out and the moisture content is always below 11 M.-% and thus far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

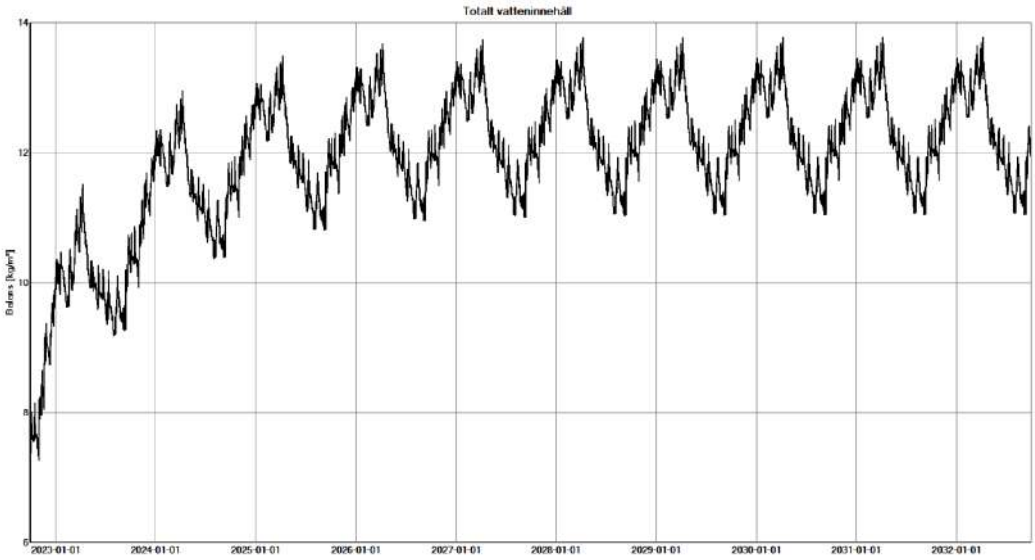
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type C - plastered facade, plaster on the inside

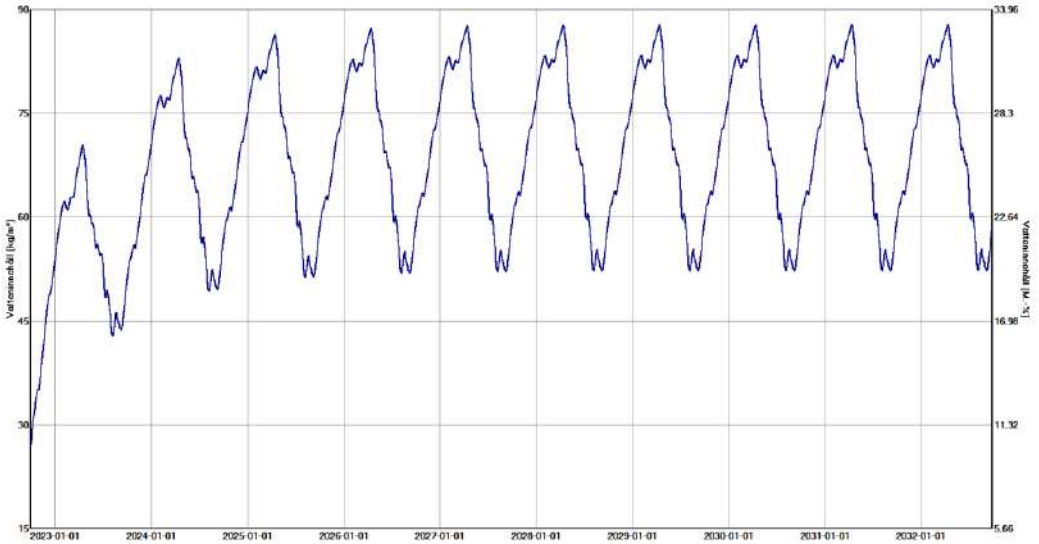
<u>The whole wall</u>



The simulation over 10 years shows an increasing percentage of moisture at the beginning and a relatively high level thereafter. There is therefore a risk of damage to the building fabric even if the work is carried out correctly.

Single layers

Wood fibre behind the plaster:

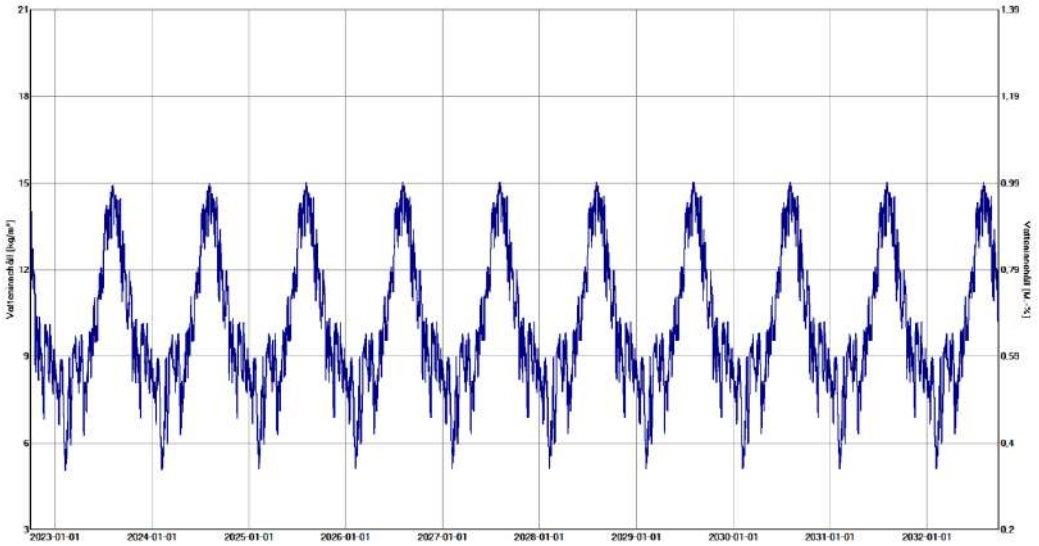


The wood fibreboard does not have the chance to dry out and the moisture content rises initially to stay all the time above the 18 M.-% which is considered the critical limit. Mould growth is likely and it is therefore not recommended to build in this way in the Bergen area.

EcoCocon panel (straw):

The water content rises in the first years and then remains at a high level throughout.

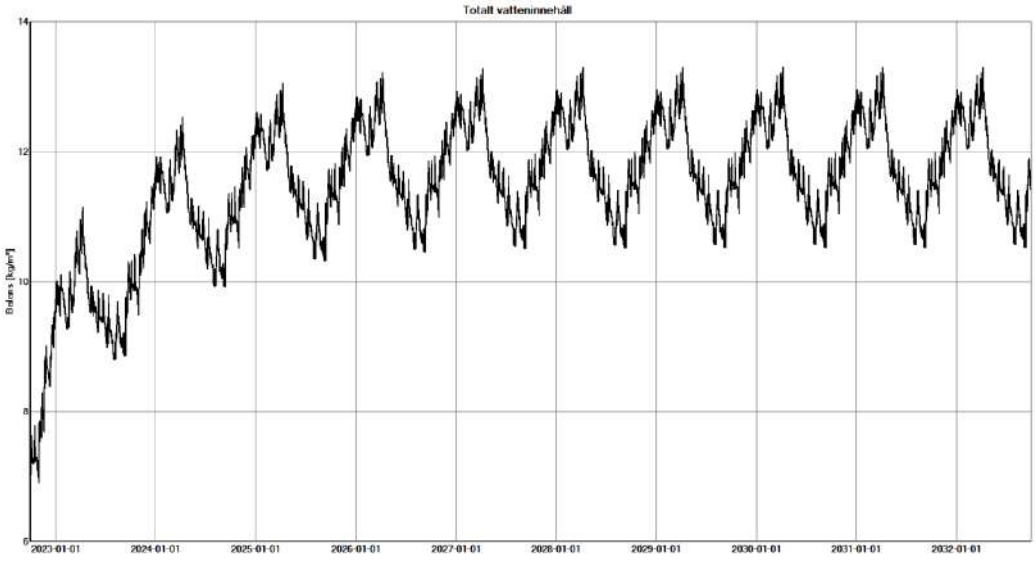
Plaster layer:



This is the only layer that does not give cause for concern. The moisture content does not take any harmful forms here.

Wall type D - plastered facade, plasterboard on the inside

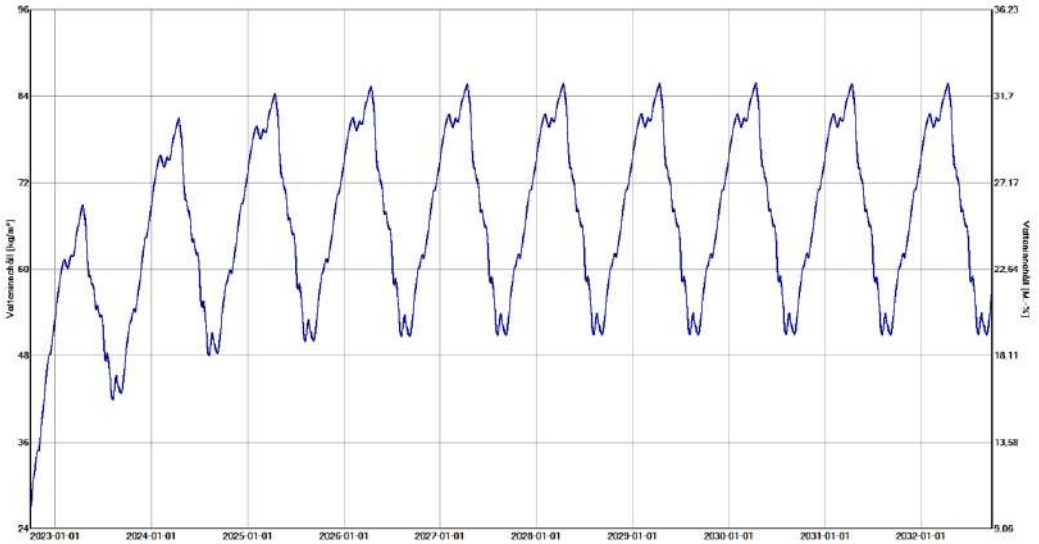
<u>The whole wall</u>



The simulation over 10 years shows an increasing percentage of moisture at the beginning and a relatively high level thereafter. There is therefore a risk of damage to the building fabric even if the work is carried out correctly.

Single layers

Wood fibre behind the plaster:

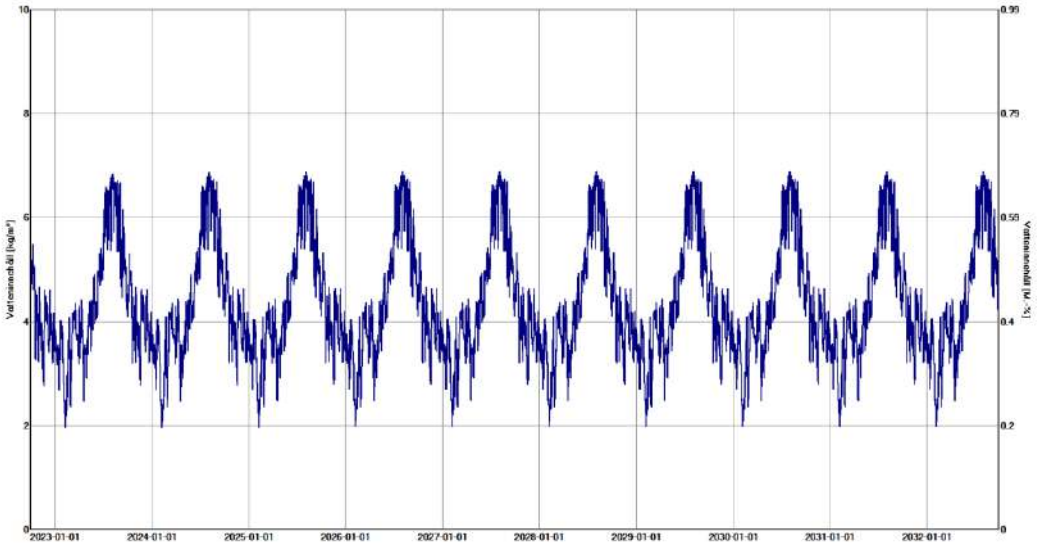


The wood fibreboard does not have the chance to dry out and the moisture content rises initially to stay all the time above the 18 M.-% which is considered the critical limit. Mould growth is likely and it is therefore not recommended to build in this way in the Bergen area.

EcoCocon panel (straw):

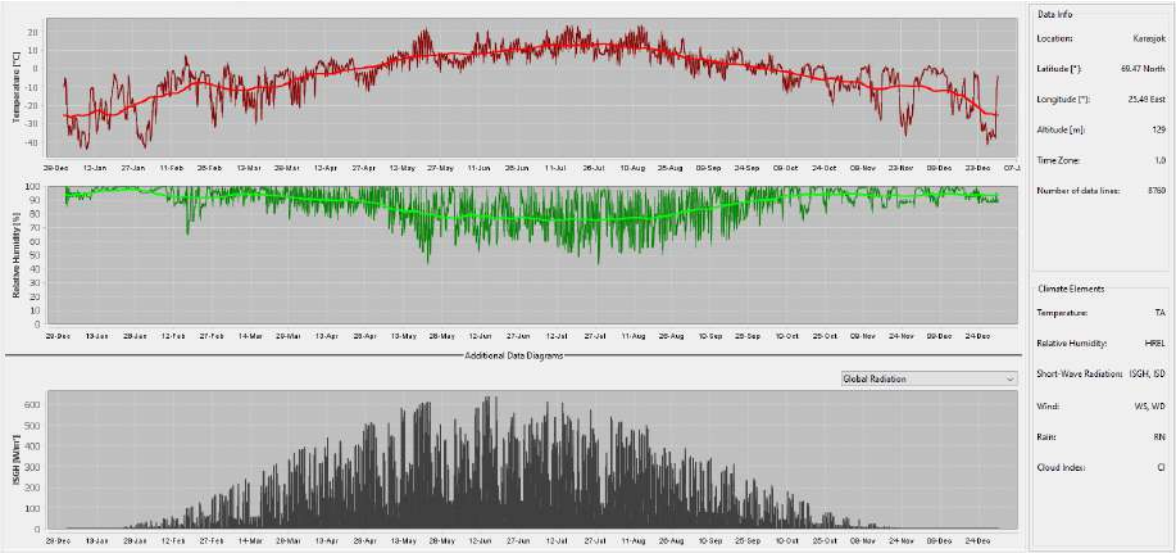
The water content rises in the first years and then remains at a high level throughout.

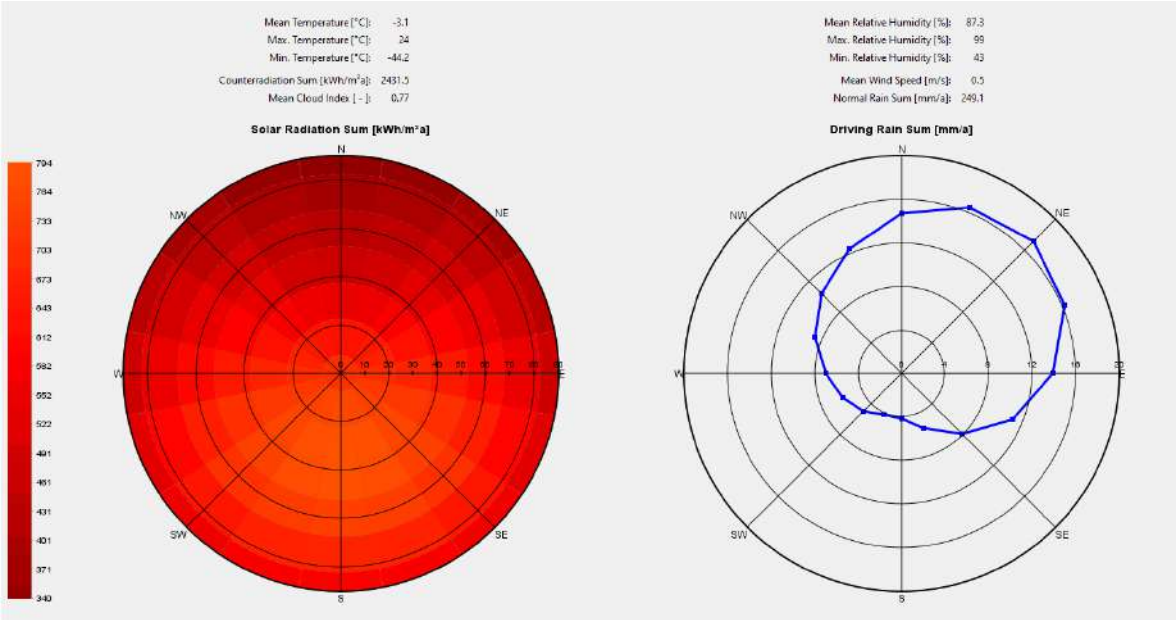
Plasterboard:



As with wall type C, this is the only layer that does not give cause for concern. The moisture content here does not take any harmful forms.

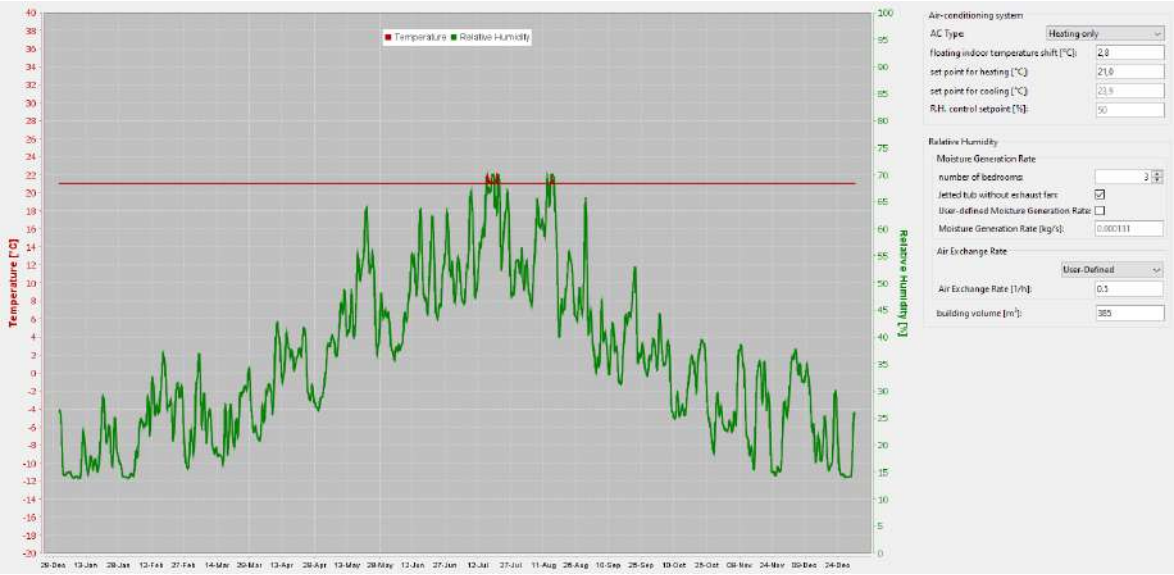
Outdoor climate Karasjok (Norway)





The direction with the most driving rain is northeast. There is also relatively little solar radiation, with lower drying capacity than that found, for example, towards the south. Therefore, this orientation is used for analyses of plastered walls. For ventilated facades, straight north is always the decisive orientation.

Indoor climate Karasjok

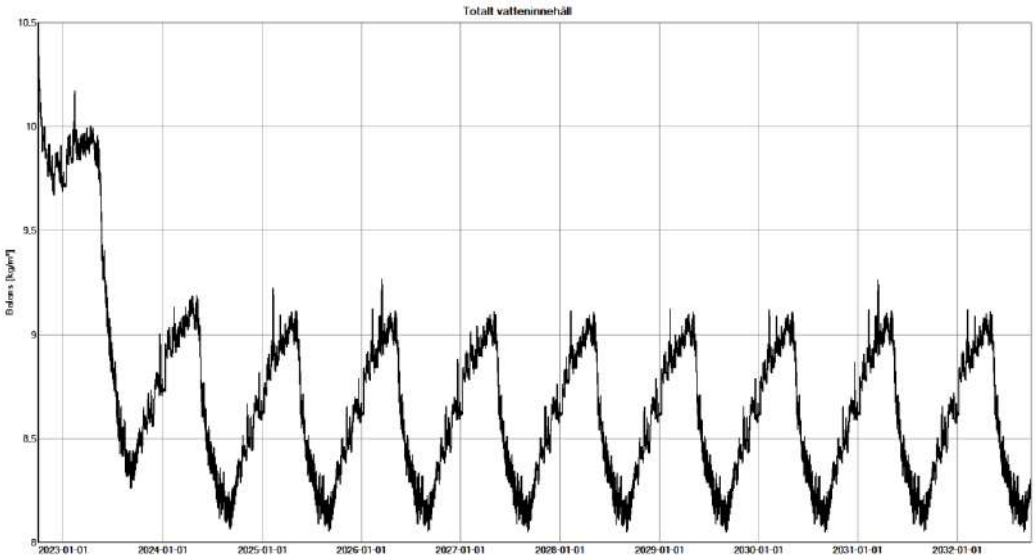


Results Karasjok

The following diagram shows the water content in total and in the individual layers.

Wall type E - ventilated facade, plaster on the inside

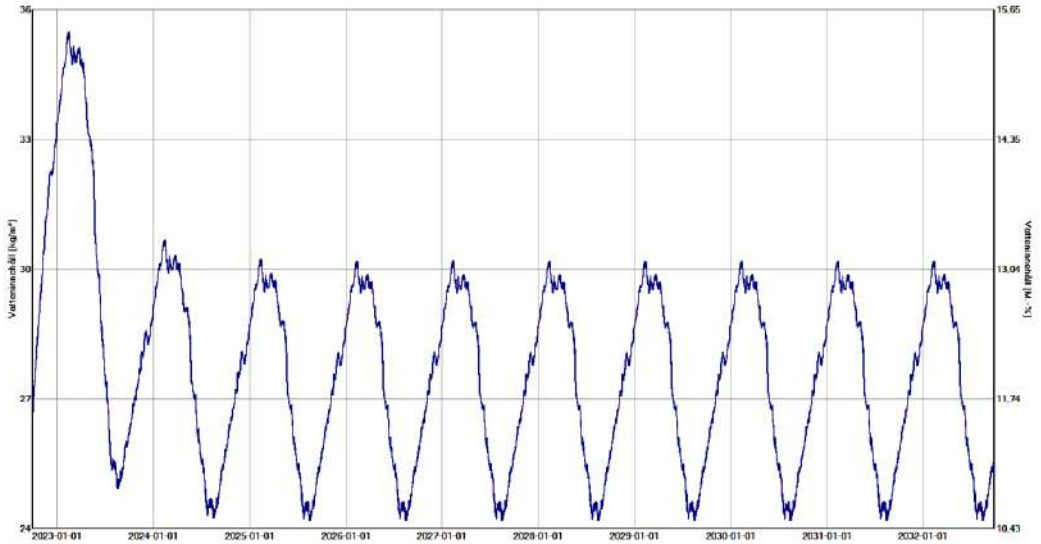
The whole wall



Even with high built-in moisture content, the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

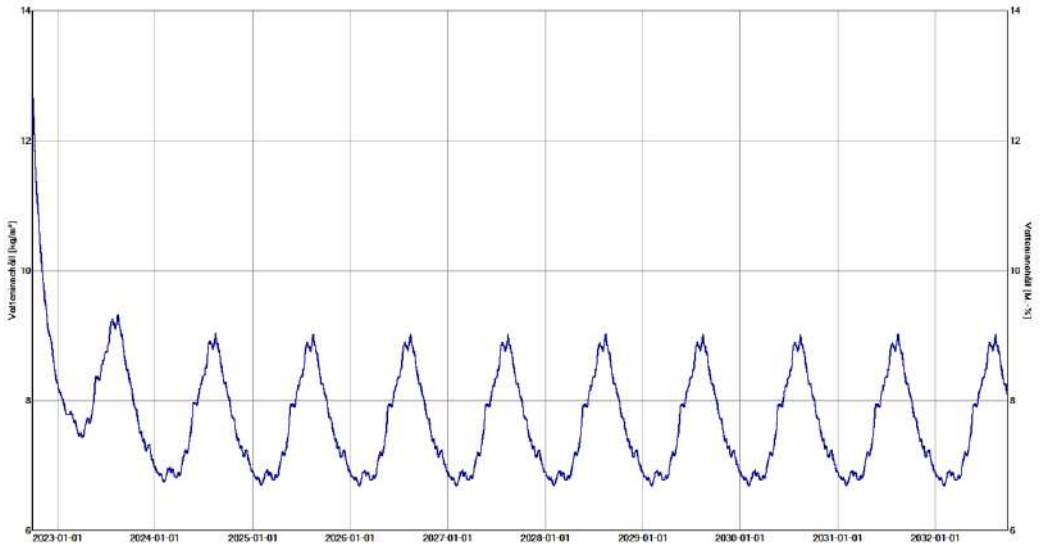
Single layers

Wood fibre behind the air gap:



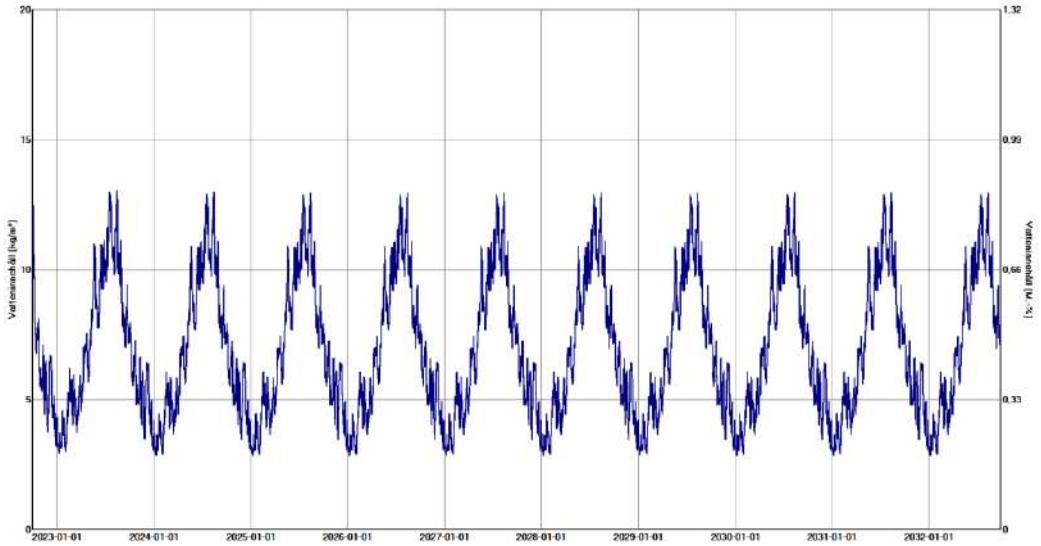
The wood fibreboard has the chance to dry out and the water content is always below 14 M.-% which is far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

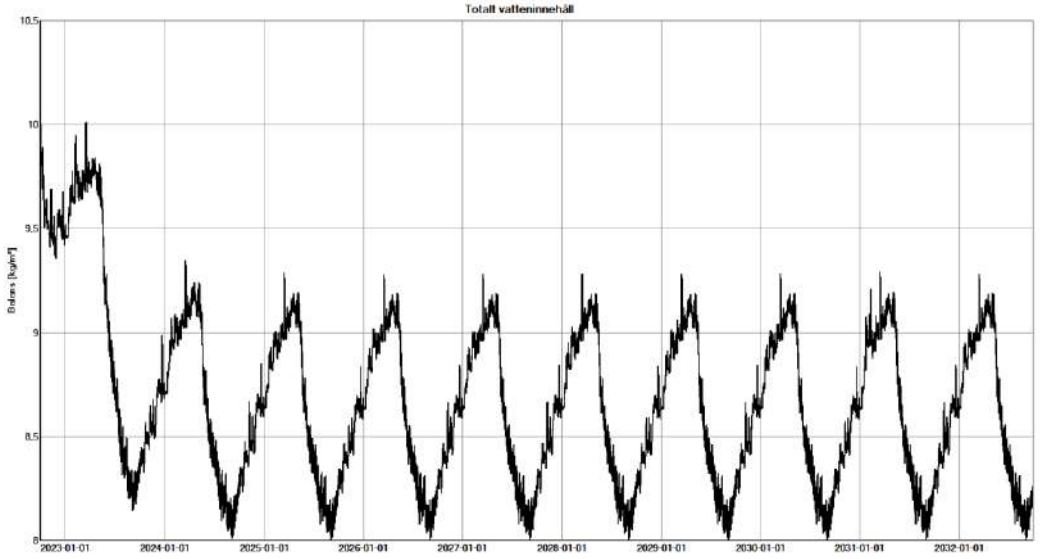
Plaster layer:



The moisture content does not take any harmful forms here - on the contrary: the layer helps to improve the indoor climate by buffering the humidity.

Wall type F - ventilated facade, plasterboard on the inside

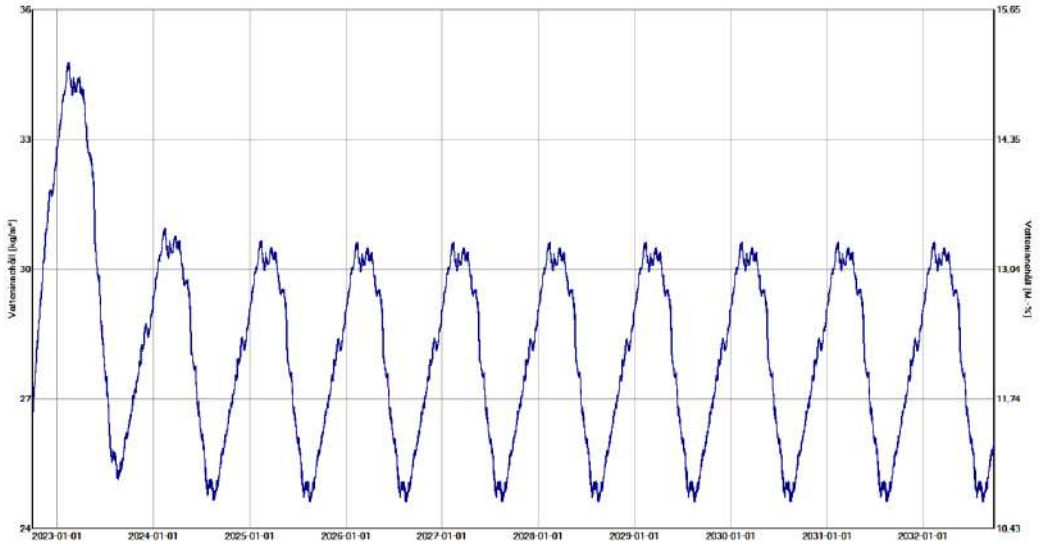
<u>The whole wall</u>



Even with a high built-in moisture content, the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

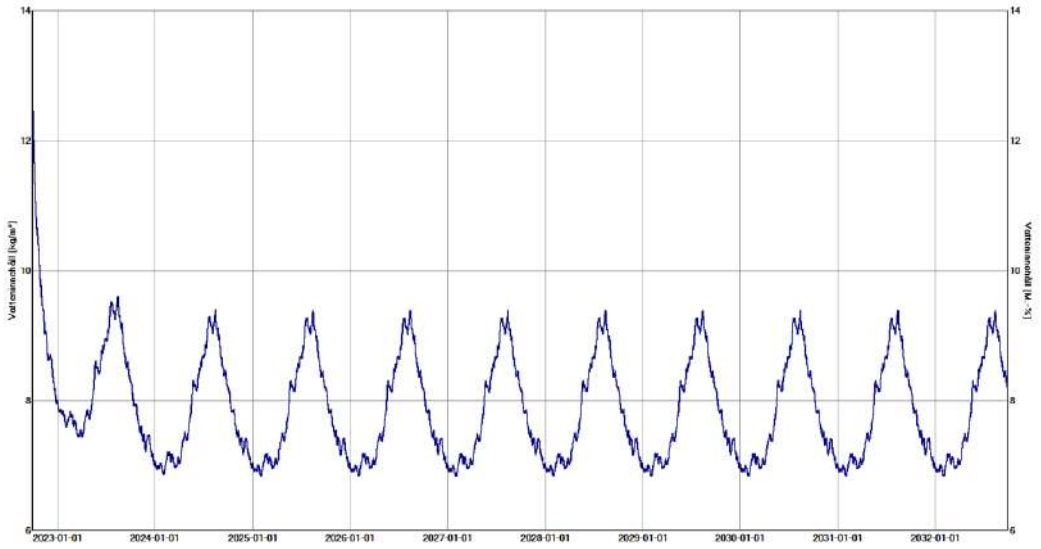
Single layers

Wood fibre behind the air gap:



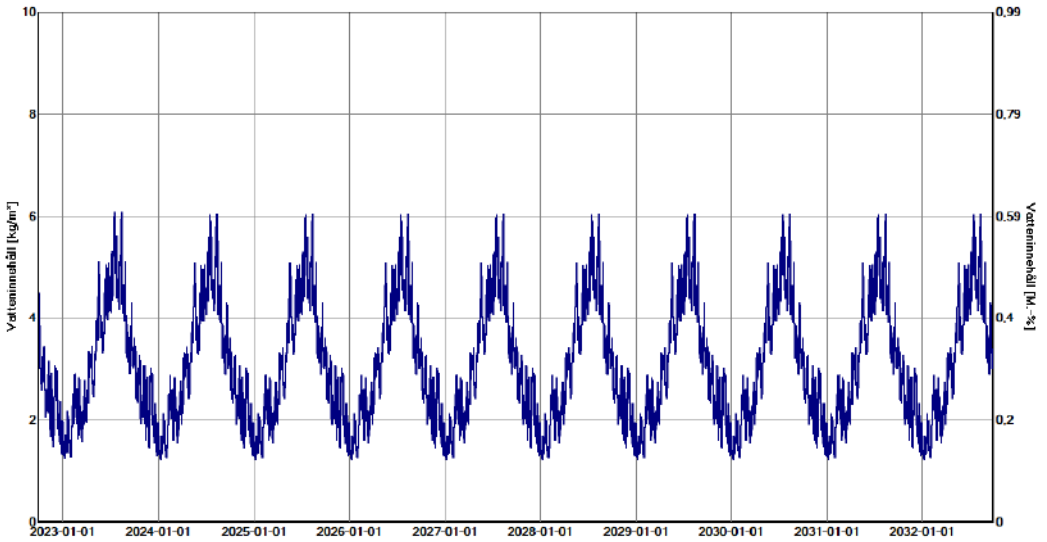
The wood fibreboard has the chance to dry out and the water content is always below 14 M.-% which is far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

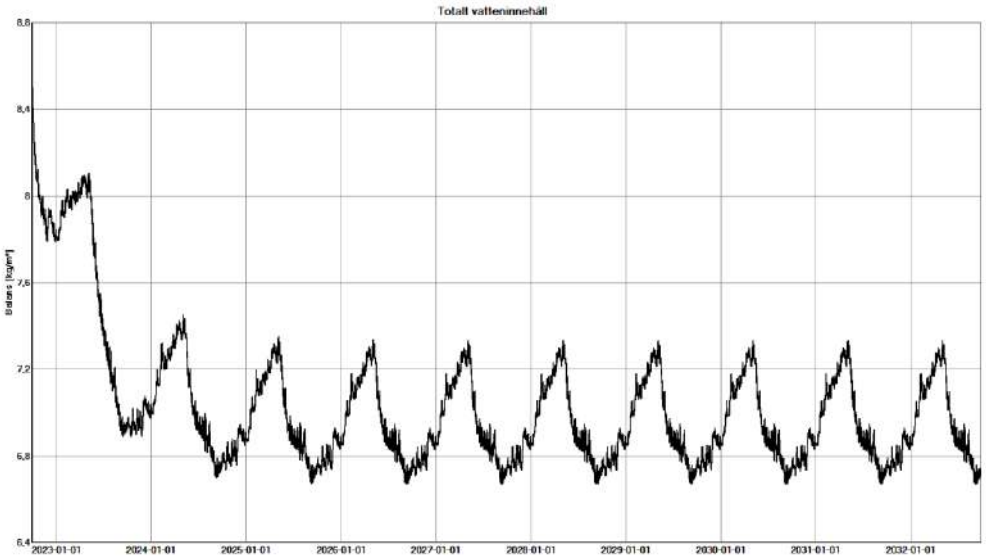
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type G - plastered facade, plaster on the inside

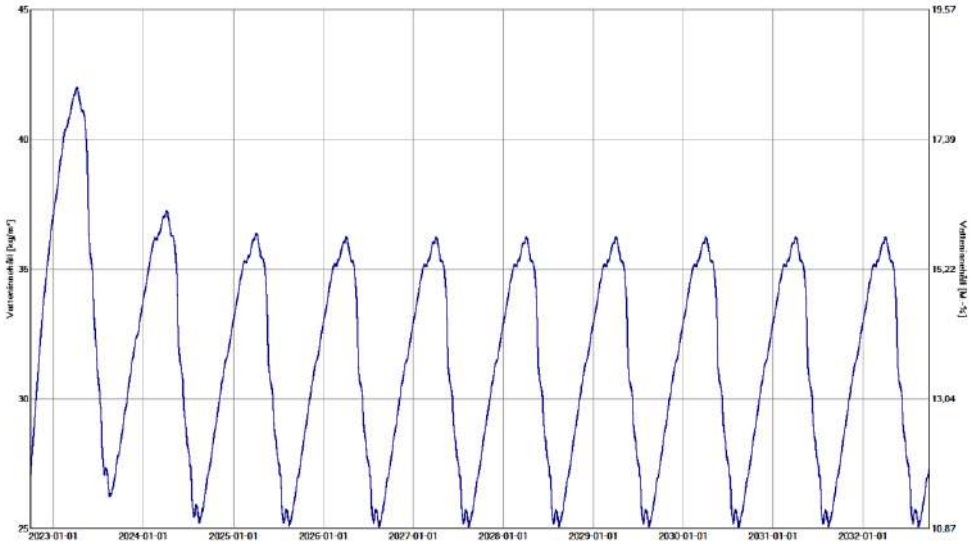
<u>The whole wall</u>



Even with high built-in moisture content (assumed at 80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

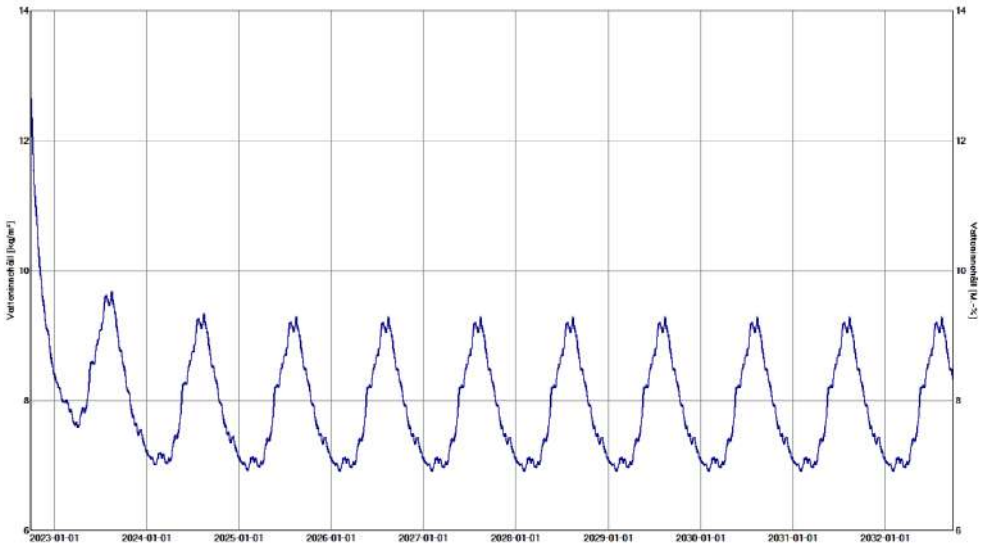
Single layers

Wood fibre behind the plaster:



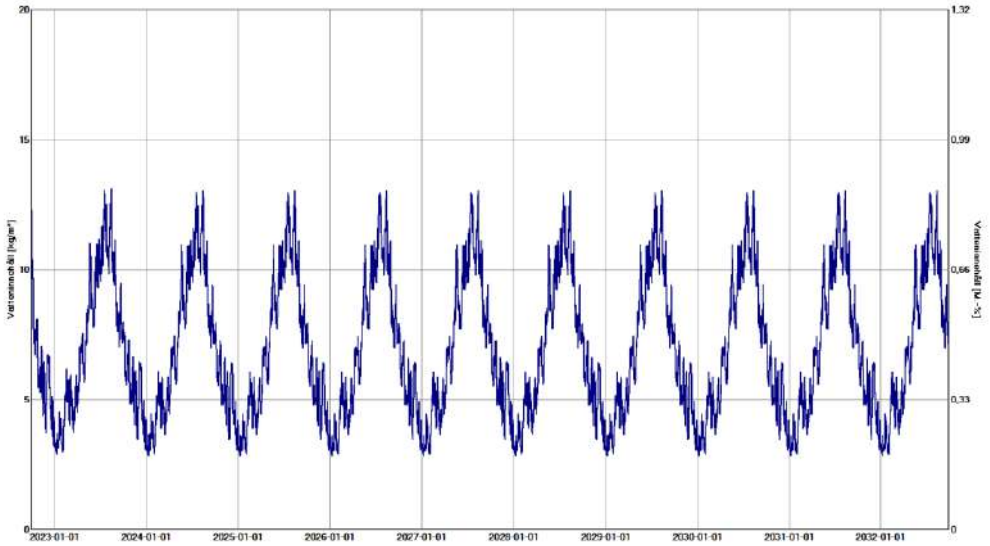
The wood fibreboard has the chance to dry out and the moisture content is always below 16 M.-%, which is below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

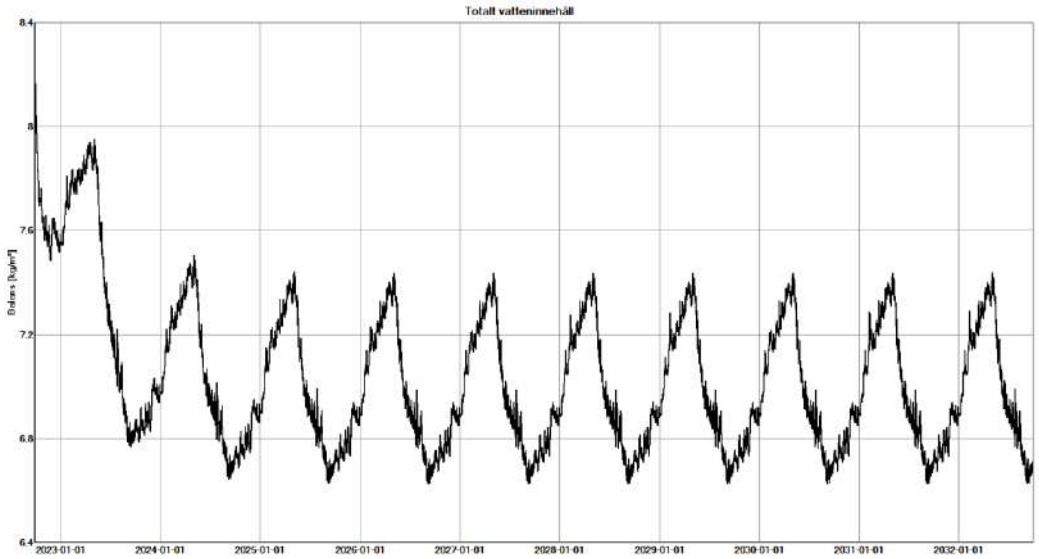
Plaster layer:



The moisture content does not take any harmful forms here.

Wall type H - plastered facade, plasterboard on the inside

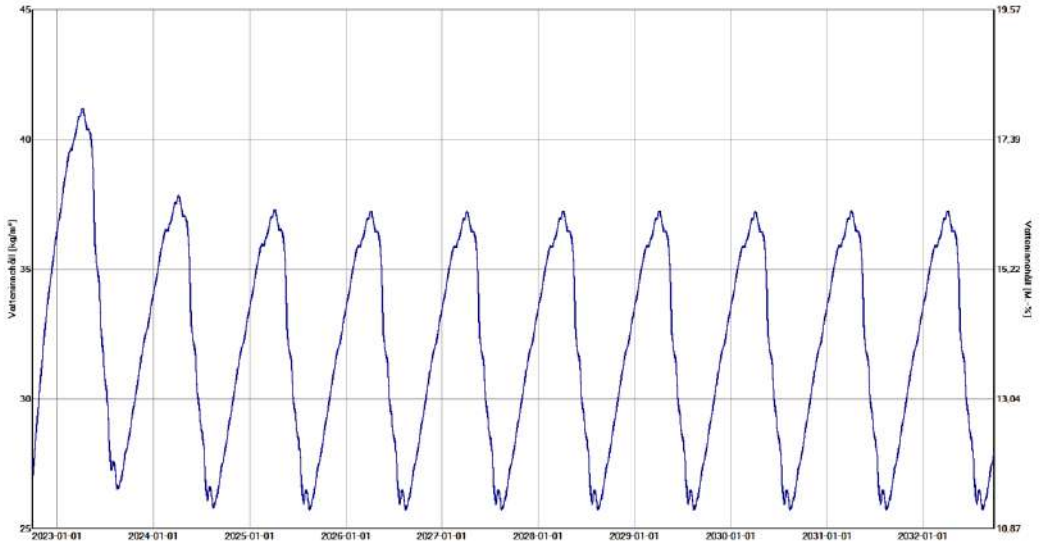
<u>The whole wall</u>



Even with a high built-in moisture content, the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

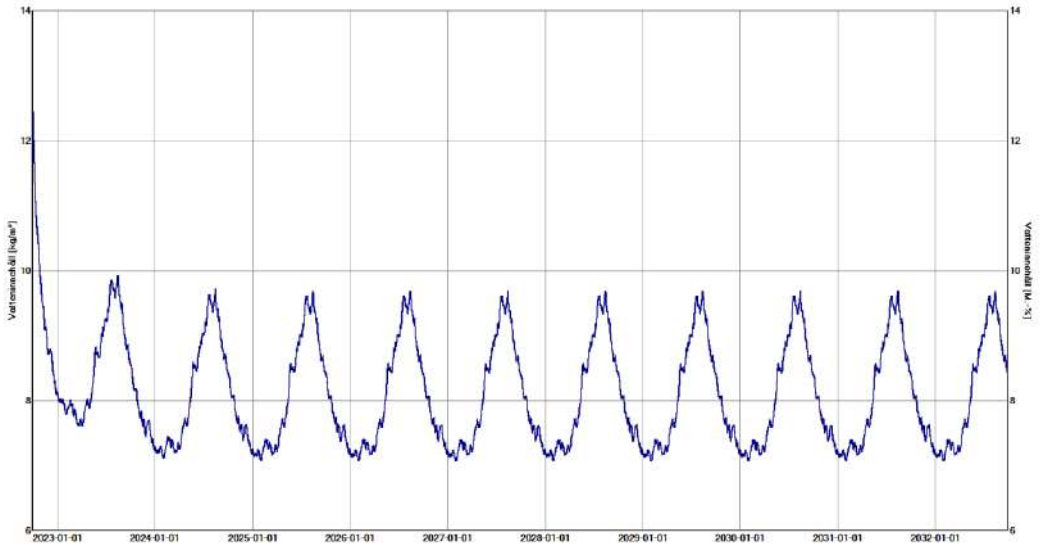
Single layers

Wood fibre behind the plaster:



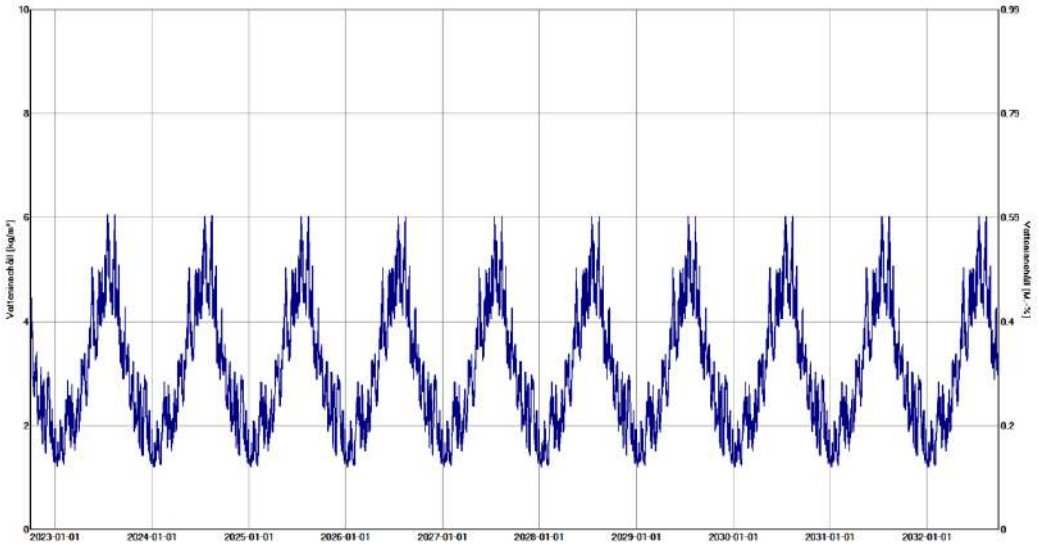
The wood fibreboard has the chance to dry out and the moisture content is always below 16 M.-% which is below the critical limit.

EcoCocon panel (straw):



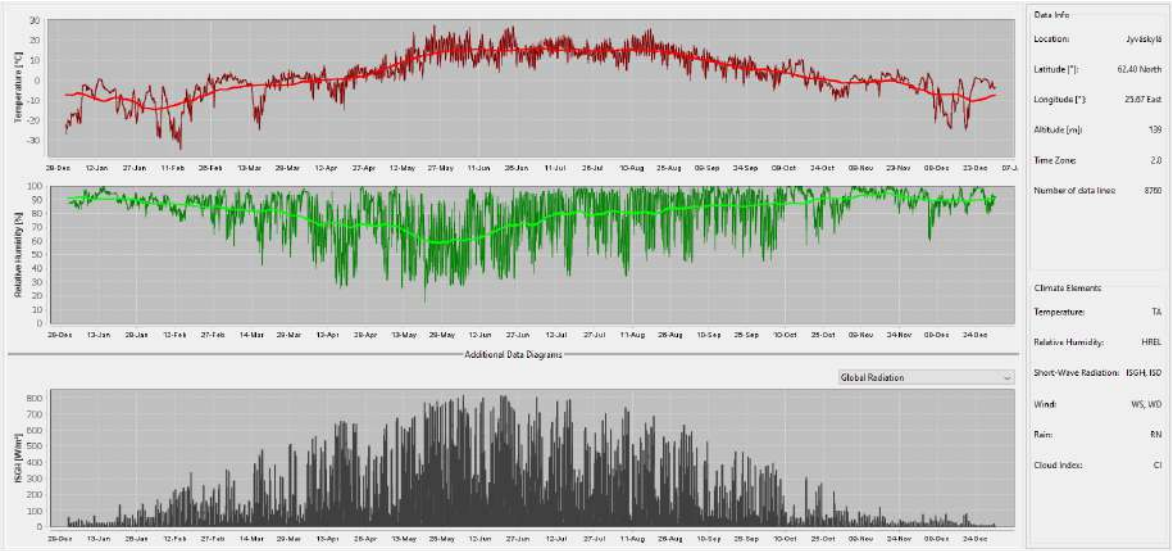
After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

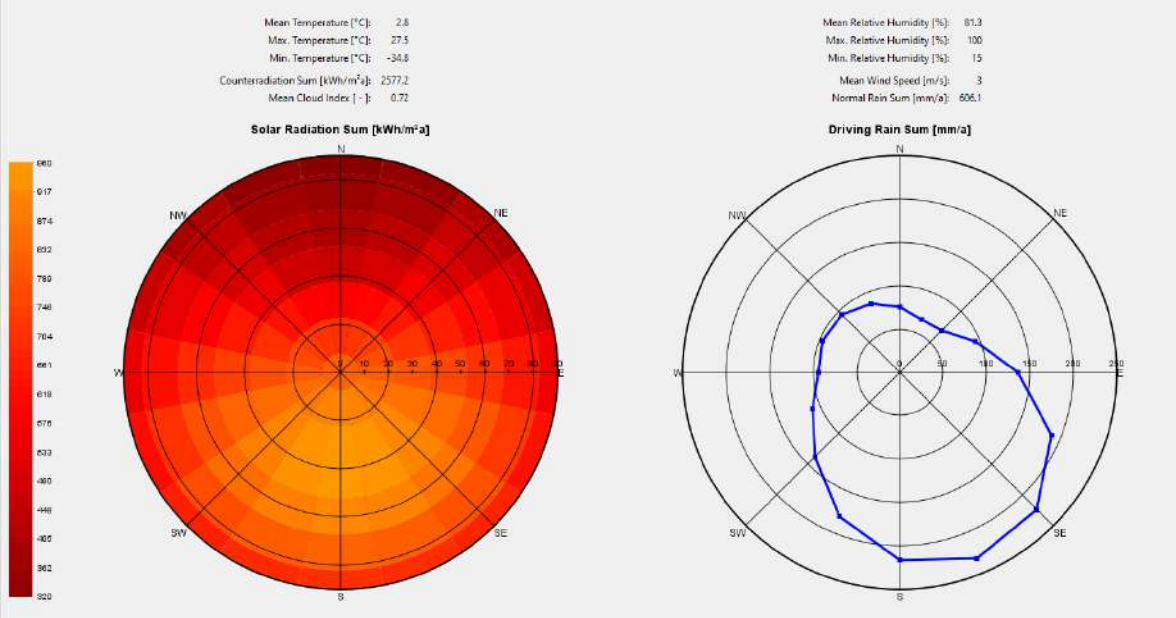
Plasterboard:



The moisture content does not take any harmful forms here.

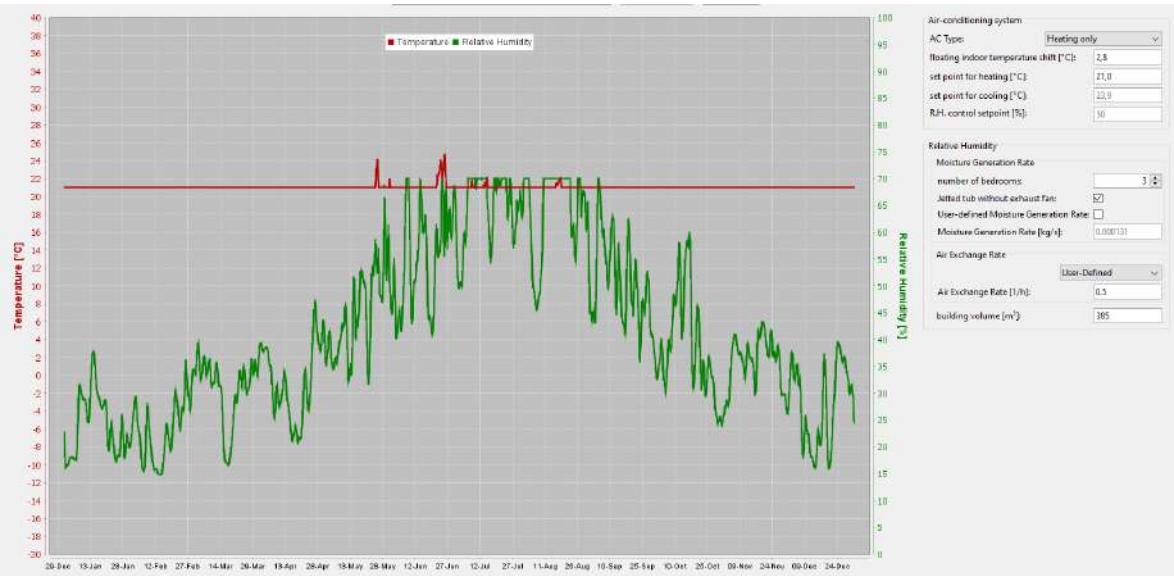
Outdoor climate Jyväskylä (Finland)





The direction with the most driving rain is south-southeast. There is a lot of solar radiation, with higher drying capacity than that towards most other orientations. Therefore, the southeast orientation is used for analyses of plastered walls, with still a lot of driving rain but slightly less drying capacity. For ventilated facades, straight north is always the decisive orientation.

Indoor climate Jyväskylä

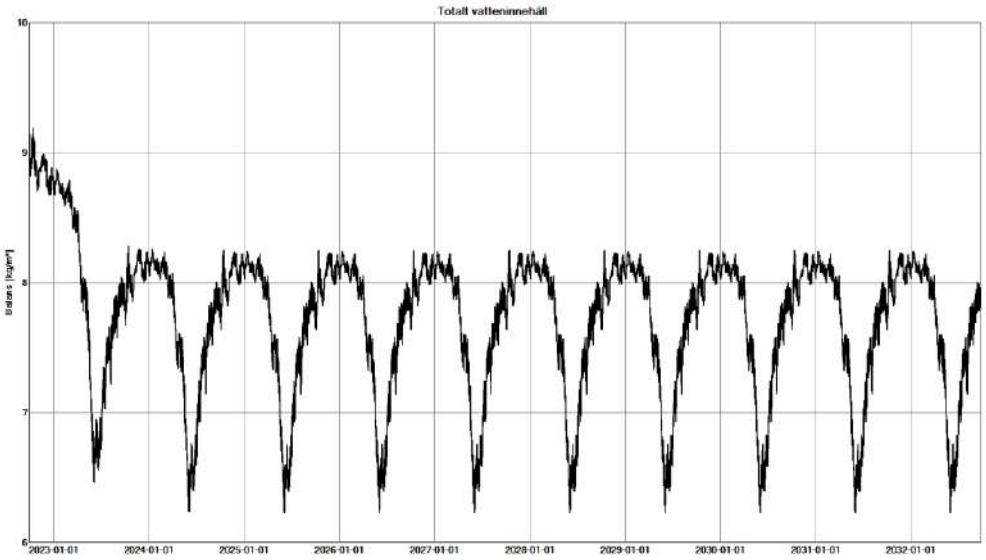


Results Jyväskyla

The following diagram shows the water content in total and in the individual layers.

Wall type A - ventilated facade, plaster on the inside

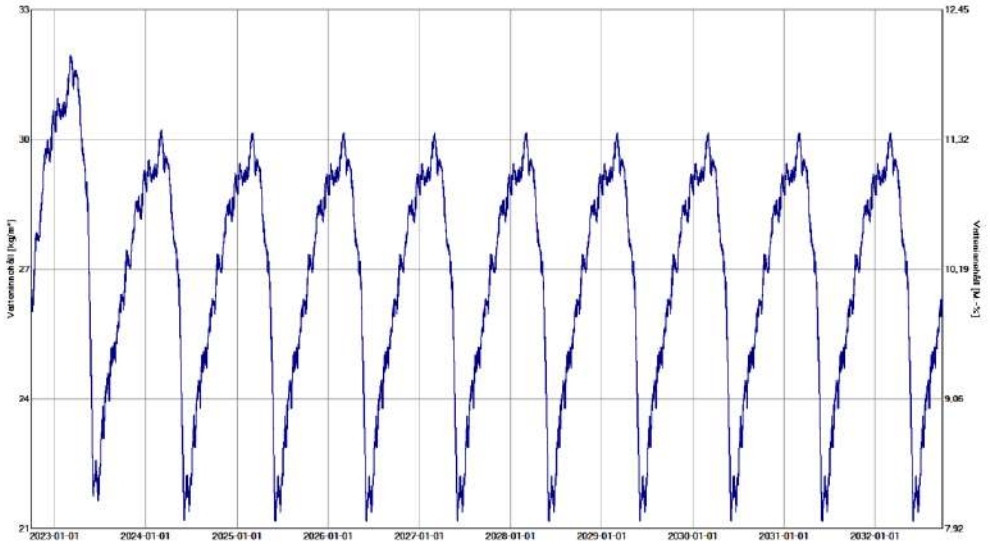
<u>The whole wall</u>



Even with a high built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

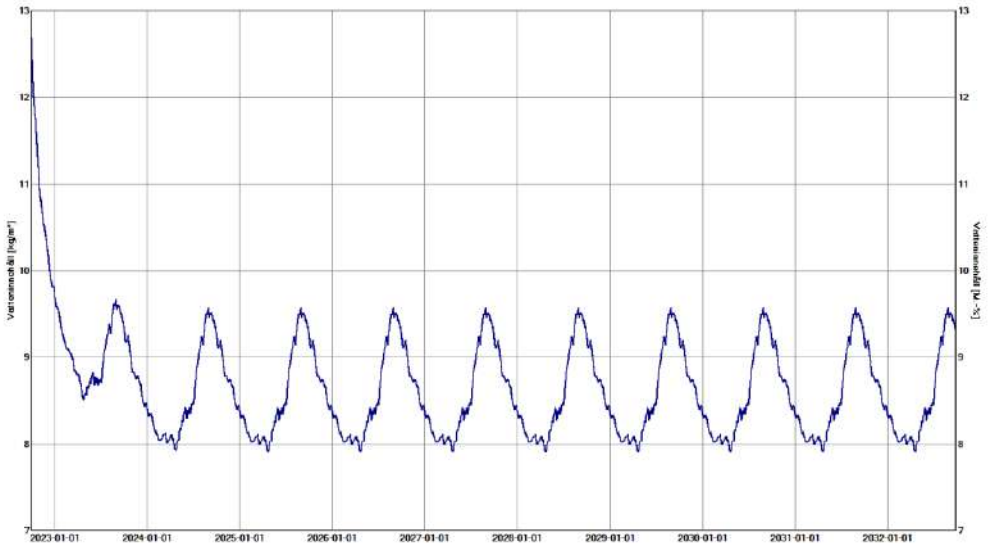
Single layers

Wood fibre behind the air gap:



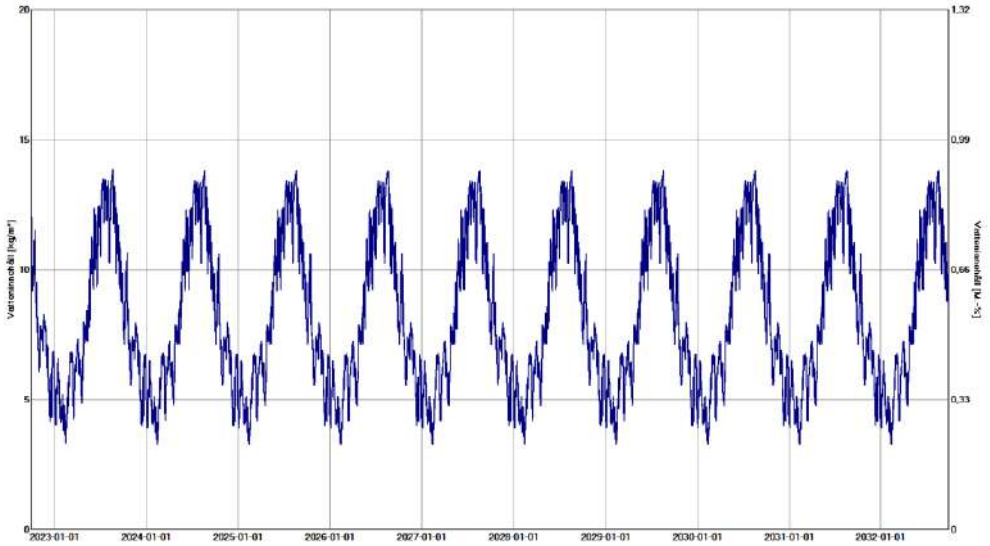
The wood fibreboard has the chance to dry out and the moisture content is always below 12 M.-% which is far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

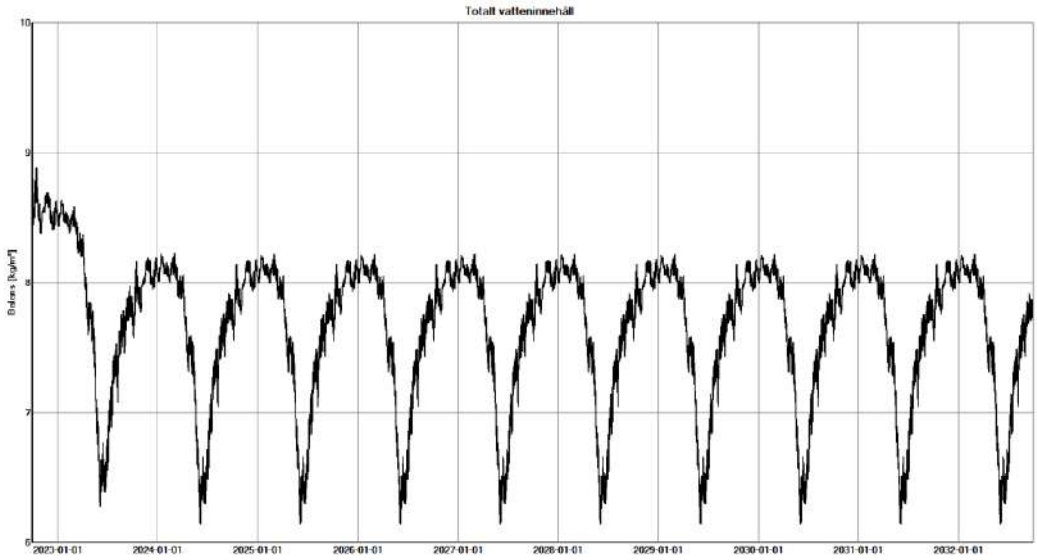
Plaster layer:



The moisture content does not take any harmful forms here. On the contrary: the layer helps to improve the indoor climate by buffering the humidity.

Wall type B - ventilated facade, plasterboard on the inside

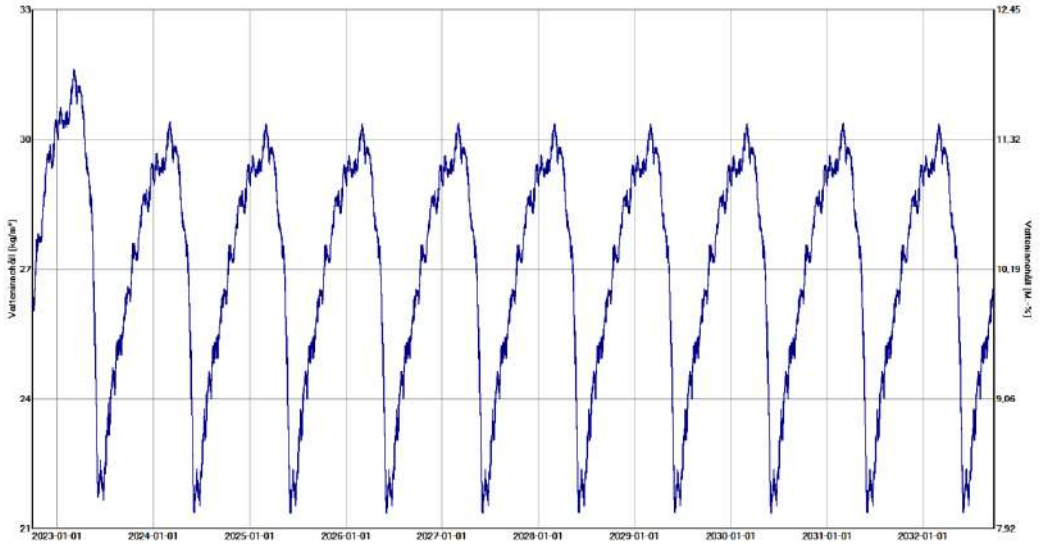
<u>The whole wall</u>



Even with a high built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

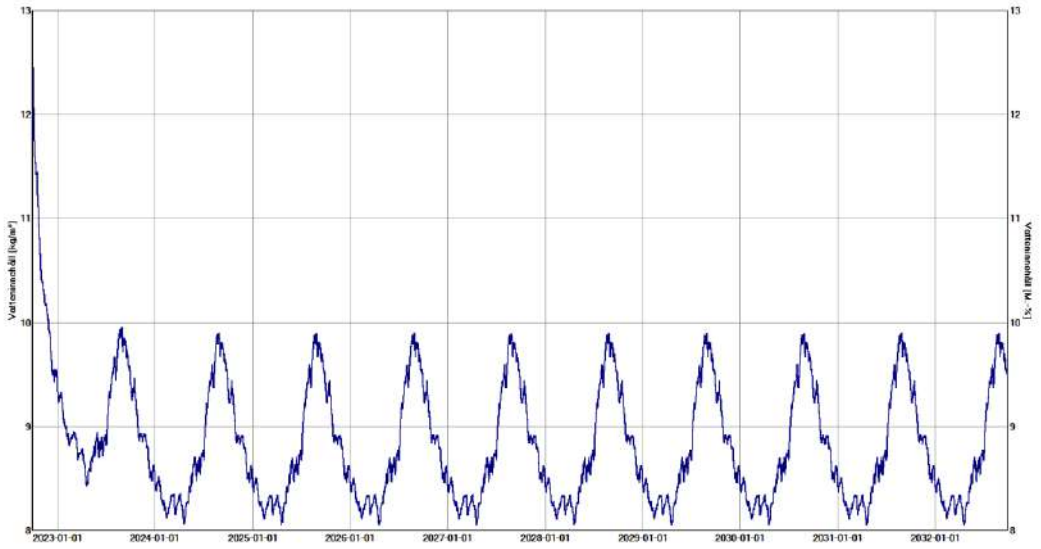
Single layers

Wood fibre behind the air gap:



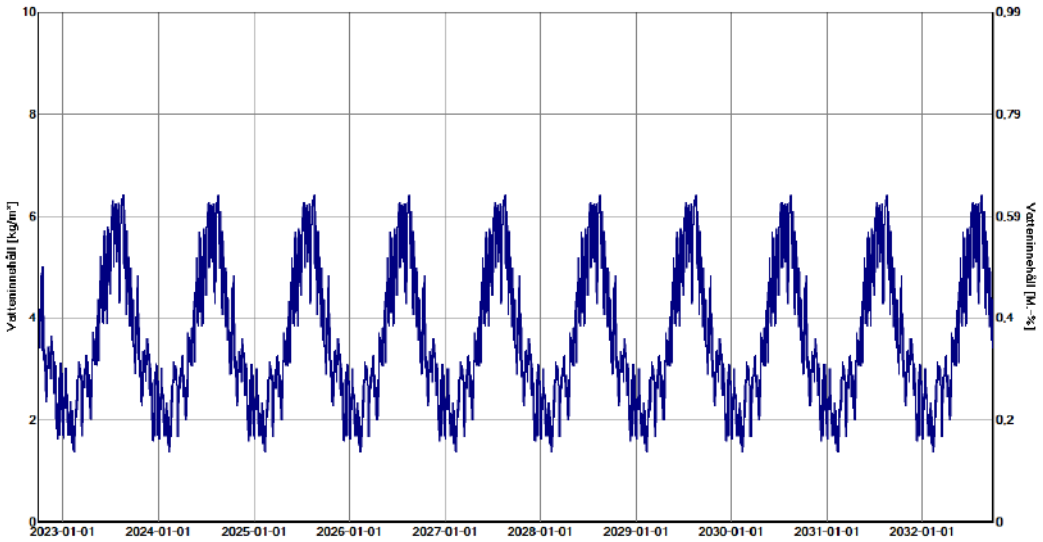
The wood fibreboard has the chance to dry out and the moisture content is always below 12 M.-% which is far below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 10 M.-% all the time.

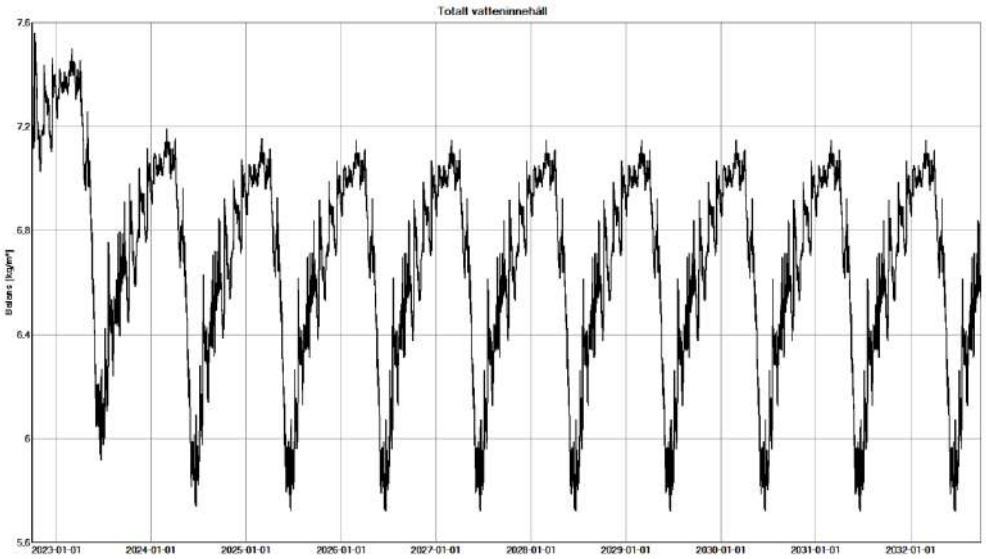
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type C - plastered facade, plaster on the inside

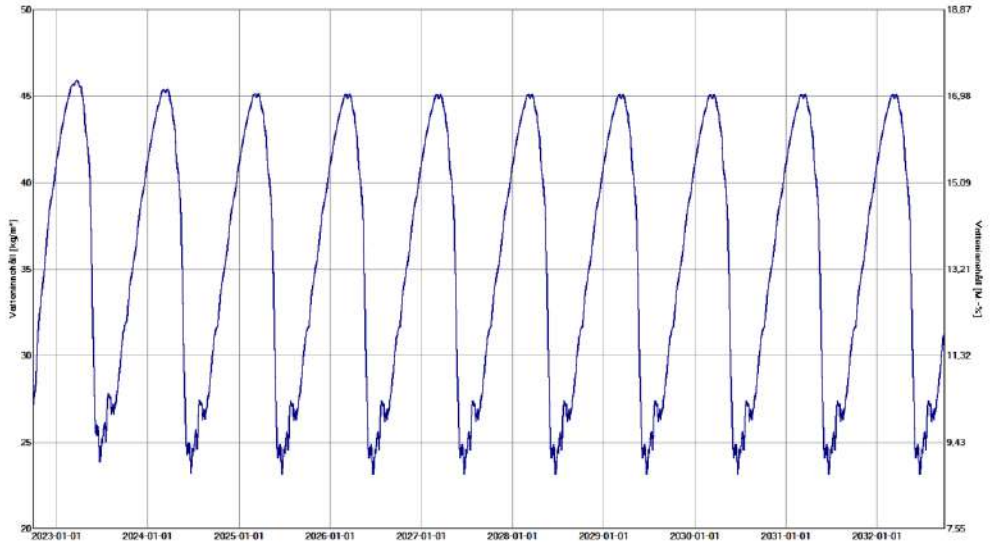
<u>The whole wall</u>



Even with a high built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

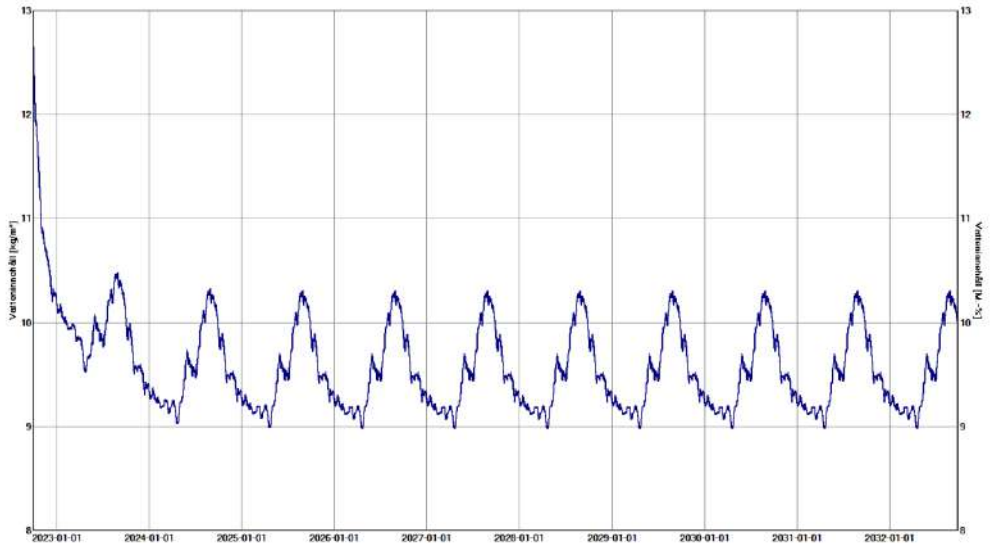
Single layers

Wood fibre behind the plaster:



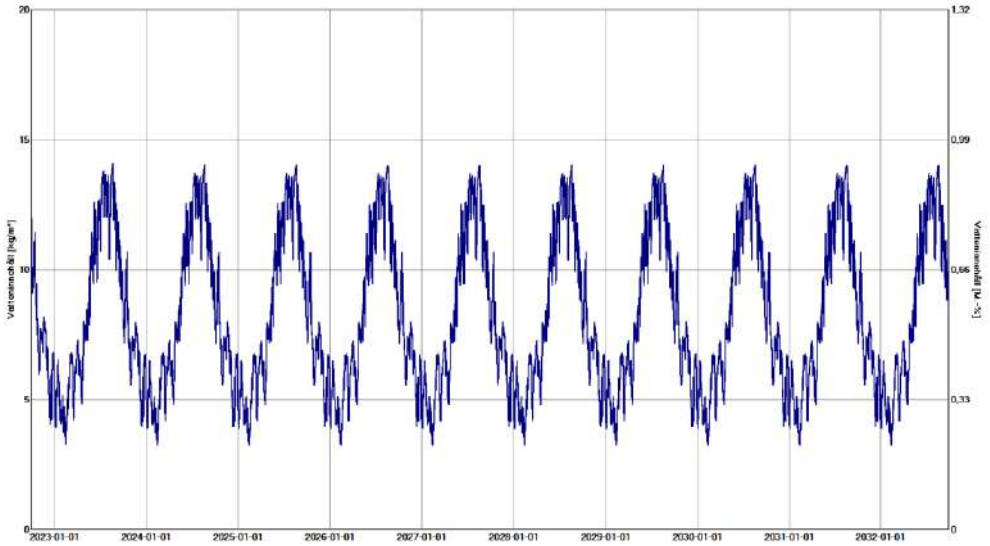
The wood fibreboard has the chance to dry out and the water content is always below the 18 M.-% which is considered the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

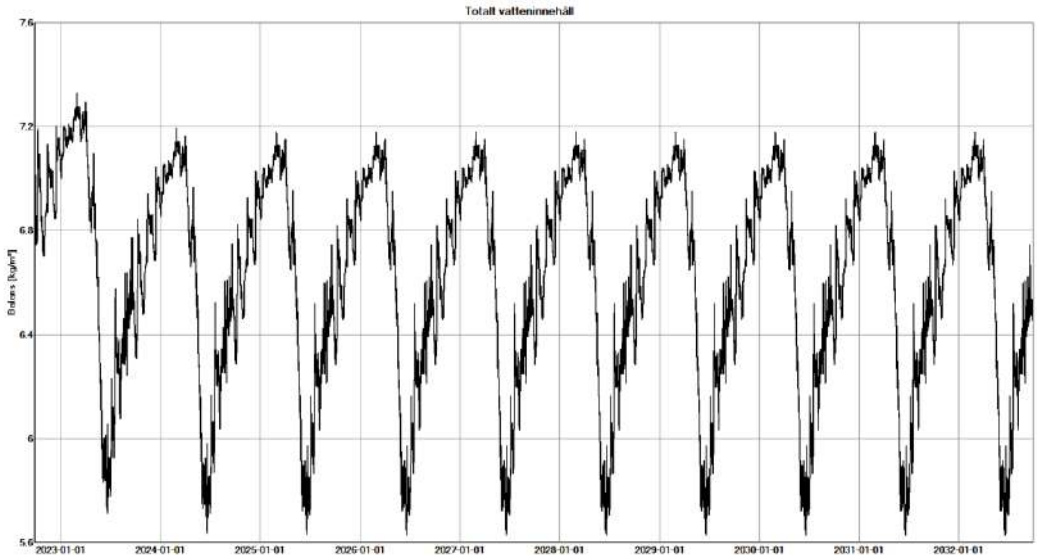
Plaster layer:



The moisture content does not take any harmful forms here.

Wall type D - plastered facade, plasterboard on the inside

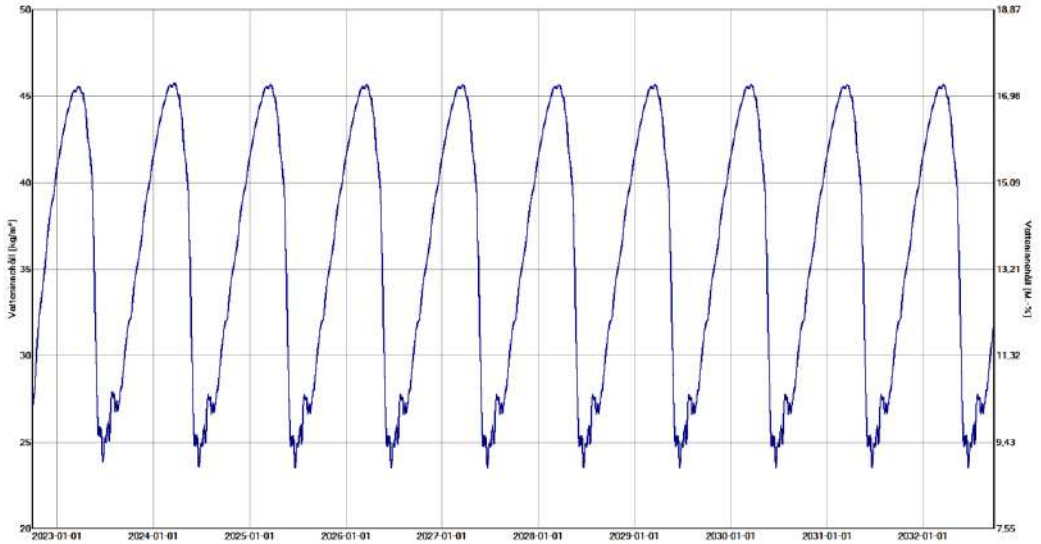
<u>The whole wall</u>



Even with a high built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

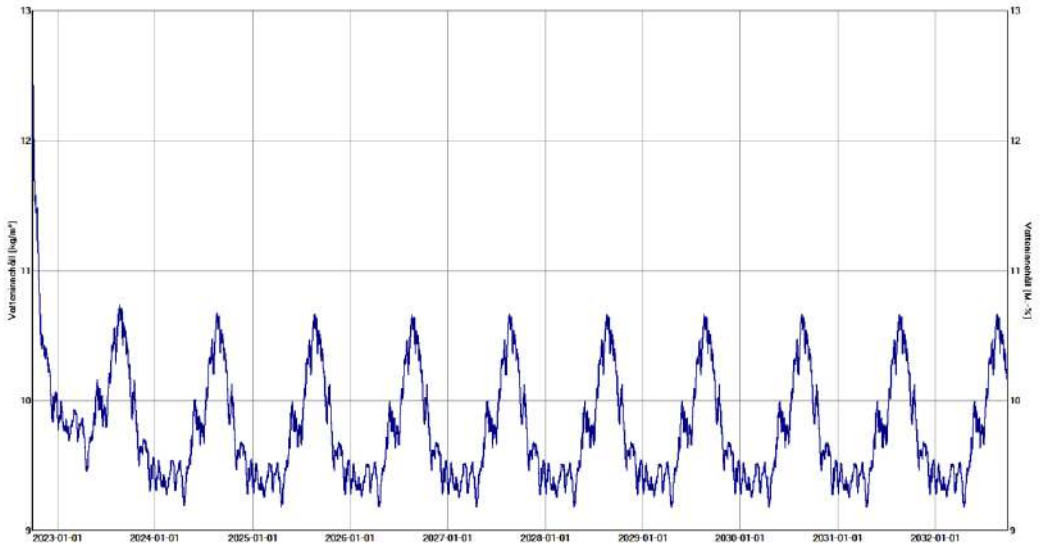
Single layers

Wood fibre behind the plaster:



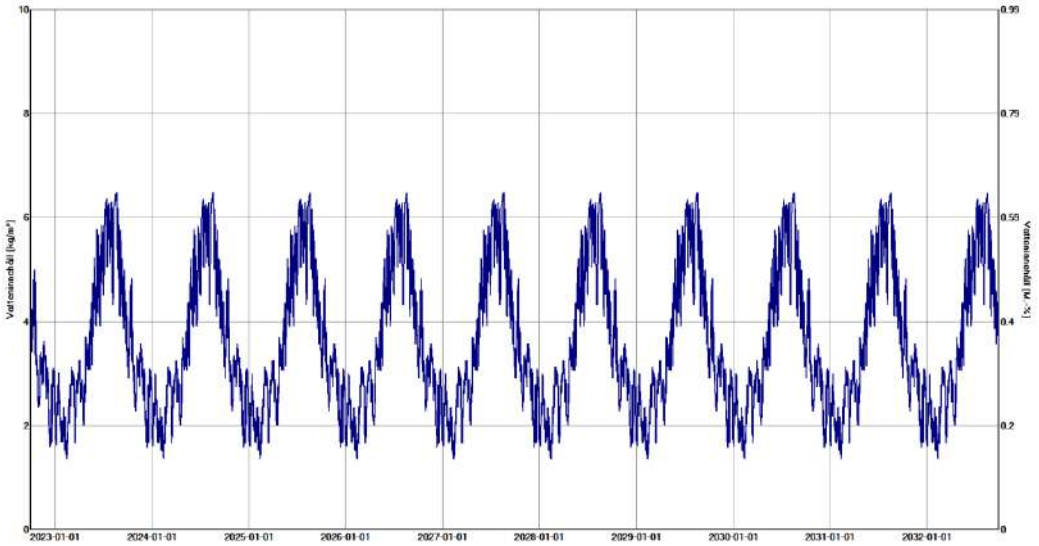
The wood fibreboard has the chance to dry out and the moisture content is always below the 18 M.-% which is considered the critical limit.

EcoCocon panel (straw):



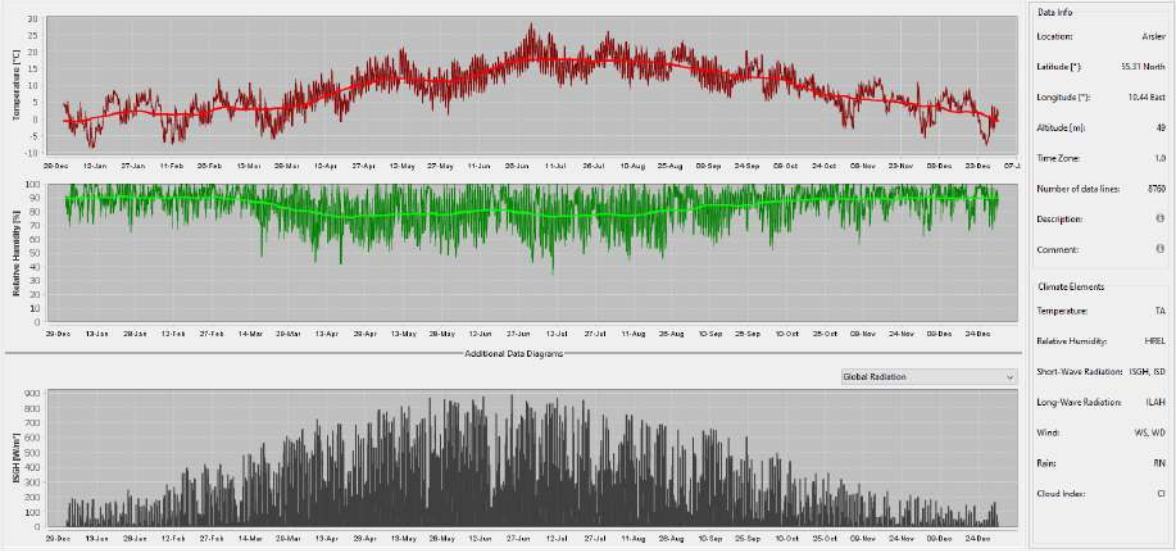
After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

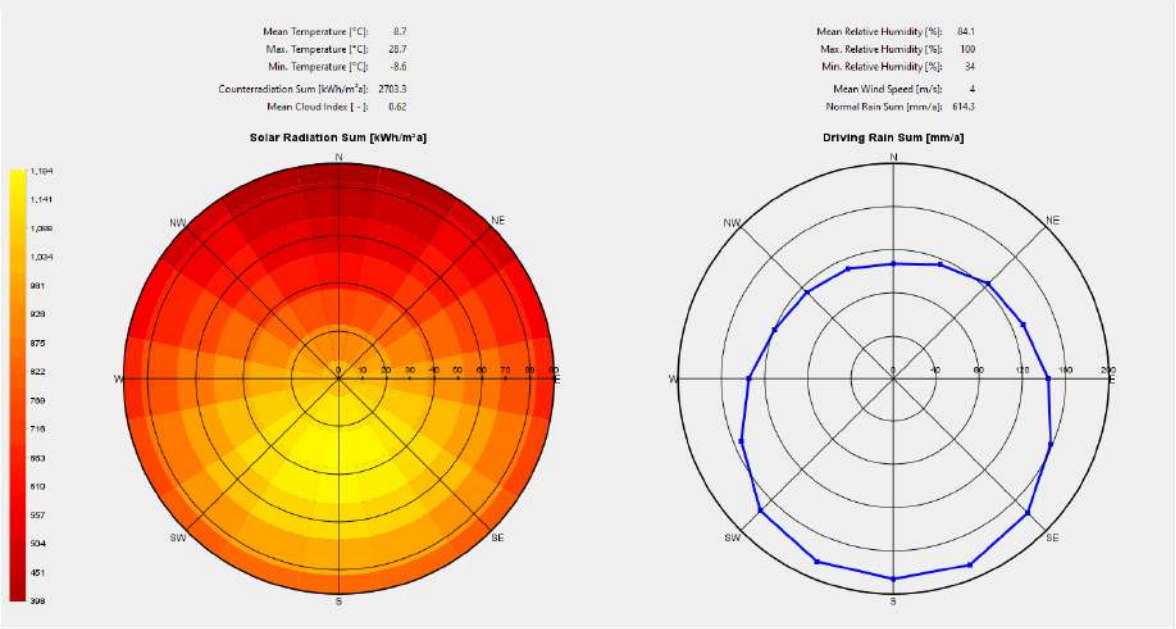
Plasterboard:



The moisture content does not take any harmful forms here.

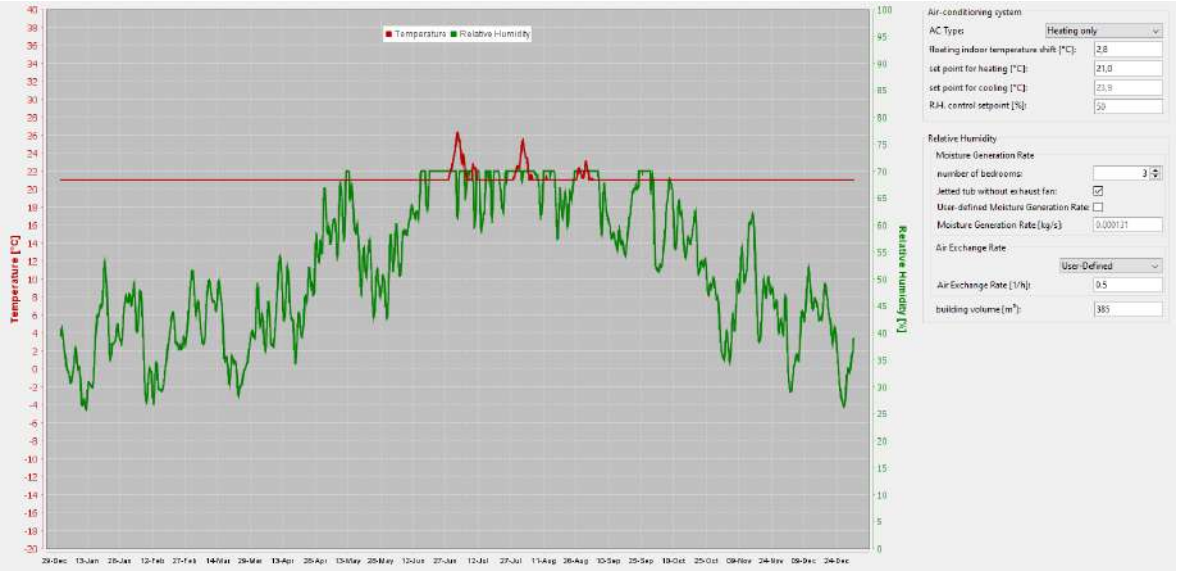
Outdoor climate Aarslev (Denmark)





The direction with the most driving rain is south. There is also the strongest solar radiation, with high drying capacity. Therefore, the southeast orientation is used for analyses of plastered walls, with still high driving rain, but less drying from solar irradiation. For ventilated facades, straight north orientation is always the decisive one.

Indoor climate Aarslev

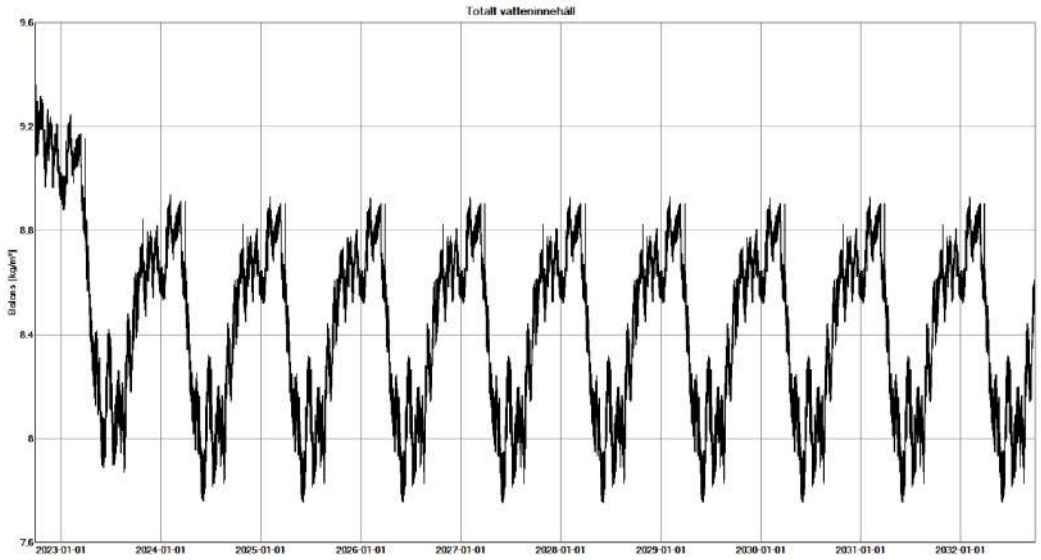


Results Aarslev

The following diagram shows the water content in total and in the individual layers.

Wall type A - ventilated facade, plaster on the inside

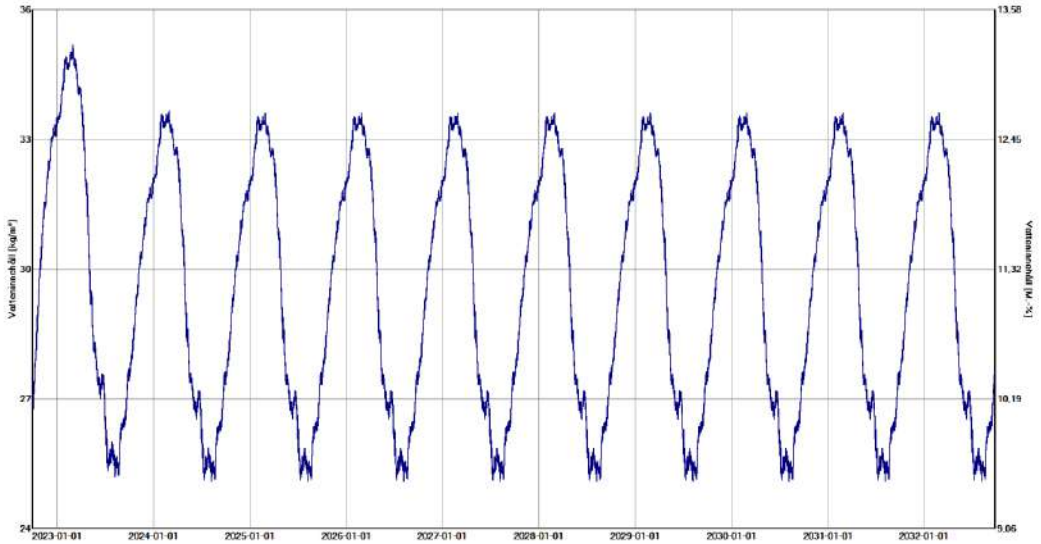
<u>The whole wall</u>



Even with built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

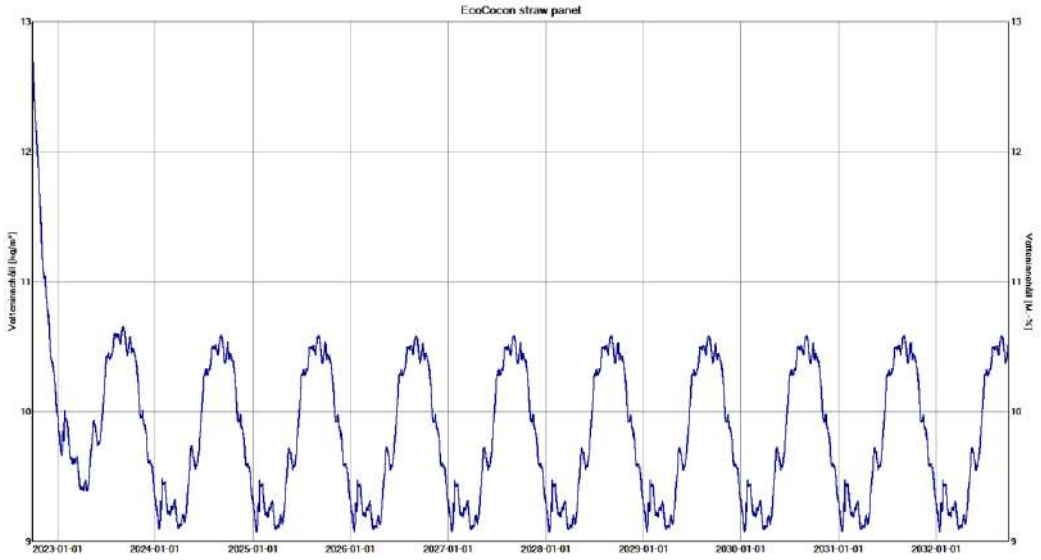
Single layers

Wood fibre behind the air gap:



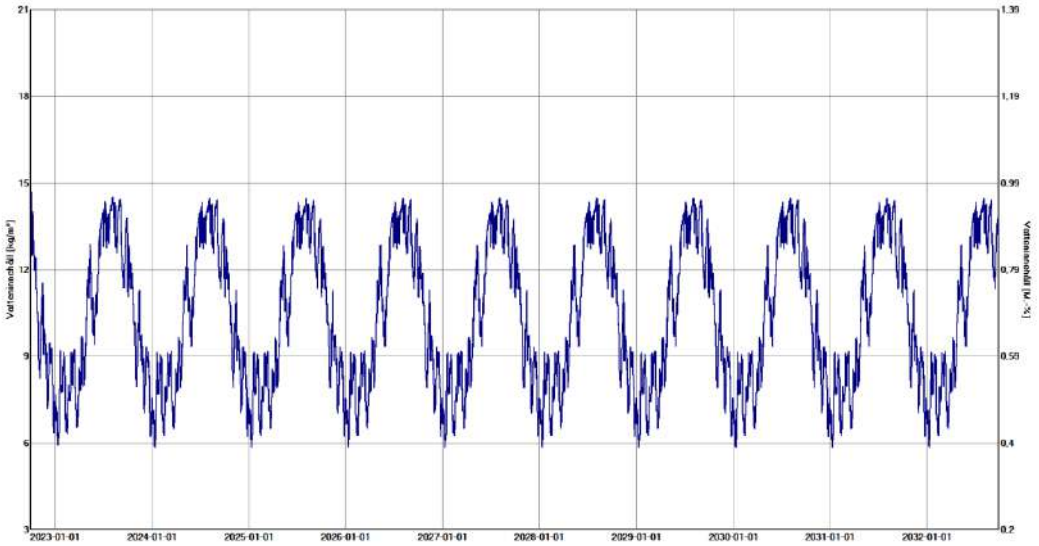
The wood fibreboard has the chance to dry out and the water content is then constantly below 13 M.-% and thus below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

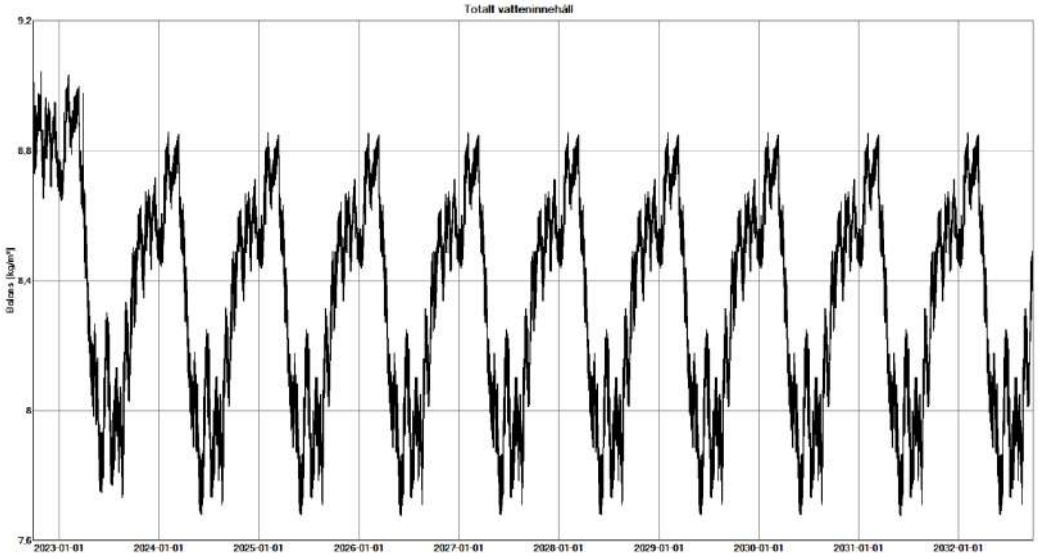
Plaster layer:



The moisture content does not take any harmful forms here - on the contrary: the layer helps to improve the indoor climate by buffering the humidity.

Wall type B - ventilated facade, plasterboard on the inside

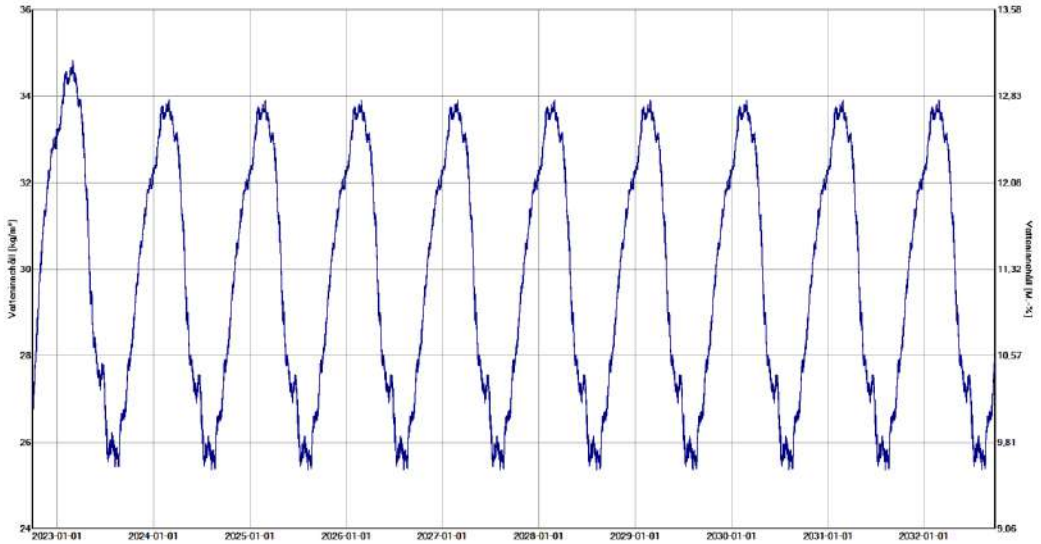
<u>The whole wall</u>



Even with built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

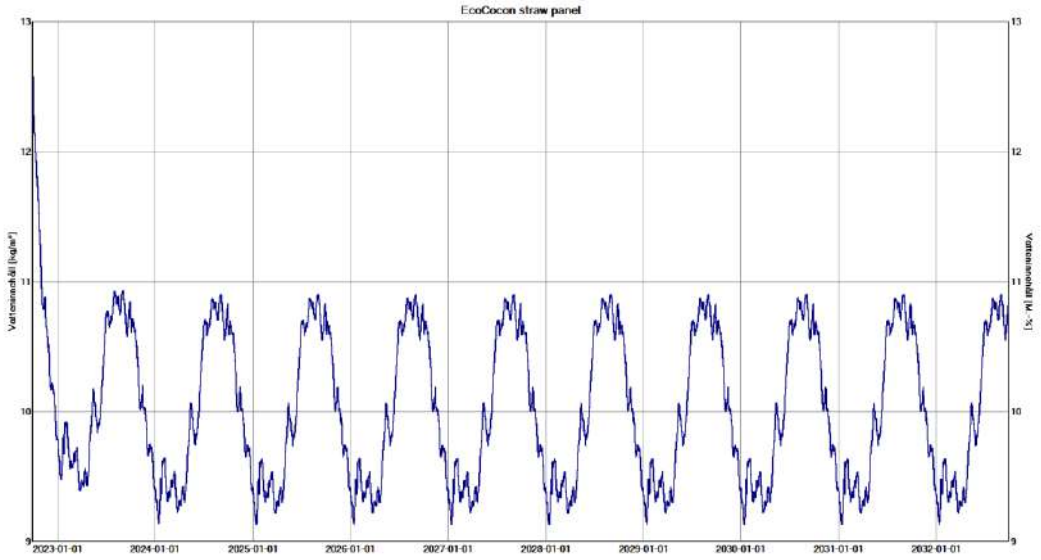
Single layers

Wood fibre behind the air gap:



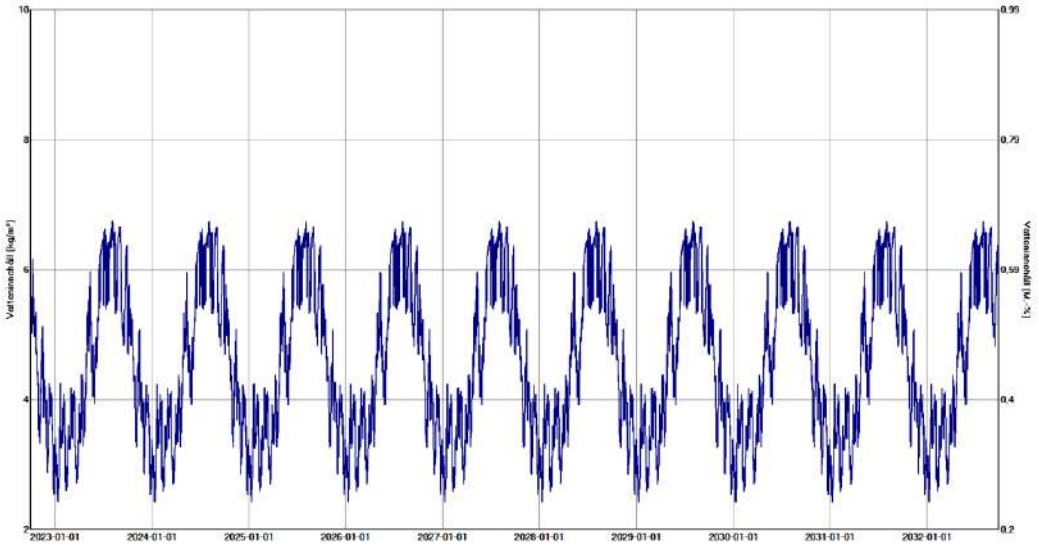
The wood fibreboard has the chance to dry out and the relative humidity is constantly below 13 M.-% and thus below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

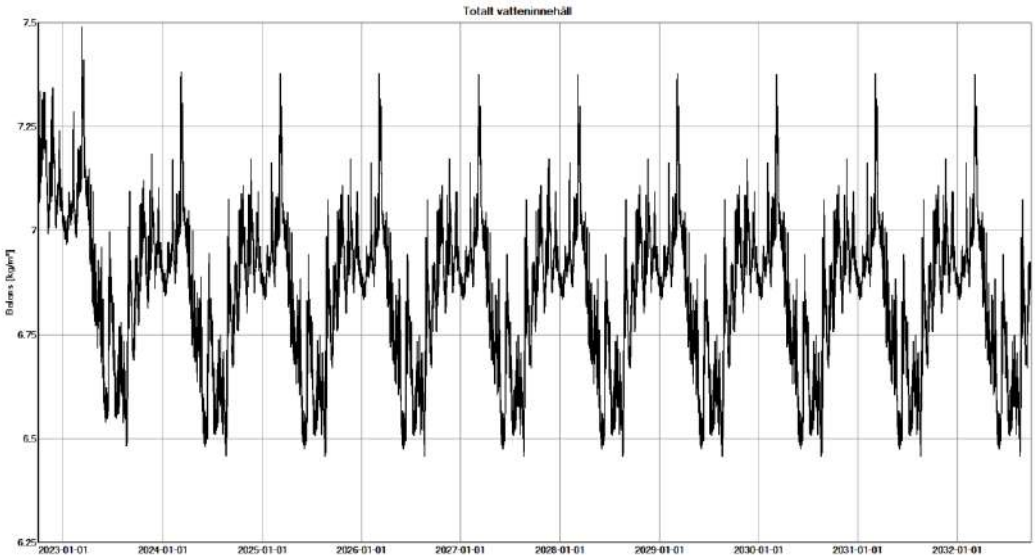
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type C - plastered facade, plaster on the inside

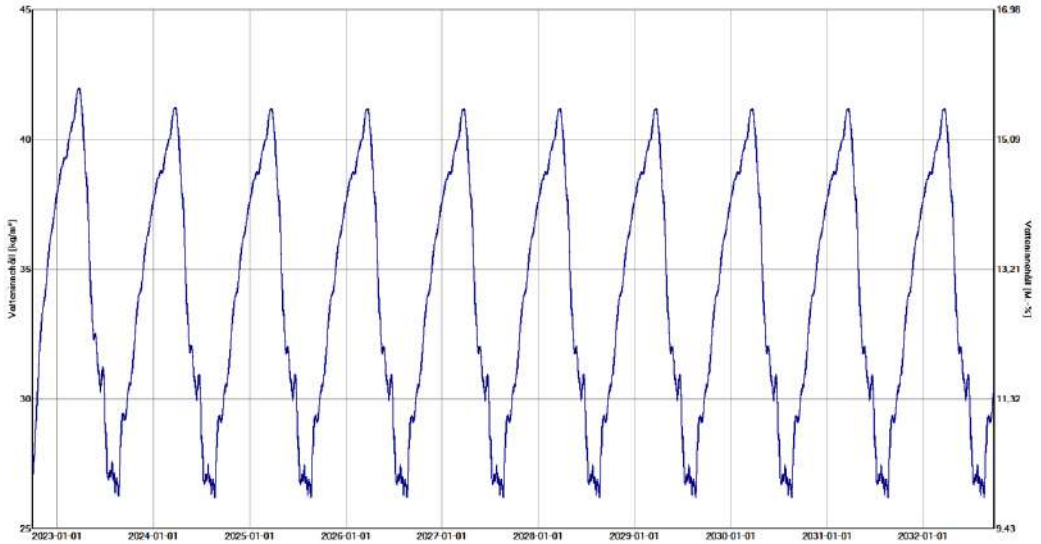
<u>The whole wall</u>



A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

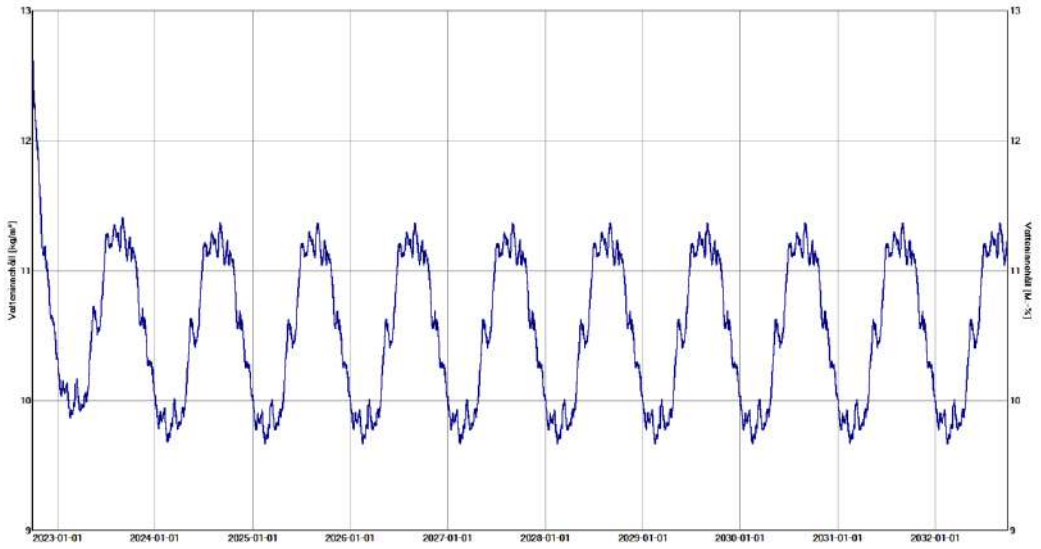
Single layers

Wood fibre behind the plaster:



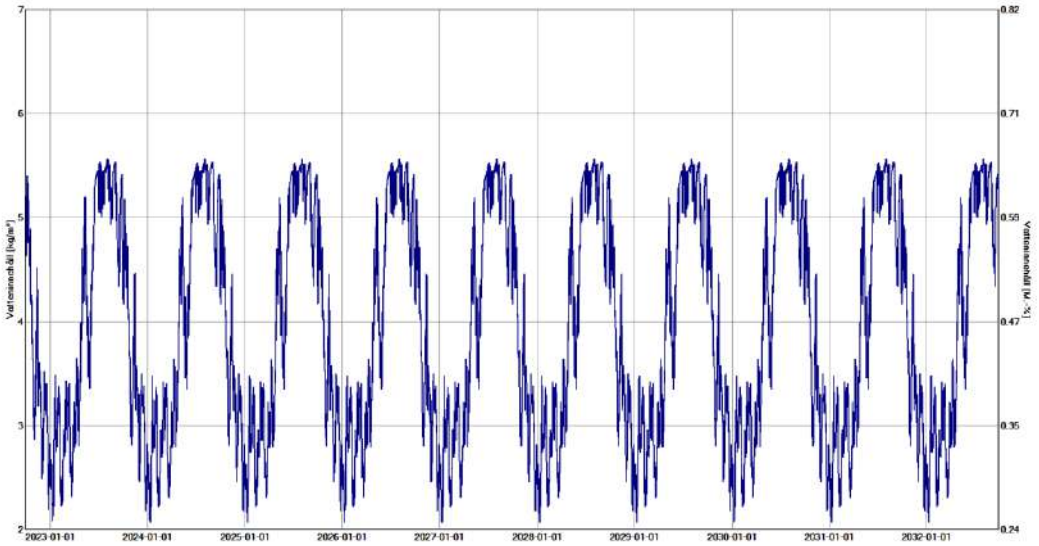
The wood fibreboard has the chance to dry out and the water content is always below the 18 M.-% which is considered the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 12 M.-% all the time.

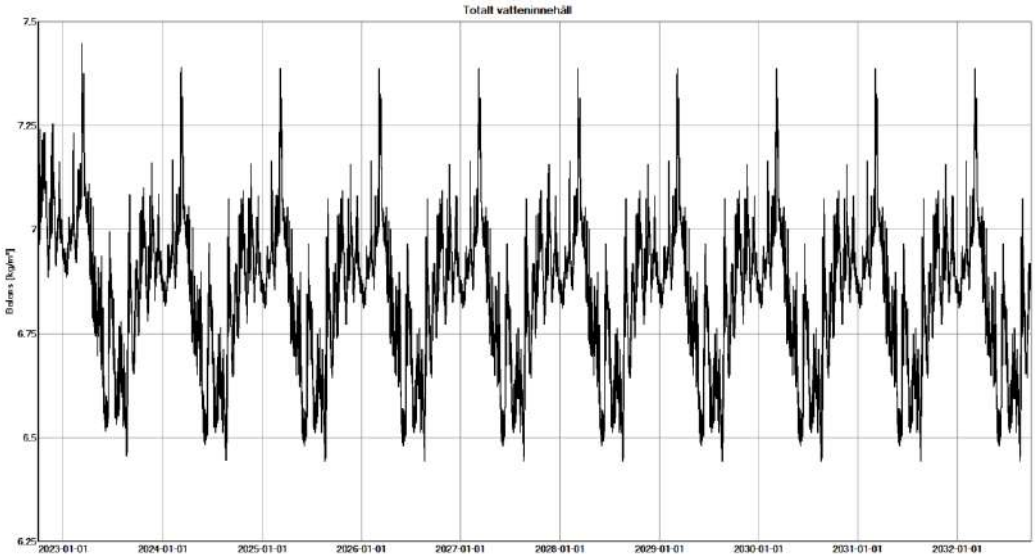
Plaster layer:



The moisture content does not take any harmful forms here.

Wall type D - plastered facade, plasterboard on the inside

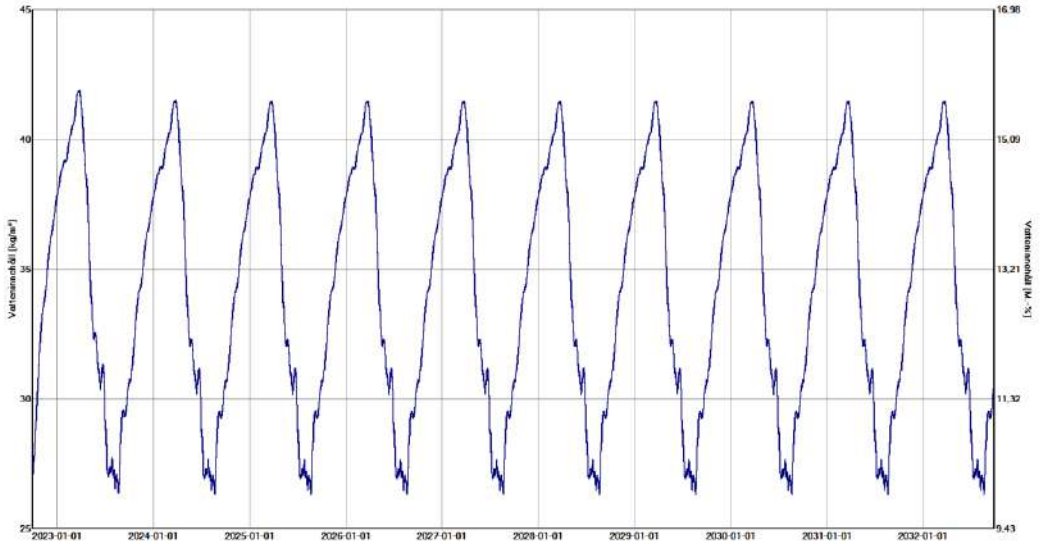
<u>The whole wall</u>



A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

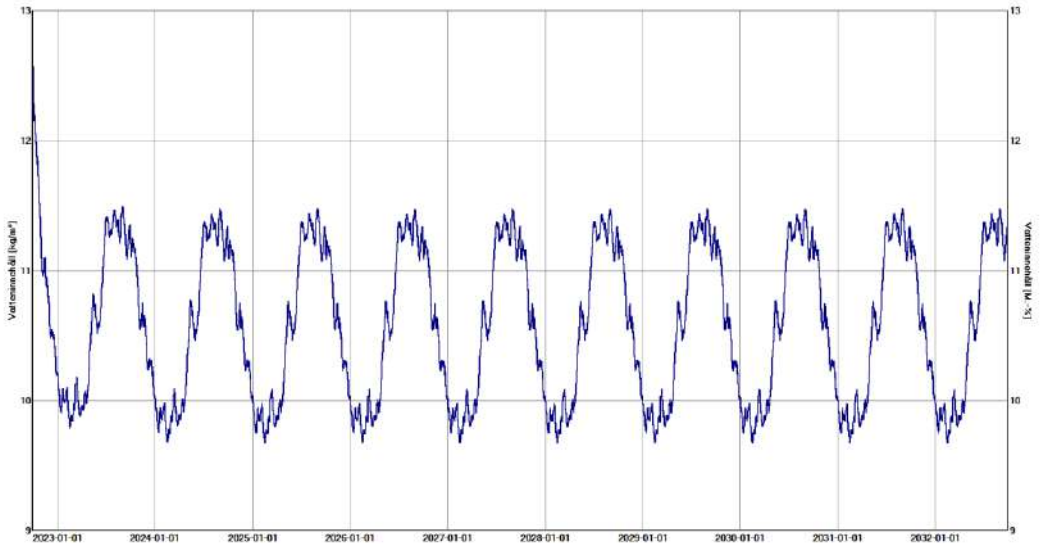
Single layers

Wood fibre behind the plaster:



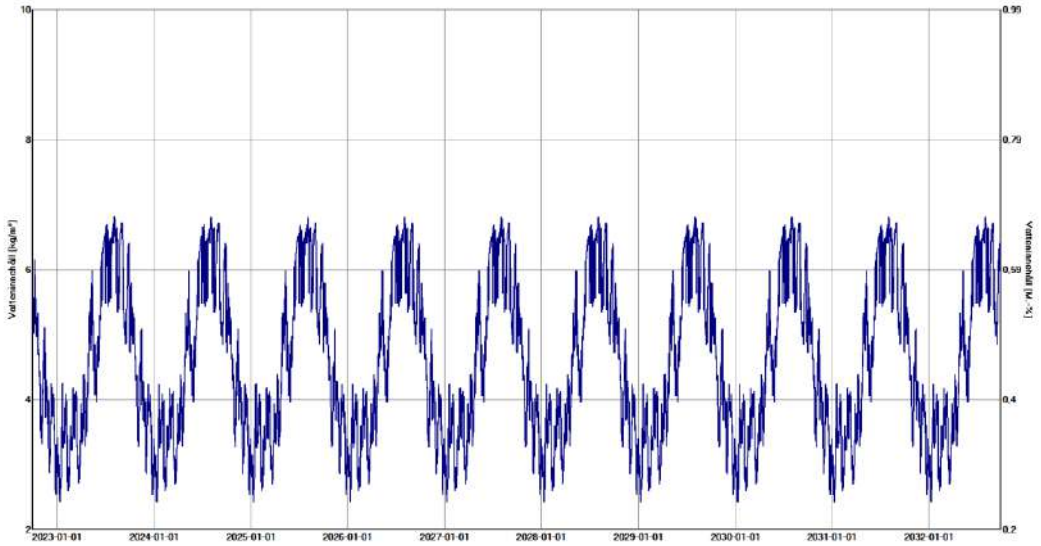
The wood fibreboard has the chance to dry out and the water content is always below the 18 M.-% which is considered to be the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 12 M.-% all the time.

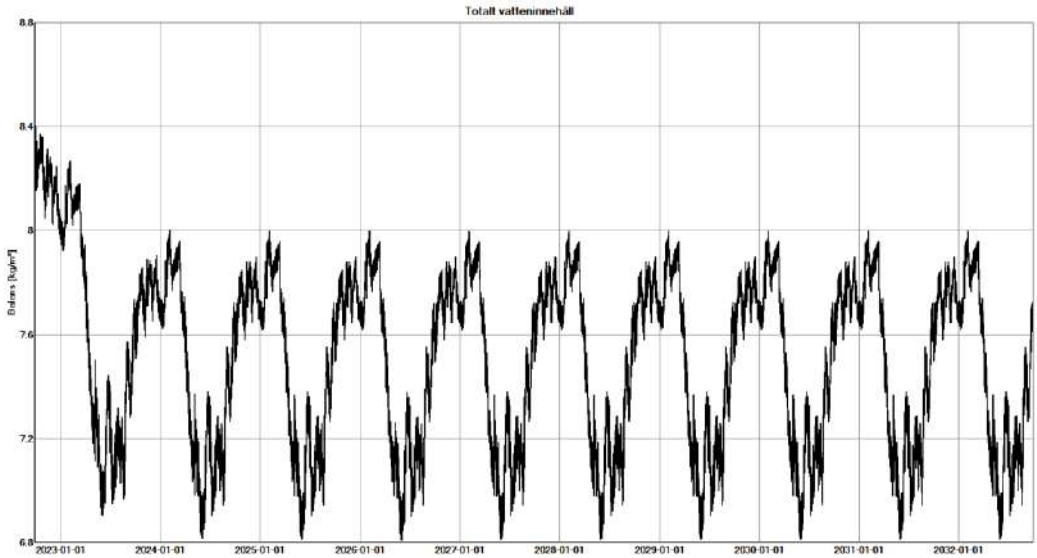
Plasterboard:



The moisture content here does not take any harmful forms.

Wall type J - ventilated facade, plaster on the inside

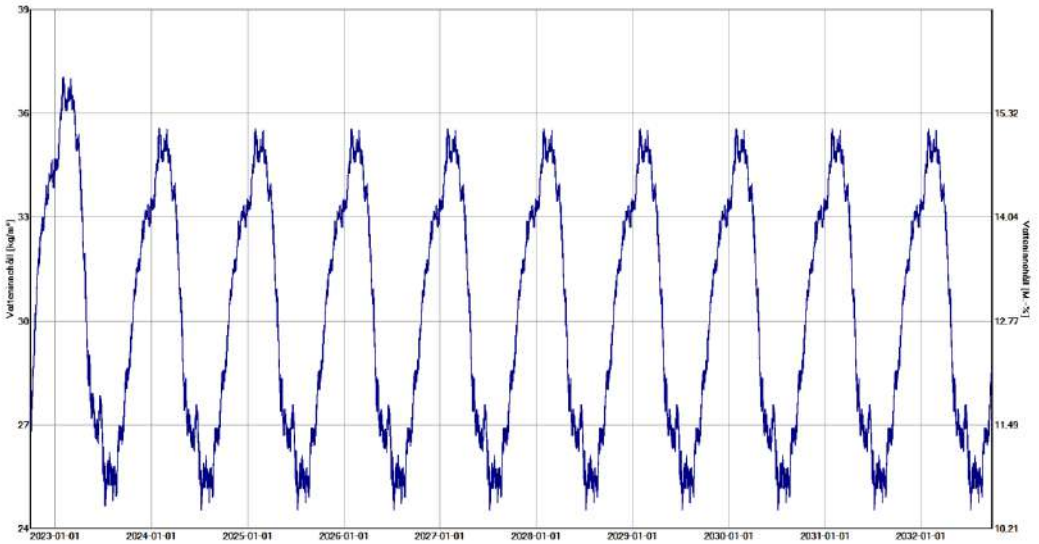
<u>The whole wall</u>



Even with built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

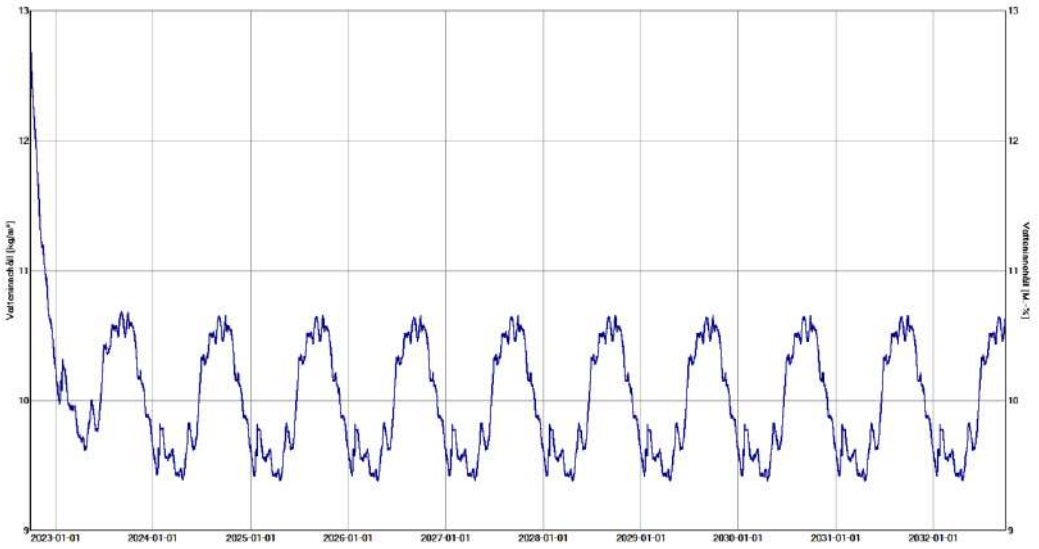
Single layers

Wood fibre behind the air gap:



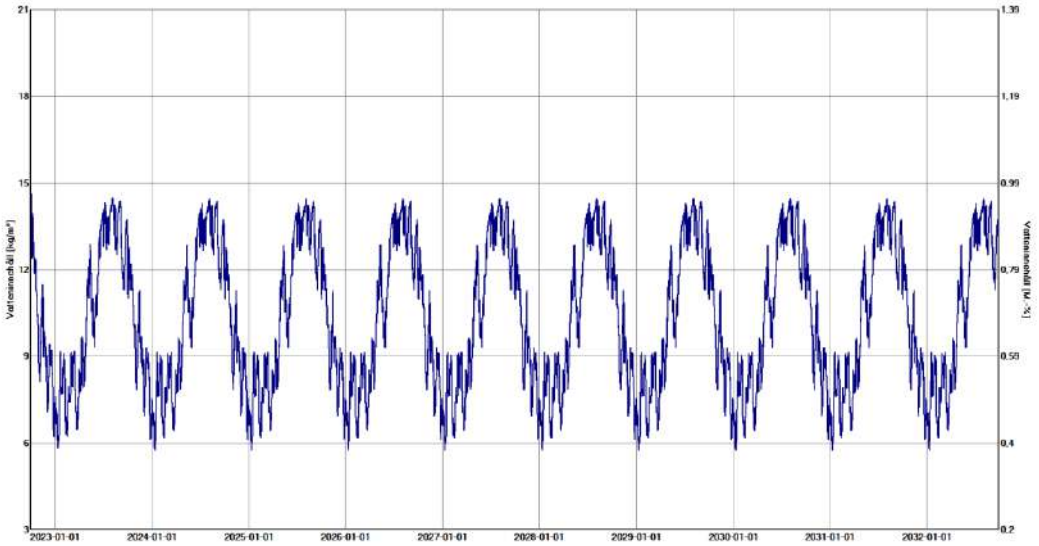
The wood fibreboard has the chance to dry out and the water content is then constantly below 15 M.-% and thus below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

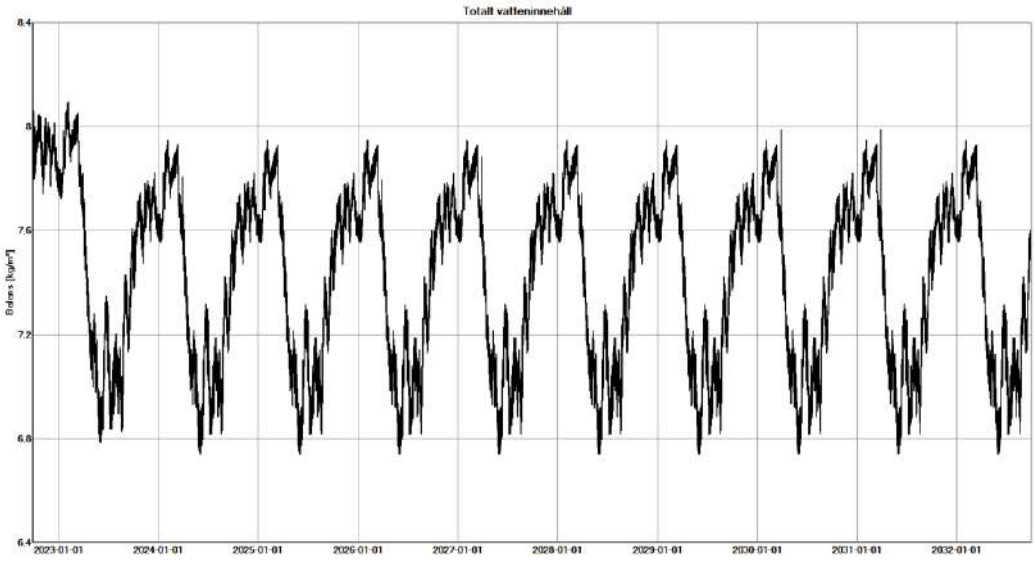
Plaster layer:



The moisture content does not take any harmful forms here - on the contrary: the layer helps to improve the indoor climate by buffering the humidity.

Wall type K - ventilated facade, plasterboard on the inside

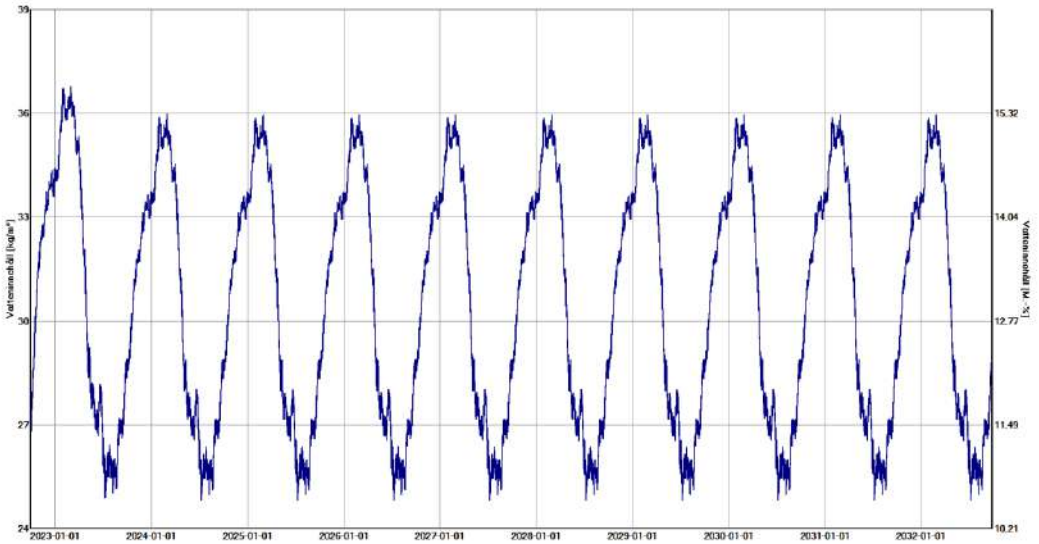
<u>The whole wall</u>



Even with built-in moisture content (80%), the entire wall structure dries out quite quickly. A simulation over 10 years shows that there is no accumulation of moisture over the long term. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly. As the building consists of prefabricated modules, the risk of internal moisture or leakage is even lower.

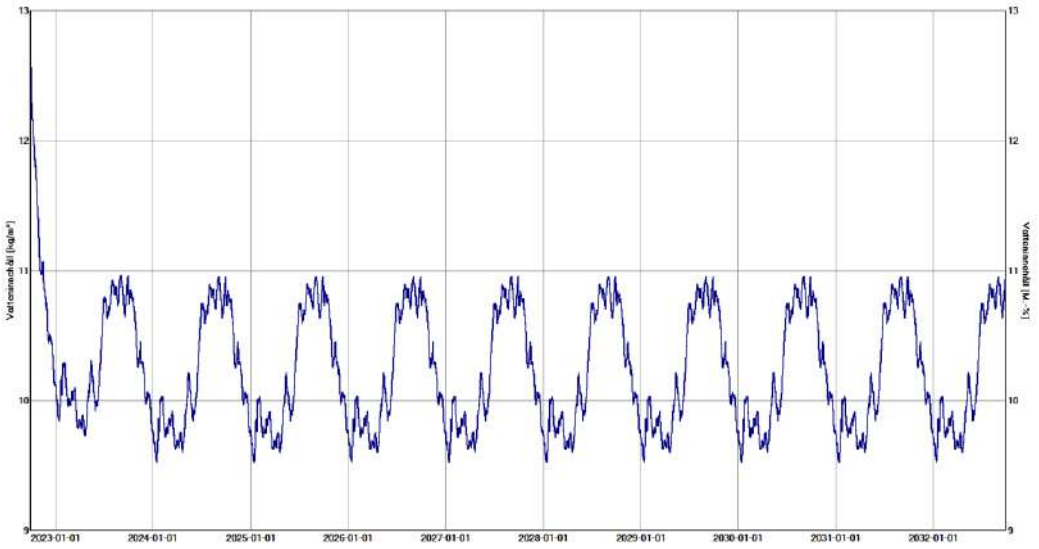
Single layers

Wood fibre behind the air gap:



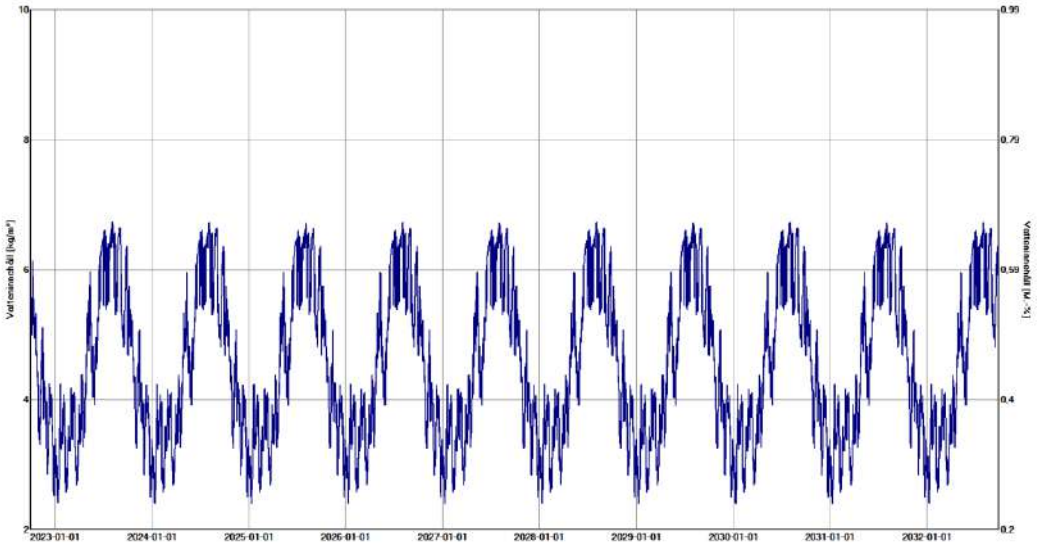
The asphalt fibreboard has the chance to dry out and the relative humidity is constantly below 16 M.-% and thus below the critical limit.

EcoCocon panel (straw):



After the deliberately high value at the beginning, the water content drops immediately and stays below 11 M.-% all the time.

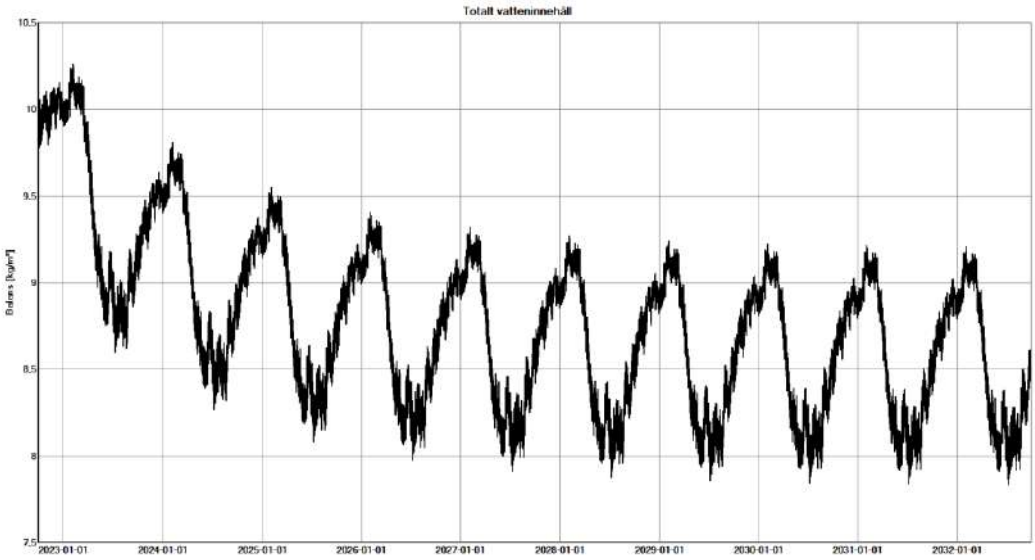
Plasterboard:



The moisture content does not take any harmful forms here.

Wall type M

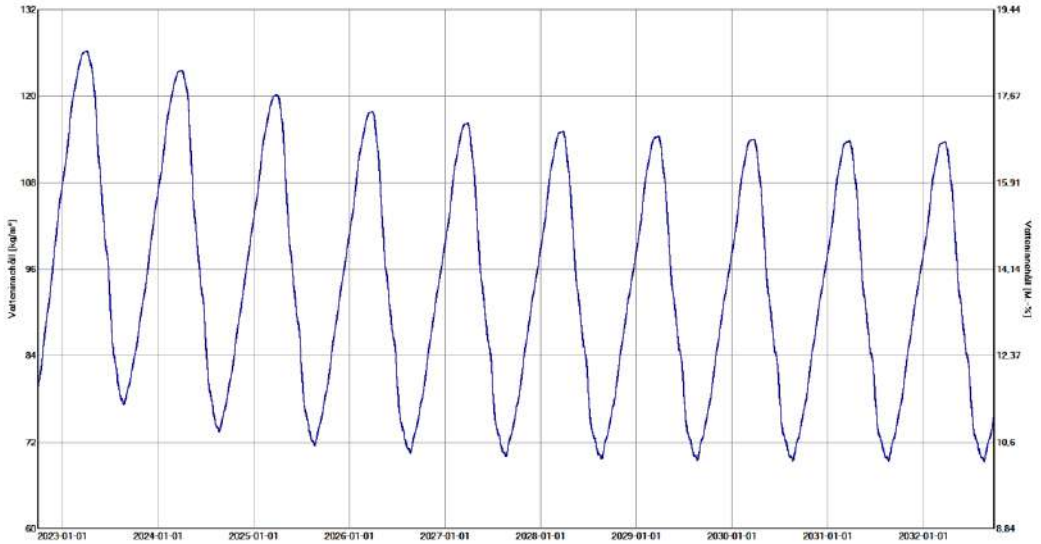
<u>The whole wall</u>



The simulation over 10 years shows that there is no accumulation of moisture over the long term, but it takes a few seasons to release the (unusually high assumed) built-in moisture. No risk of damage to the building fabric, or mould, can be expected if the work is carried out correctly.

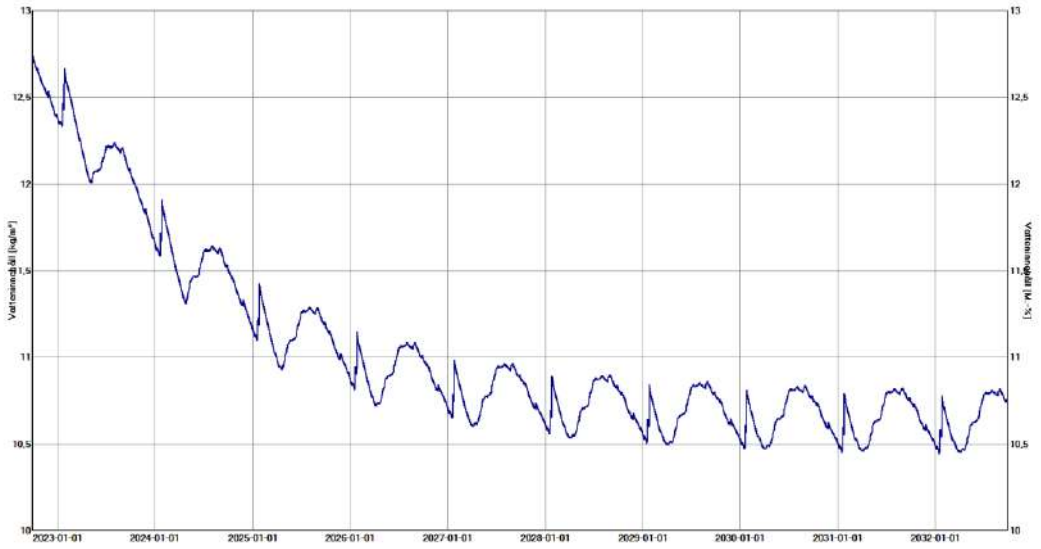
Single layers

The OSB board towards the outside:



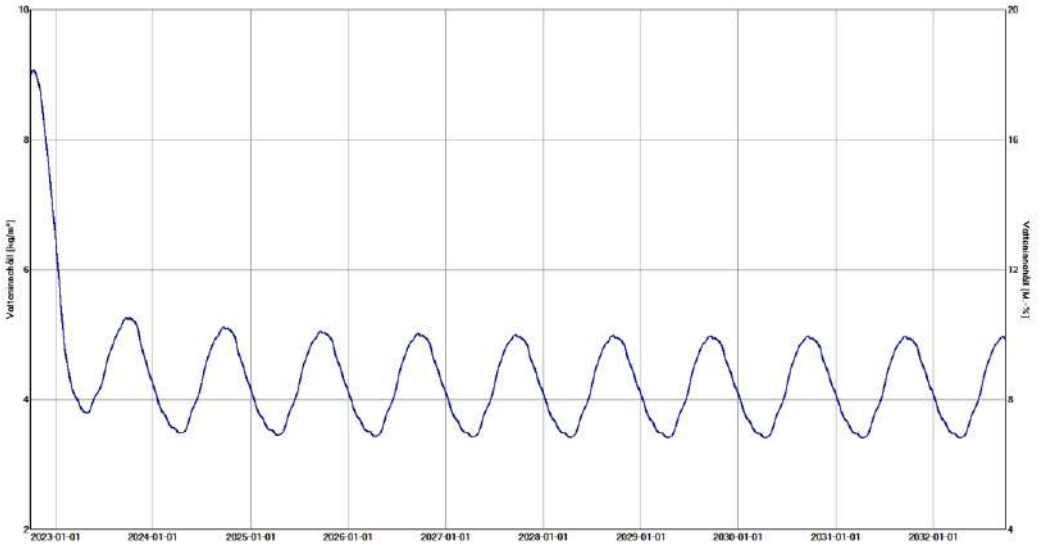
After a few seasons of drying out, the water content is permanently below 17 M.-%.

EcoCocon panel (straw):



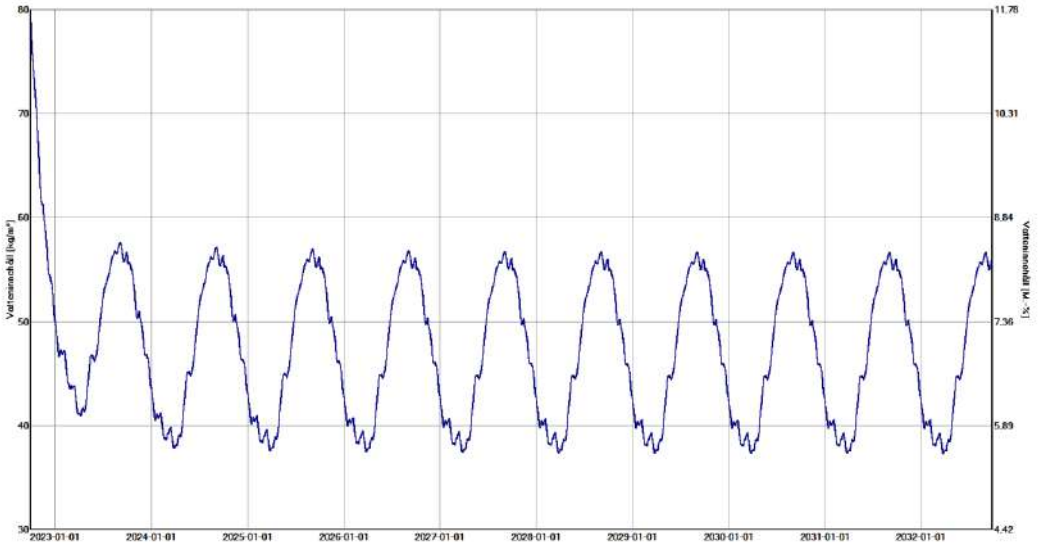
Again, it takes several seasons to come down to a lower level, but even after the intentionally high value at the beginning, the water content drops over time and is below 13 M.-% all the time.

The fibreboard:



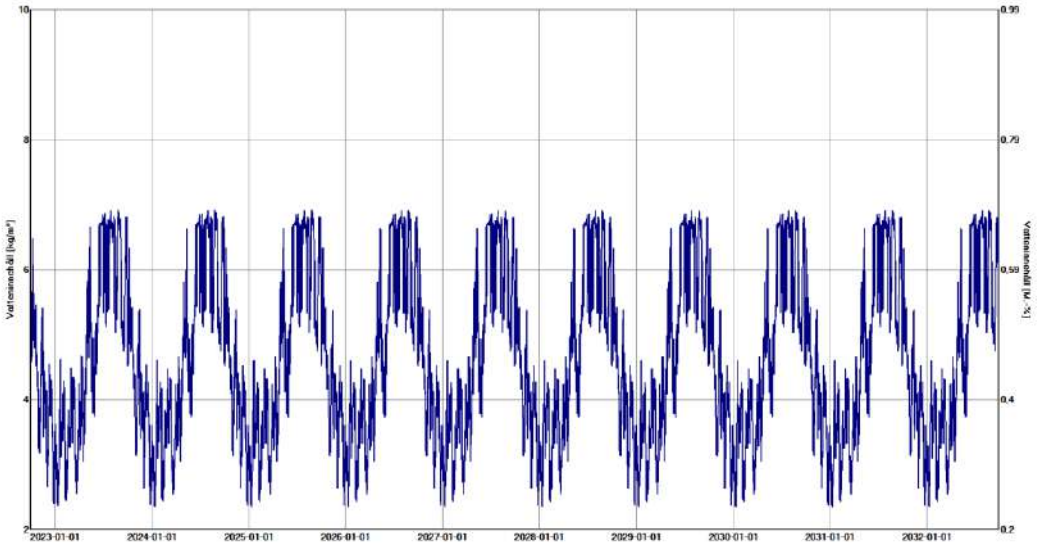
A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 12 M.-%.

The OSB panel towards the inside:



A low moisture level is reached after only a few months. Even with the intentionally high value at the beginning, the water content drops quickly and stays below 9 M.-%.

Plasterboard:



The moisture content does not take any harmful forms here.

Summary

The simulation shows that all examined wall types in all locations - except externally rendered facades in Bergen - dry out quickly, even if they have 80% moisture content at the start of construction. Of course, there is a periodic accumulation and reduction of moisture in the individual layers, but this never reaches alarming proportions.

The straw panels themselves and the inner layer (plaster or plasterboard) do not present any problems, but the wood fibre board is more sensitive - especially in the case of walls with external plaster. For walls with external plaster in the Bergen climate, the simulation shows that the moisture content of the wood fibre layer is too high for a long time, i.e. even at temperatures that can favour mould growth. It is therefore recommended that in the Bergen area only exterior walls with ventilated facades are used.

The rendered facades have been simulated with exterior plasters that have a water absorption coefficient of 0.1 kg/(m²·h$^{0.5}$). If the value is higher, it is a major hazard for the structure. The external plaster must also be carefully selected and maintained.

A simulation is only as good as its input data, including boundary conditions. The calculation was made with extra safety margins, but each case and situation are special. Therefore, when applying the results in the report, certain aspects have to be taken into account:

1) The calculations are only related to the defined and specified boundary conditions and the named object and substructures and cannot be transferred without further verification, even if the design is the same or similar.
2) For the calculation to be representative, accurate production is required and the contractor is responsible for ensuring that the specifications are consistently maintained.
3) Airtightness and, if necessary, airtightness testing are prerequisites.
4) The specified moisture content of the materials, specific to wood or wood-based products, must not be exceeded. Careful, clean and dry storage must be a prerequisite.

Tvärred, 14 February 2023

Ingo Theoboldt
Building physicist, accredited certifier and designer for passive houses

Passivhusbyrån Ingo Theoboldt
Tel: 0762-874024
Address: Vasared 301, 523 94 Tvärred
E-mail: info@passivhusbyran.se

Report

Scotland (Perth)
Hygrothermal Analysis (WUFI)

Version 1.0 - Updated 19.04.2022

eco cocon

1 Assembly Modelled

The EcoCocon wall system comprises structural timber-straw wall panels (Figure 1.1) that are available in a variety of shapes (i.e., standard, column, lintel, sill, etc) to facilitate the design and construction of custom home plans. The EcoCocon system is a certified Passivhaus component and has achieved Cradle to Cradle Silver licensing.

Figure 1.1 – 3D representation of an EcoCocon wall panel (left) and photograph of an assembled EcoCocon wall system to form a gable with window.
[both images from EcoCocon]

The building assembly as modelled is summarized in Table 1.1, from exterior to interior. A visual representation of the assembly, taken from WUFI 6.5, is presented in Figure 1.2. Further material data are provided in Appendix A. Additional details about the modelled assembly are provided in Table 2.1 in Section 2 below.

TABLE 1.1 – ASSEMBLY MATERIALS AND DETAILS			
Material Layer (thickness)	Data Source	Summary of Modifications	Additional Details
Scottish Larch cladding (25 mm)	Adapted from *Southern Yellow Pine* from the *North America Database* in WUFI 6.5.3	Density: 550 kg/m^3[1] Thermal conductivity: 0.14 W/m·K[2]	Charred finish
Ventilated gap (50 mm)	*Air Layer 50 mm* from the *Generic Materials Database* in WUFI 6.5.3	None	Air changes/hr: 10
Wood-fiber insulation board (60 mm)	*Wood-fibre Insulation* from the *Fraunhofer-IBP Database* in WUFI 6.5.3	None	-
Weather resistive barrier with max sd=0.2m (0.001 mm)	*Weather resistive barrier (sd=0.2 m*) from the *Fraunhofer-IBP Database* in WUFI 6.5.3	None	-
EcoCocon panel (400 mm)	Adapted from *Straw Bales* from the *Fraunhofer-IBP Database* in WUFI 6.5.3	Density: 100 kg/m^3 Porosity: 0.9 m^3/m^3 Spec. heat capacity: 2000 J/kg·K Thermal conductivity: 0.045 W/m·K VDRF: 1.3	Material data provided by EcoCocon.
Interior plaster (25 mm)	*Interior plaster (gypsum plaster)* from the *Fraunhofer-IBP Database* in WUFI 6.5.3	None	-

[1] Russwood Ltd (2022). *Scottish Larch Cladding: Scotlarch*. Retrieved from: https://www.russwood.co.uk/cladding/products/scotlarch/
[2] Architecture-Design Scotland (nd). *Larch Cladding*. Retrieved from: https://materials.ads.org.uk/larch-cladding/

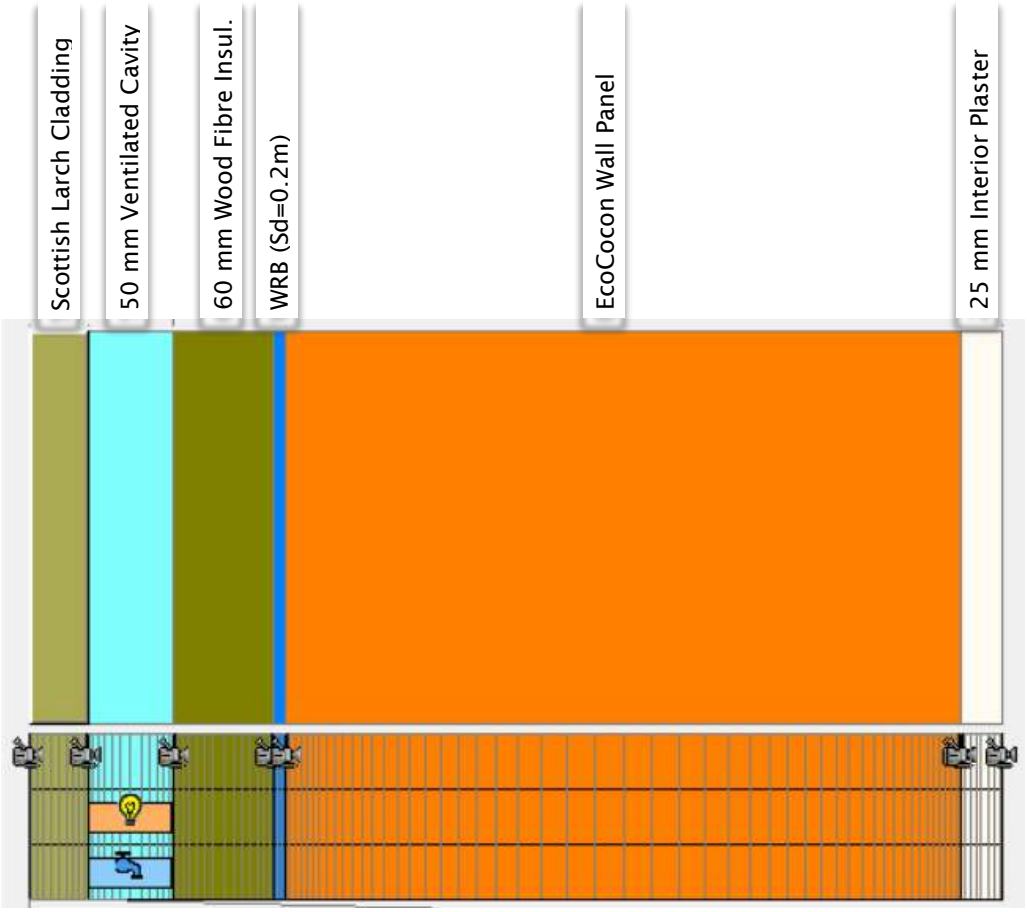


Figure 1.2 – Image of assembly from WUFI.

2 Model Parameters and Building Information

Table 2.1 provides details of the building and modeling parameters. Briefly, the building is a 2-story residential design located in Perth, Scotland. It is new construction. The design is 1056 m^3, containing 5 bedrooms, 4 bathrooms, a kitchen, and additional gathering spaces (i.e., family room and cinema room). The building has an attached garage.

Other important considerations for moisture management include:

- → Indoor Humidity Levels - The warrant drawings indicate mechanical ventilation with a heat recovery unit and exhaust fans in all bathrooms and the kitchen. This analysis assumes these systems are installed and operated to maintain safe indoor humidity conditions (i.e., below 40% RH in winter months; below 70% RH in summer).
- → Door and Window Installation – This analysis assumes the windows are water -penetration resistant and that the installation prevents water leakage into the wall assembly.
- → Construction Moisture Management - The warrant drawings specify that all materials shall be stored in a weather proofed manner. This analysis assumes built-in moisture is at equilibrium with 80% RH (i.e., consistent with requirements of ASHRAE 160).

TABLE 2.1 – MODEL PARAMETERS AND BUILDING INFORMATION		
Criteria	ASHRAE 160 Requirements	Model Parameters
Analytic program	Requirements listed in ASHRAE 160-2021 Section 5	WUFI Pro 6.5.3 – standard program for evaluating moisture conditions in building envelopes. Performs one-dimensional hygrothermal calculations on building component cross-sections. Incorporates all requirements listed in Section 5
Total Model Count	Not specified	4 models
Orientation	Described in ASHRAE 160-2021 Section 4.5.1	Not required based on method selected (chose Weather Data method, Section 4.5.2). However, modelled two orientations to assess performance. - North (least solar radiation) - Southeast (most wind-driven rain)
Interior Design Temperature	Requirements listed in ASHRAE 160-2021 Section 4.2	21˚C ± 2.8˚C Based on design setpoint provided and Table 4.1, Heating Only, where 18.3˚C < $T_{0,24h}$ ≤ 21.1˚C
HVAC Equipment and Controls	Requirements listed in ASHRAE 160-2021 Section 4.3	Mechanical system with heat-recover ventilation. Local exhausts in kitchen and bathrooms. Controls not provided.
Indoor Design Humidity	Requirements listed in ASHRAE 160-2021 Section 4.3.2 and Section 7.4	ASHRAE 160 option in WUFI Pro 6.5, based on Intermediate Method: - Residential occupancy - Number of bedrooms (n = 5) - Air exchange rate (0.3/h) - Building volume (1056 m^3) - No air conditioning
Airflow Effects	Requirements listed in ASHRAE 160-2021 Section 4.4	Not considered (assumes airtight assembly)

Table 2.1 continued

Criteria	ASHRAE 160 Requirements	Model Parameters
Moisture Design Weather Data	Requirements listed in Section 4.5.2 ASHRAE 160-2021	10-year data for Perth, Scotland (Jan 1/2012 to Dec 31/2021; sourced from meteoblue[3] with hourly data comprising air temperature, relative humidity, direct and diffuse solar radiation, average wind speed and direction, air pressure, precipitation, and cloud index) Models run for 10 years (Jan 1/2012 to Dec 31/2021)
Rain Exposure Factor	Requirements listed in Section 4.6 ASHRAE 160-2021	1.0, based on a building height of <10 m and medium exposure category.
Rain Deposition Factor	Requirements listed in Section 4.6 ASHRAE 160-2021	0.35, based on “walls below a steep sloped roof” factor
Rain Penetration	Requirements listed in Section 4.6.1 ASHRAE 160-2021	1% of incident rainwater to be applied to the exterior surface of the water-resistive barrier (as system sensitivity test)

The historical outdoor climate (Jan 1, 2012 to Dec 31, 2021) and modelled indoor climate are presented in Figure 2.1 through Figure 2.3.

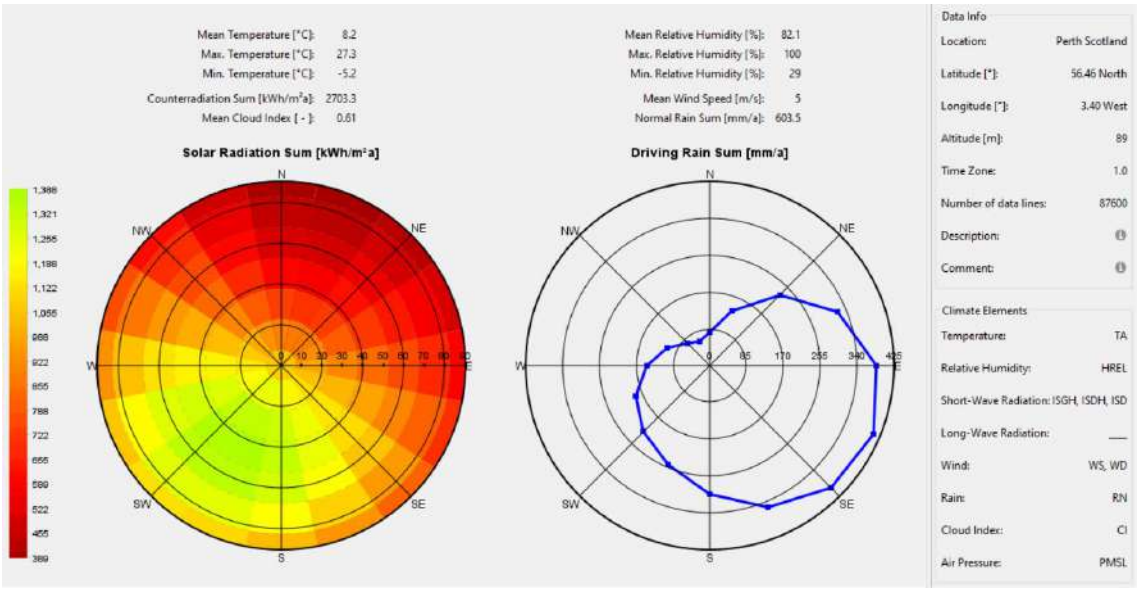


Figure 2.1 – Solar radiation and driving rain data for Perth, Scotland.

[3] https://content.meteoblue.com/en/about-us

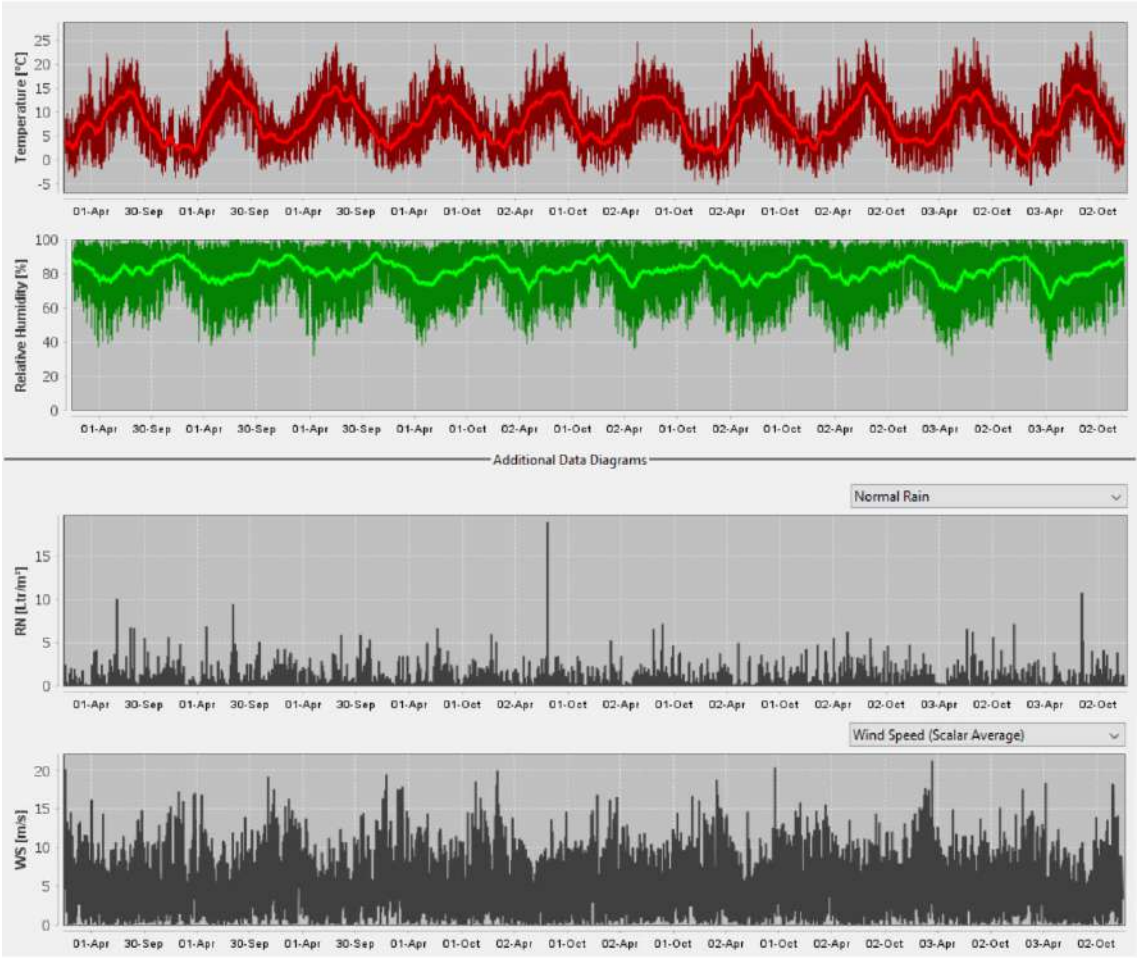


Figure 2.2 – Time series graphs of outdoor temperature, relative humidity, rain, and wind speed for Perth, Scotland.

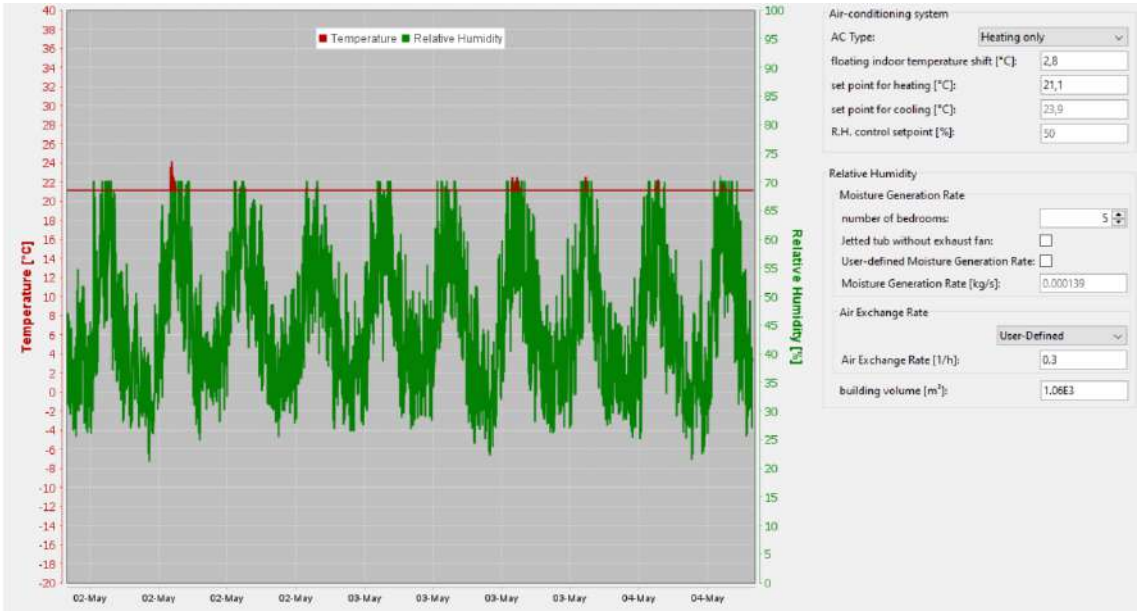


Figure 2.3 – Time series graphs of indoor temperature and relative humditiy conditions.

3 Moisture Performance and Evaluation

ASHRAE 160-2021, Section 6 requires the modelled assembly be evaluated through consideration of several key moisture performance criteria. In this assessment the performance of the EcoCocon assembly was evaluated for undue risk related to moisture accumulation, decay, and mold growth.

3.1 Total water content

In this assessment moisture accumulation was evaluated through consideration of the predicted total water content (TWC) in the assembly. Figure 3.1 presents the predicted TWC for a southeast-facing assembly with no rain leaks and with the ASHRAE 160-2021 prescribed rain leak test of 1% (applied to the outside face of the WRB). In these simulations the built-in moisture is predicted to dry over the first 6 months of operation then the assembly achieves a pseudo-steady state pattern with TWC peaking in the wet season (winter) and drying back out the following summer. Wetter years are predicted to have only slightly larger impact. The 1% rain leak is safely accommodated by the assembly. ***No long-term moisture accumulation is predicted.***

Consideration of North-facing assemblies are presented in Appendix B.

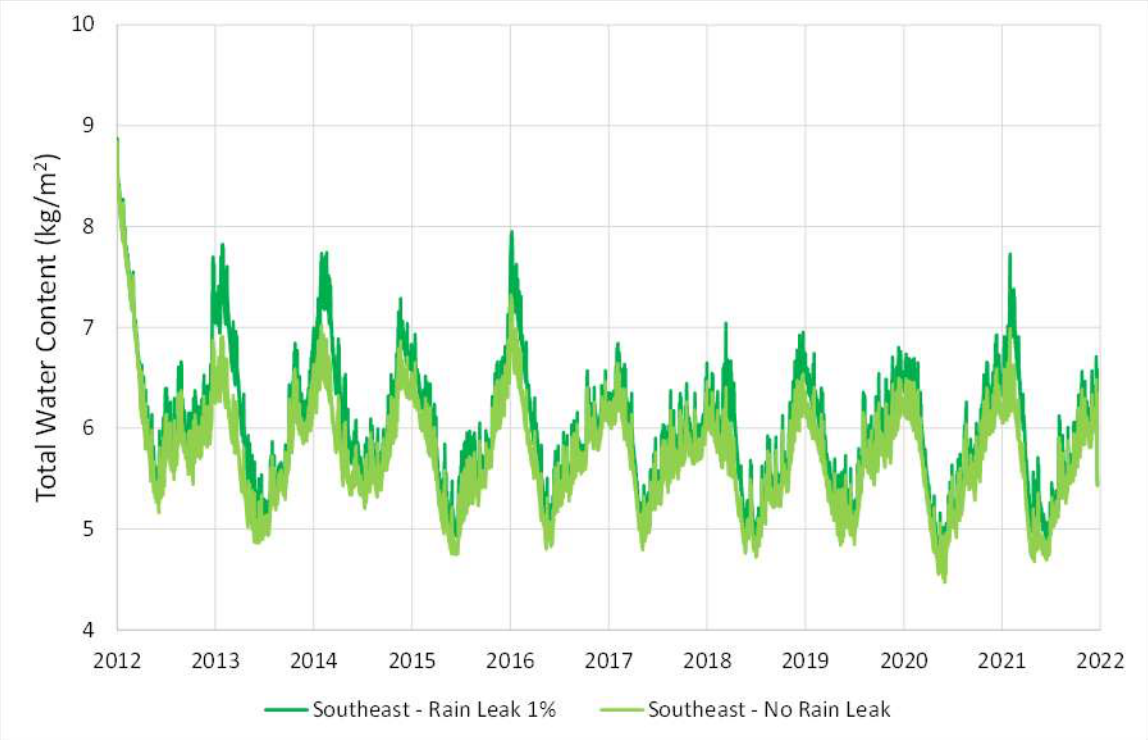


Figure 3.1 – Total water content graph: southeast orientation.

3.2 Moisture Content

ASHRAE 160-2021 requires consideration of the critical moisture content within sensitive material layers. In this assessment moisture content of the wood-fiber-insulation board and EcoCocon straw core were considered. These cellulose-based materials can be susceptible to decay if high moisture levels persist. The time series data are presented in Figure 3.2 and Figure 3.3 and Appendix B. ***Moisture content levels in the wood-fiber and straw layers are predicted to remain below accepted thresholds for decay.***

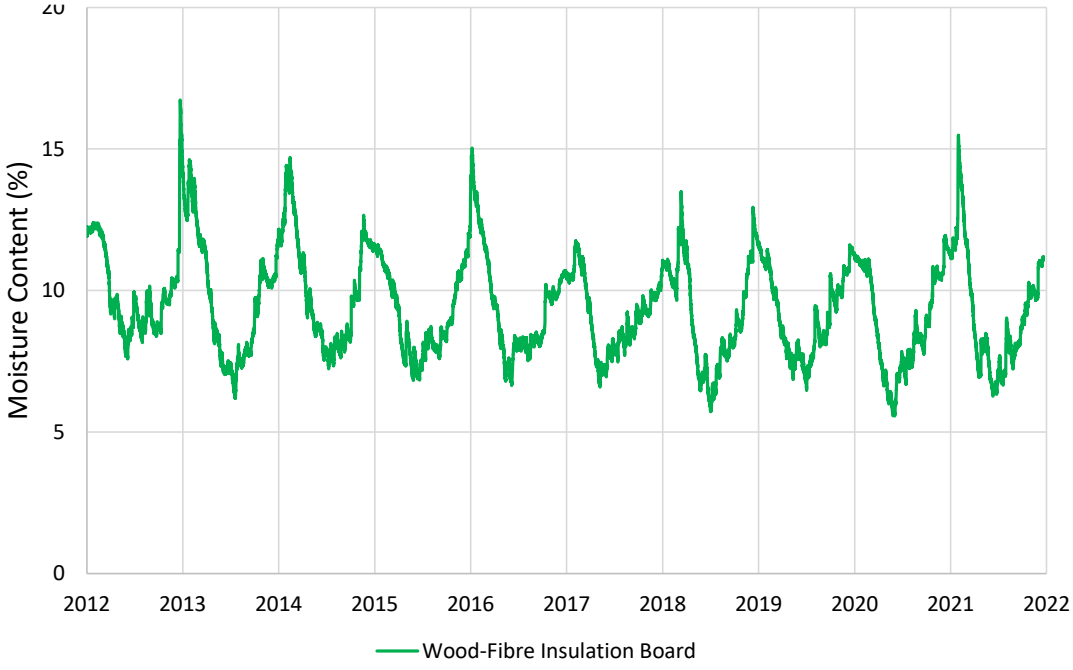


Figure 3.2 – Moisture content graph for wood-fibre insulation board: southeast oriented, 1% rain leak.

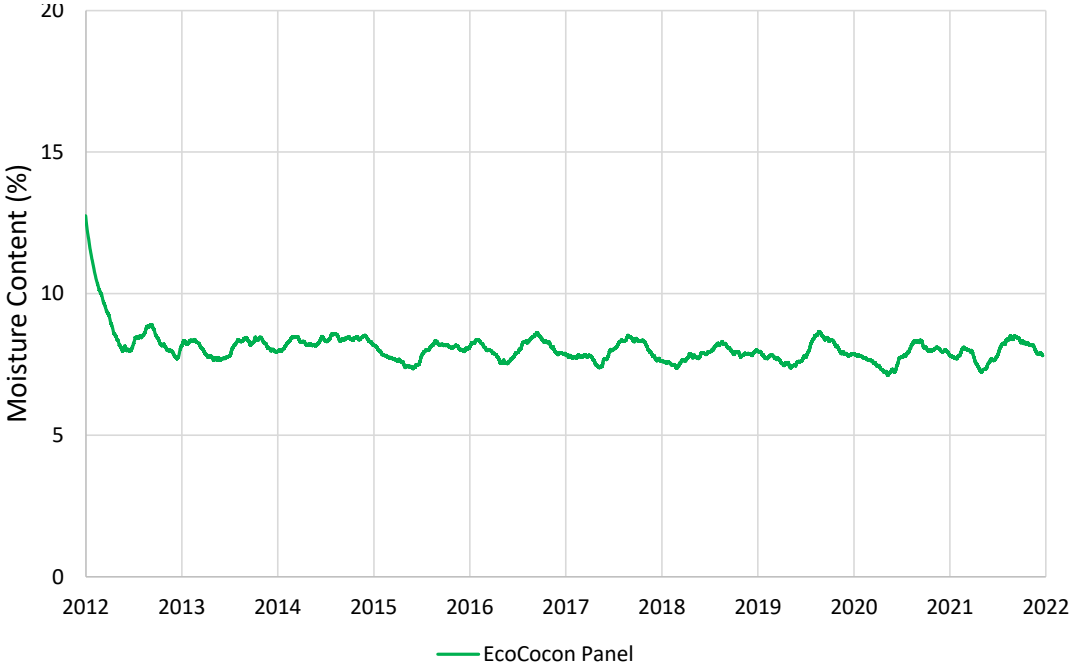


Figure 3.3 – Moisture content graph for EcoCocon panel: southeast oriented, 1% rain leak.

3.3 WUFI Model Videos

The temperature, relative humidity, and moisture content values across the entire modelled assembly were captured in the WUFI 6.5 model videos. Snapshots in time from the videos are presented in Figure 3.4 and Appendix B. These images provide the viewer a sense of the range and spatial distribution of moisture contents over the course of the 10 years simulated.

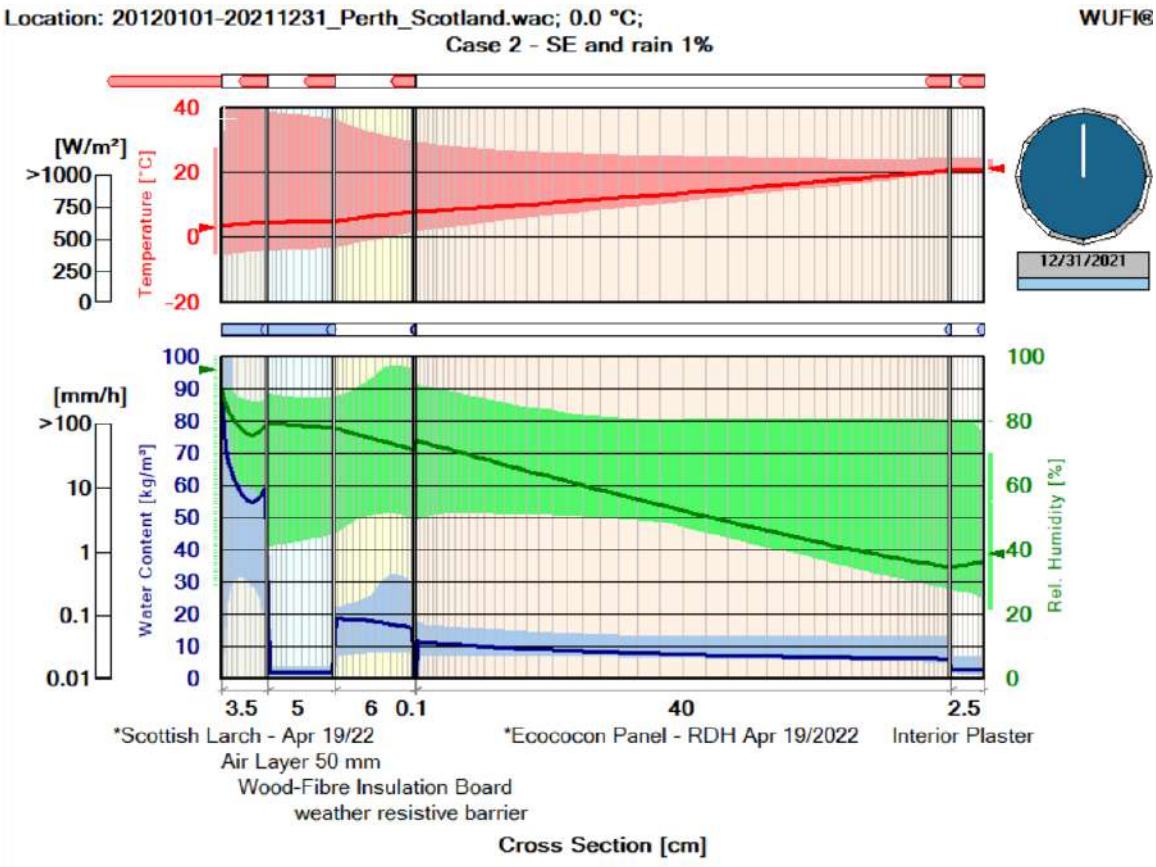


Figure 3.4 – WUFI model video: southeast oriented, 1% rain leak.

3.4 Mold risk:

ASHRAE 160-2021, Section 7, provides a model for assessing mold growth risk. In this assessment the mold growth risk was evaluated at the inside and outside faces of the wood-fiber insulation board and EcoCocon panels. Details of this assessment are outlined in Table 3.1 and the time series data are presented in Figure 3.5 and Appendix C. None of the layers considered were predicted to exceed the ASRHAE 160-accepted mold index of 3, hence ***all assemblies passed the mold risk assessment.***

TABLE 3.1 – MOLD GROWTH EVALUATION CRITERIA		
Criteria	ASHRAE 160 Requirements	Final Model
Sensitivity Class	Requirements listed in Table 6-1 ASHRAE 160-2021	Very sensitive
Mold Index Decline Coefficient	Requirements listed in Section 6.2 ASHRAE 160-2021	No mold index decline values were provided, therefore $k_3 = 0.1$ was applied in this analysis.
Time Series T & RH Data	Not specified.	Time series data for 2 locations in each material were selected for analysis: 1) Surface closest to exterior 2) Surface closest to interior
Pass/Fail Criteria	Requirements listed in Section 6.2	Mold index must not exceed 3.0 (Scale covers range of 0-6)

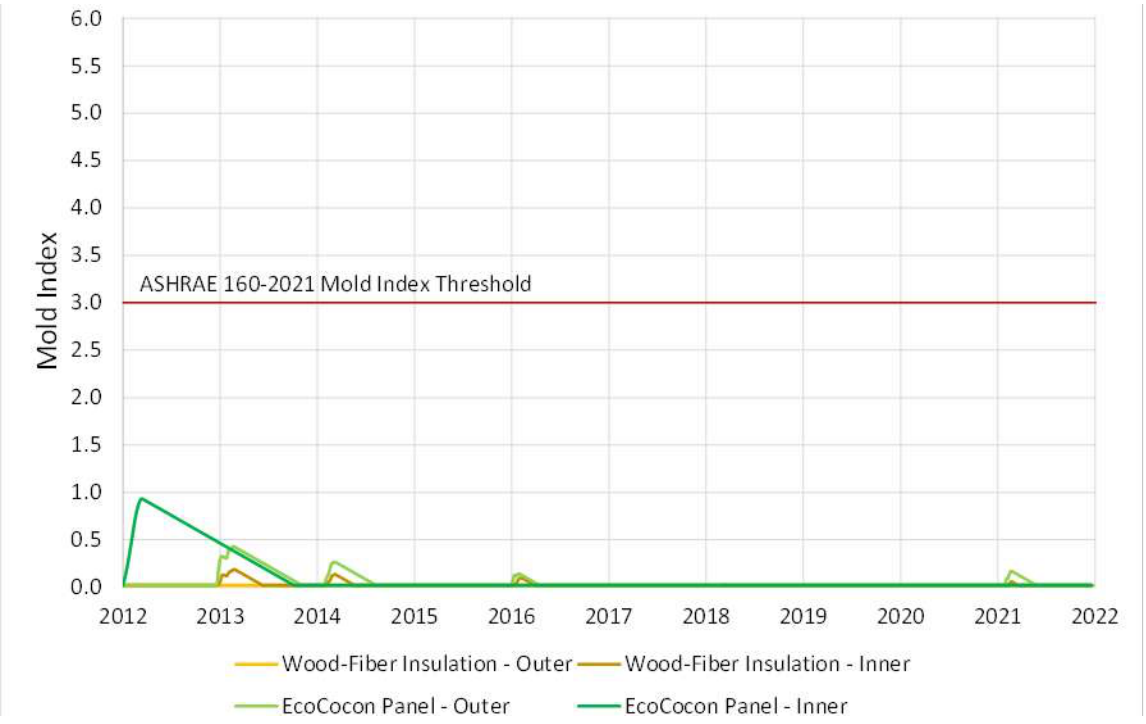


Figure 3.5 – Mold index graph: southeast oriented, 1% rain leak.

4 Conclusion

This hygrothermal modelling assessment was undertaken to evaluate the predicted thermal and moisture performance of an EcoCocon wall system for a house in Perth, Scotland. The modelling and assessment were undertaken following ASHRAE Standard 160-2021. The assembly was evaluated for moisture accumulation, critical moisture content (e.g., for decay), and mold risk. The assessed EcoCocon wall system is predicted to provide acceptable performance in this building application, in Perth, Scotland.

It is important to note that the modeling activities undertaken herein reflect best practice construction for this specific assembly design and in this specific climate. Best practice includes the implementation of appropriate and effective air, water, and thermal control layers and features in both design and construction. It is also important that these elements be routinely inspected, maintained, and repaired through the operational life of the building.

Should you have any questions about the contents of this report, please do not hesitate to contact us directly.

Yours truly,

Claire Kieri | MPH, WELL AP®
Building Science Analyst
ckieri@rdh.com
T 548-889-0068
RDH Building Science Inc.

Chris Schumacher | M.A.Sc.
Principal, Senior Building Science Specialist
cschumacher@rdh.com
T 519-504-4257
RDH Building Science Inc.

Reviewed by
Dr. John Straube | PhD, P.Eng.
Principal, Senior Building Science Specialist
jstraube@rdh.com

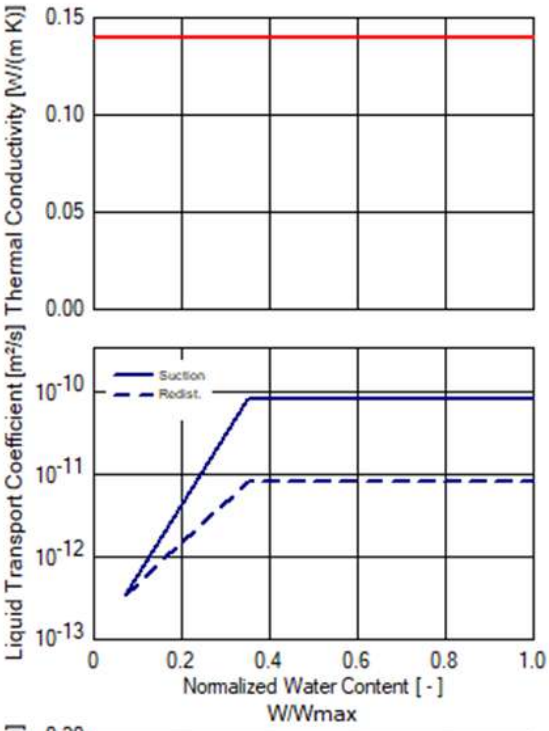
Appendix A

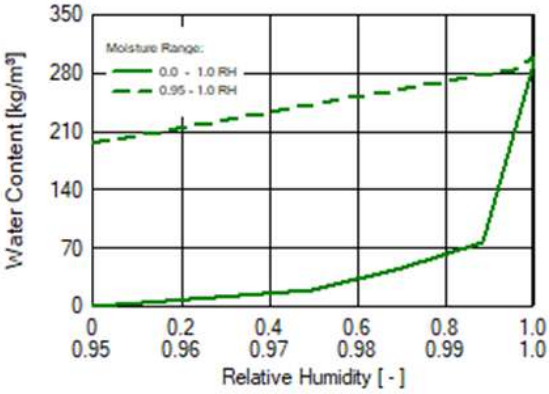
Assembly Material Data

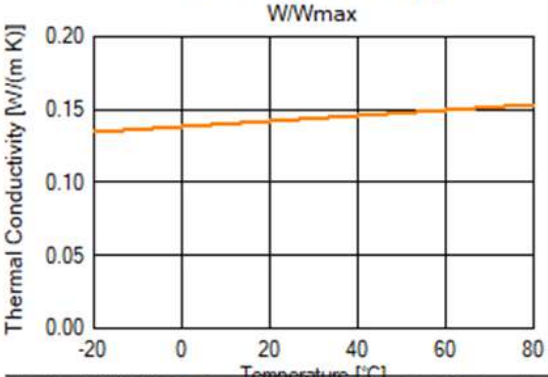
WUFI Pro 6.5

Material: *Scottish Larch - Apr 19/22

Property	Unit	Value
Bulk density	[kg/m³]	550
Porosity	[m³/m³]	0.858
Specific Heat Capacity, Dry	[J/(kg K)]	1880
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.14
Water Vapour Diffusion Resistance Factor	[-]	1734.1
Reference Water Content	[kg/m³]	62.2
Free Water Saturation	[kg/m³]	300
Water Absorption Coefficient	[kg/(m² s^0.5)]	0.0014
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	0.0002



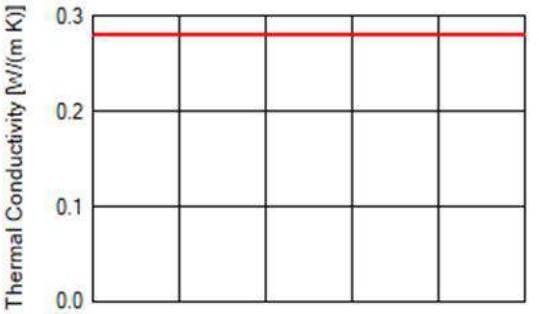


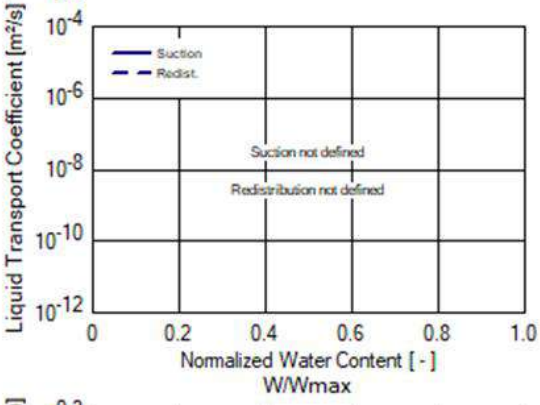


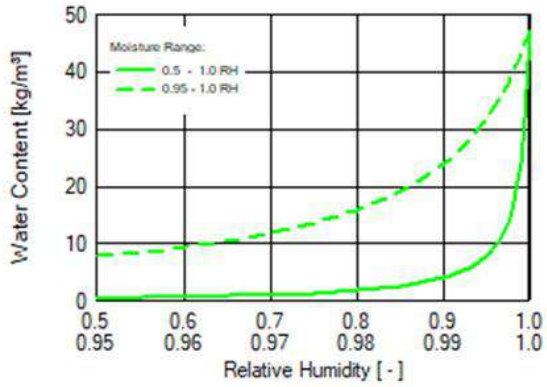
WUFI Pro 6.5

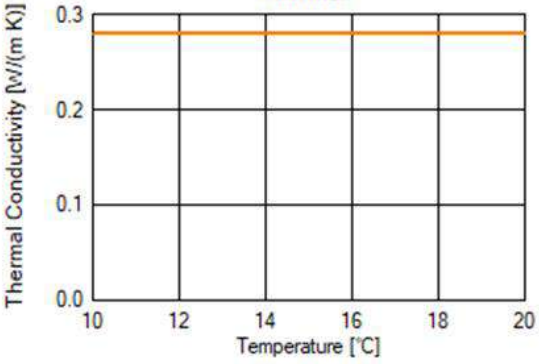
Material: Air Layer 50 mm

Property	Unit	Value
Bulk density	[kg/m³]	1.3
Porosity	[m³/m³]	0.999
Specific Heat Capacity, Dry	[J/(kg K)]	1000
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.28
Water Vapour Diffusion Resistance Factor	[-]	0.32





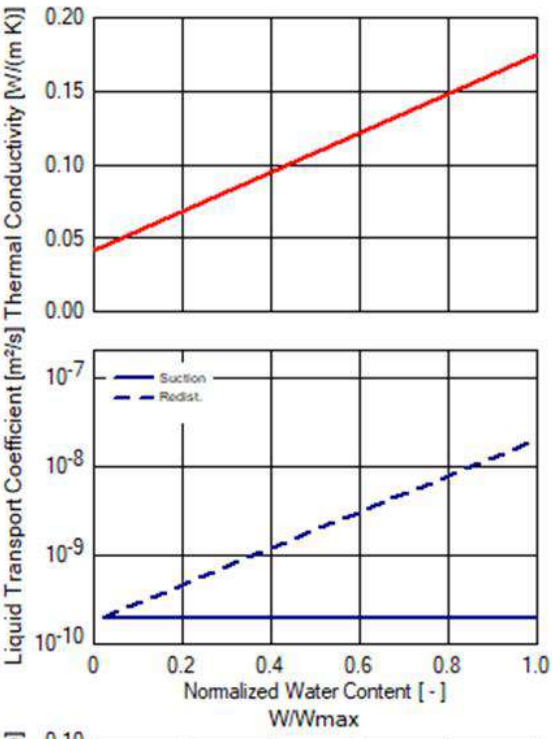


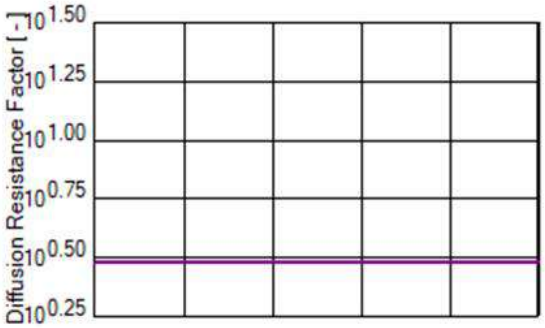


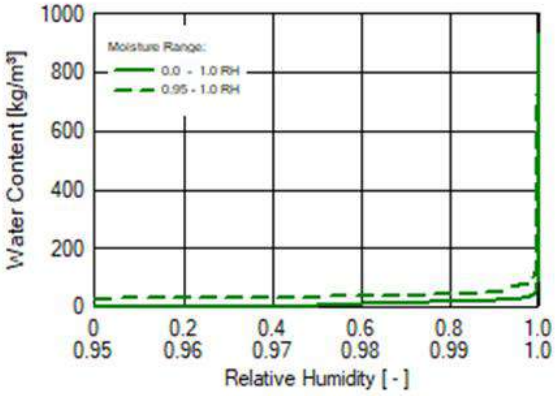
WUFI Pro 6.5

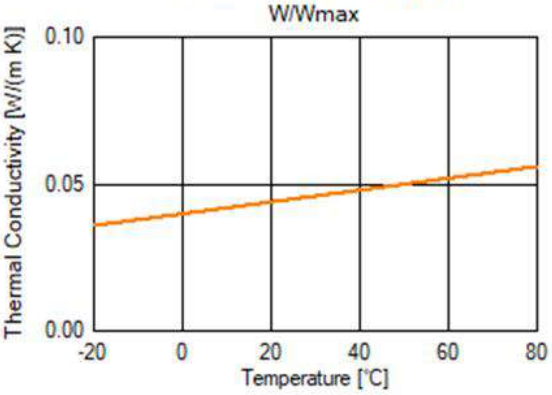
Material: Wood-Fibre Insulation Board

Property	Unit	Value
Bulk density	[kg/m³]	155
Porosity	[m³/m³]	0.981
Specific Heat Capacity, Dry	[J/(kg K)]	1400
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.042
Water Vapour Diffusion Resistance Factor	[-]	3
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	0.5
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





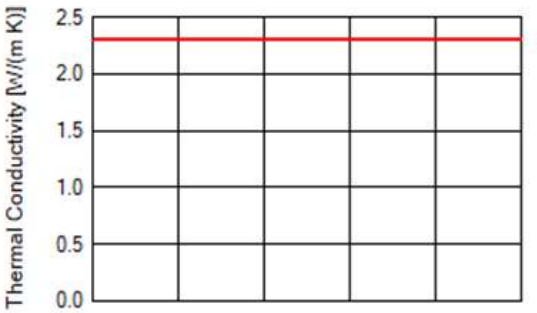


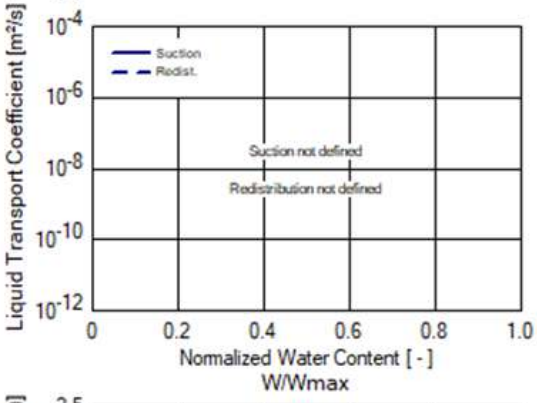


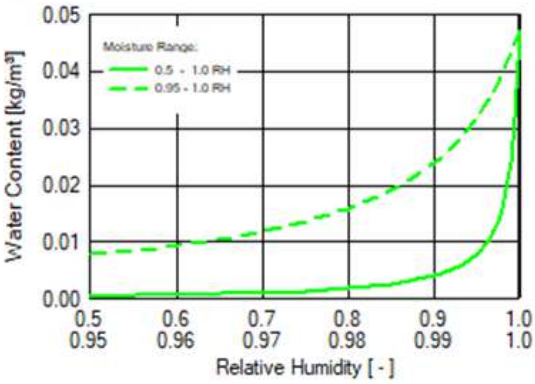
WUFI Pro 6.5

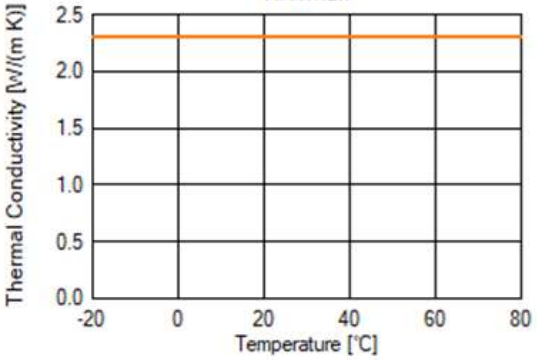
Material: weather resistive barrier (sd=0,2m)

Property	Unit	Value
Bulk density	[kg/m³]	130
Porosity	[m³/m³]	0.001
Specific Heat Capacity, Dry	[J/(kg K)]	2300
Thermal Conductivity, Dry, 10°C	[W/(m K)]	2.3
Water Vapour Diffusion Resistance Factor	[-]	200
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4





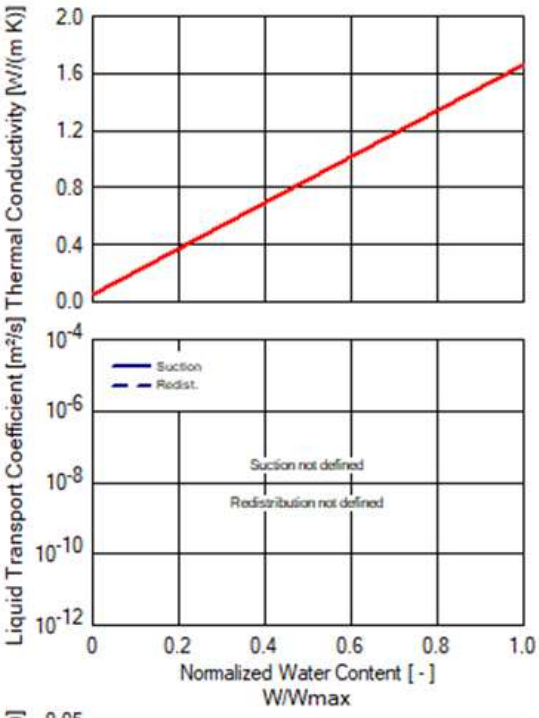


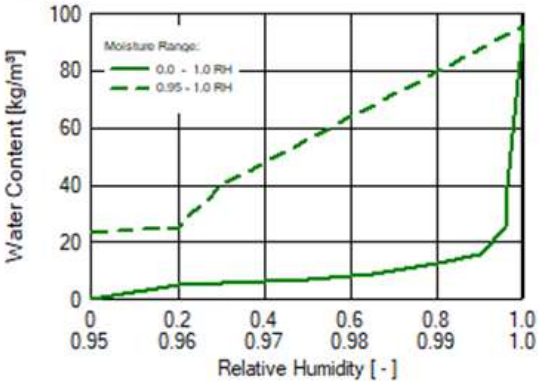


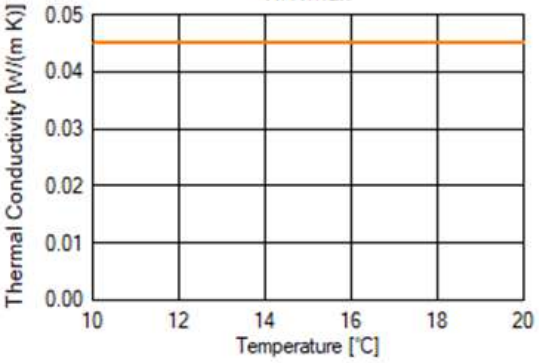
WUFI Pro 6.5

Material: *Ecococon Panel - RDH Apr 19/2022

Property	Unit	Value
Bulk density	[kg/m³]	100
Porosity	[m³/m³]	0.9
Specific Heat Capacity, Dry	[J/(kg K)]	2000
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.045
Water Vapour Diffusion Resistance Factor	[-]	1.3
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	4



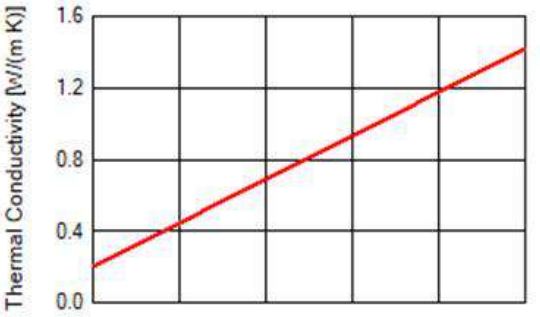


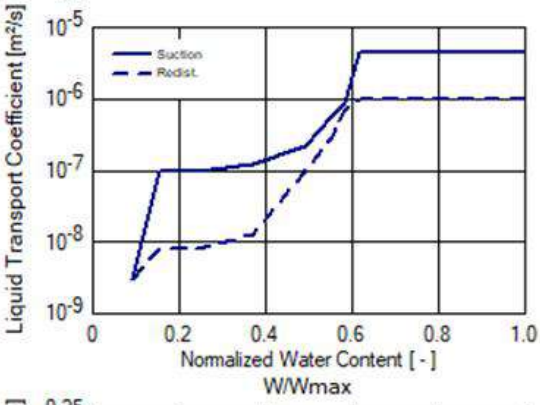


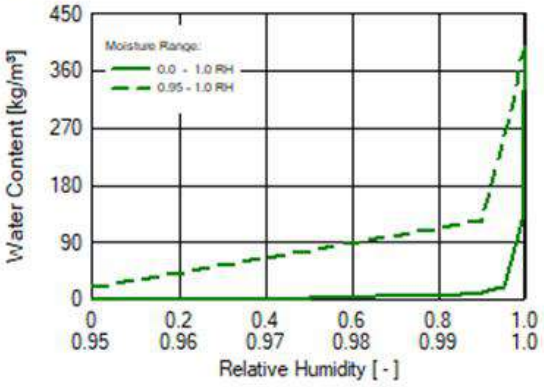
WUFI Pro 6.5

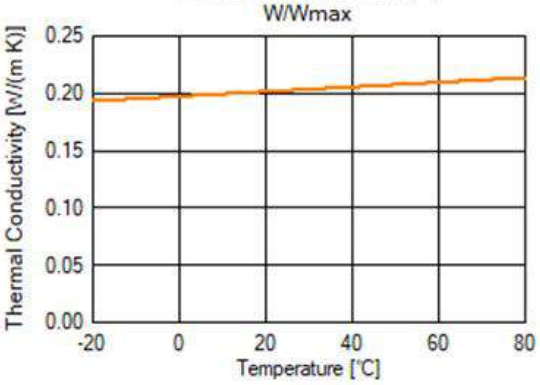
Material: Interior Plaster (Gypsum Plaster)

Property	Unit	Value
Bulk density	[kg/m³]	850
Porosity	[m³/m³]	0.65
Specific Heat Capacity, Dry	[J/(kg K)]	850
Thermal Conductivity, Dry, 10°C	[W/(m K)]	0.2
Water Vapour Diffusion Resistance Factor	[-]	8.3
Moisture-dep. Thermal Cond. Supplement	[%/M.-%]	8
Temp-dep. Thermal Cond. Supplement	[W/(m K²)]	2.00000E-4









Appendix B

Moisture Performance Analysis:

Total Water Content Graphs

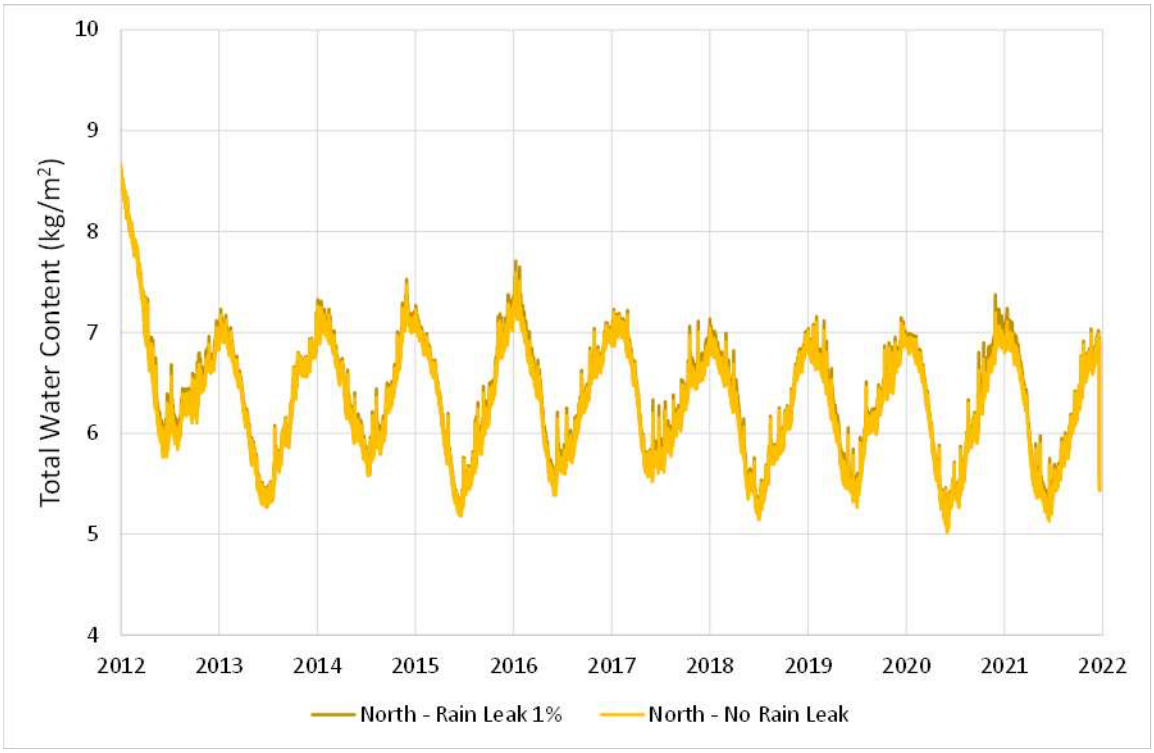


Figure 4.1 - Total water content: north orientation.

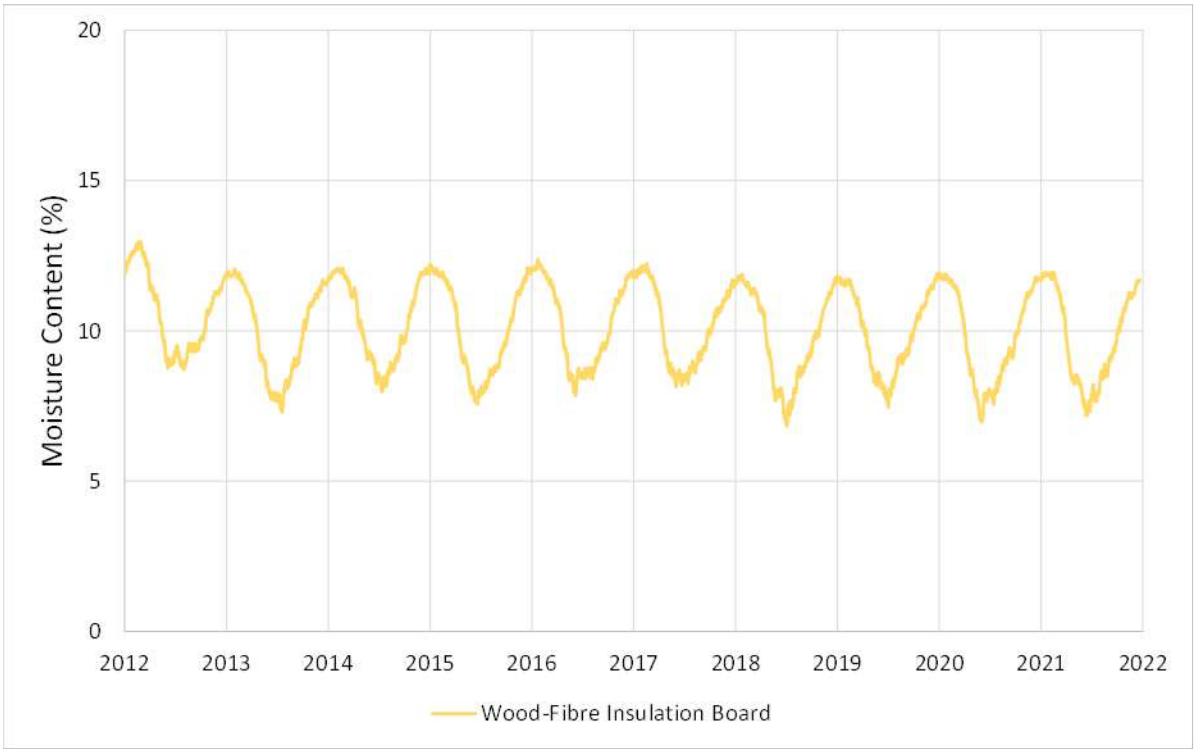


Figure 4.2 – Moisture content graph for wood-fibre insulation board: north oriented, no rain leak.

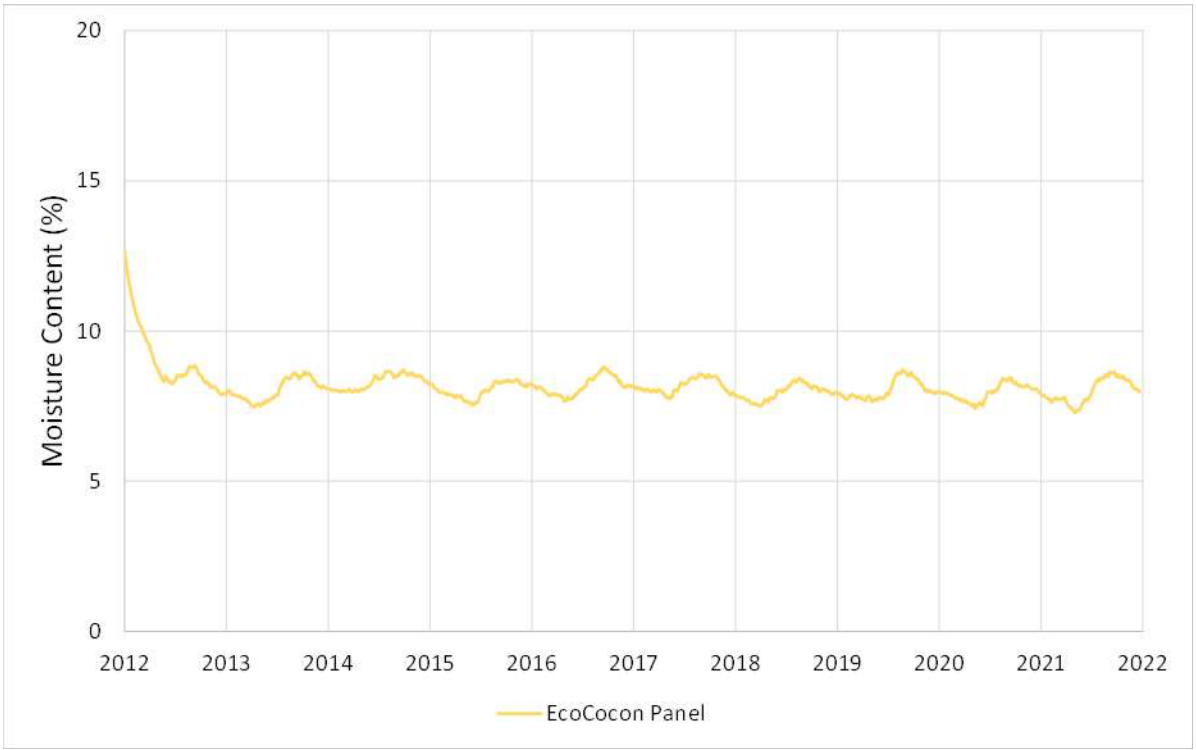


Figure 4.3 – Moisture content graph for EcoCocon panel: north oriented, no rain leak.

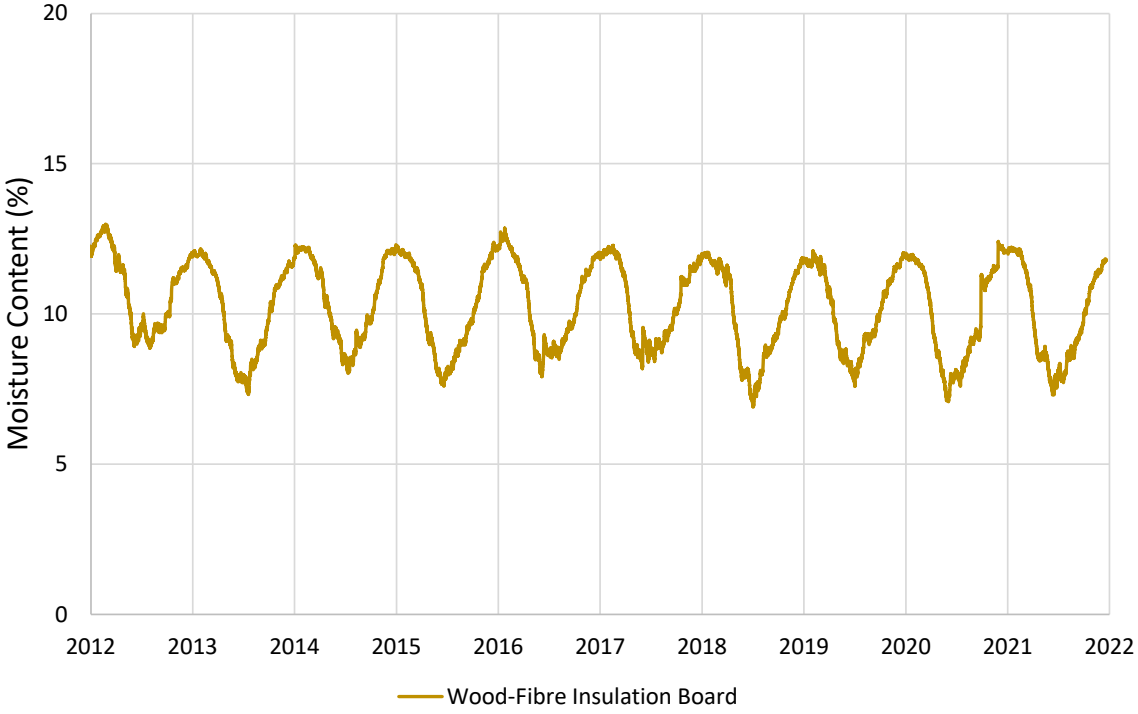


Figure 4.4 – Moisture content graph for wood-fibre insulation board: north oriented, 1% rain leak.

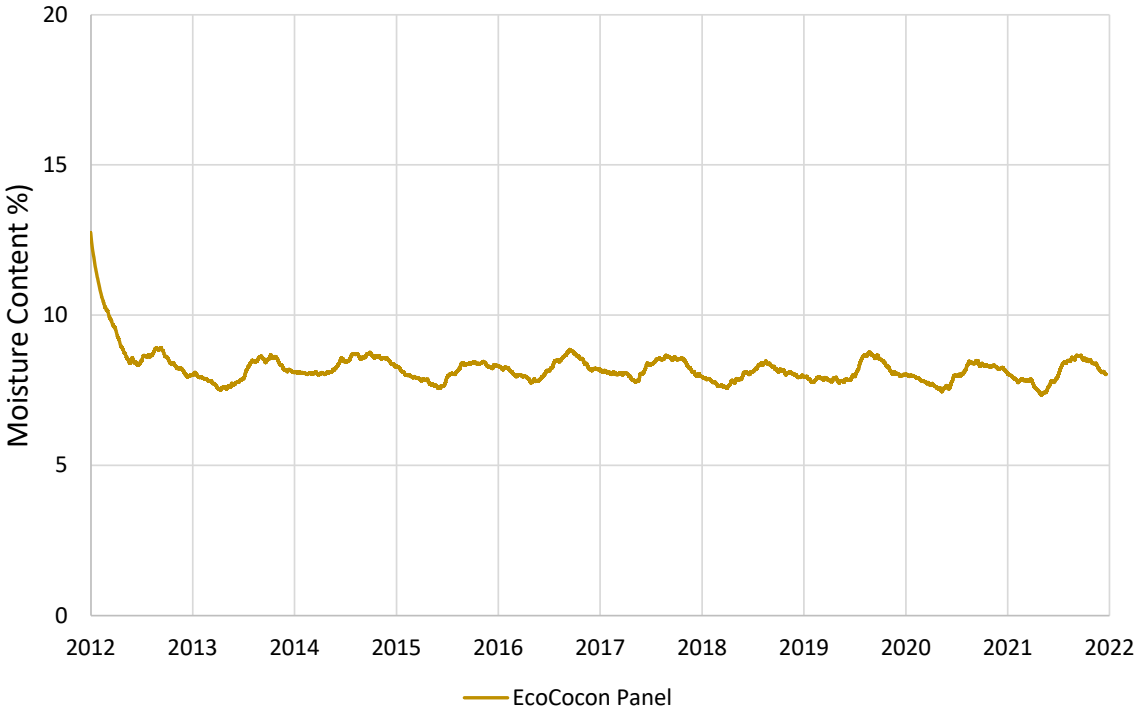


Figure 4.5 – Moisture content graph for EcoCocon panel: north oriented, 1% rain leak.

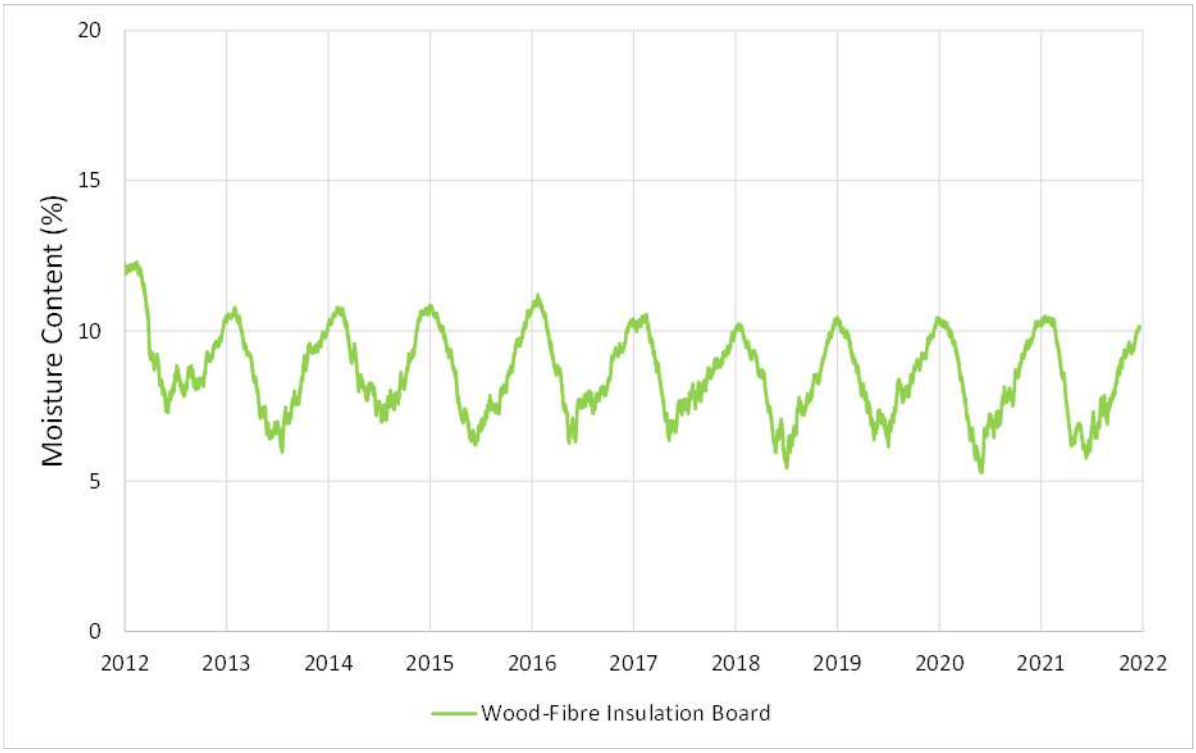


Figure 4.6 – Moisture content graph for wood-fibre insulation board: southeast oriented, no rain leak.

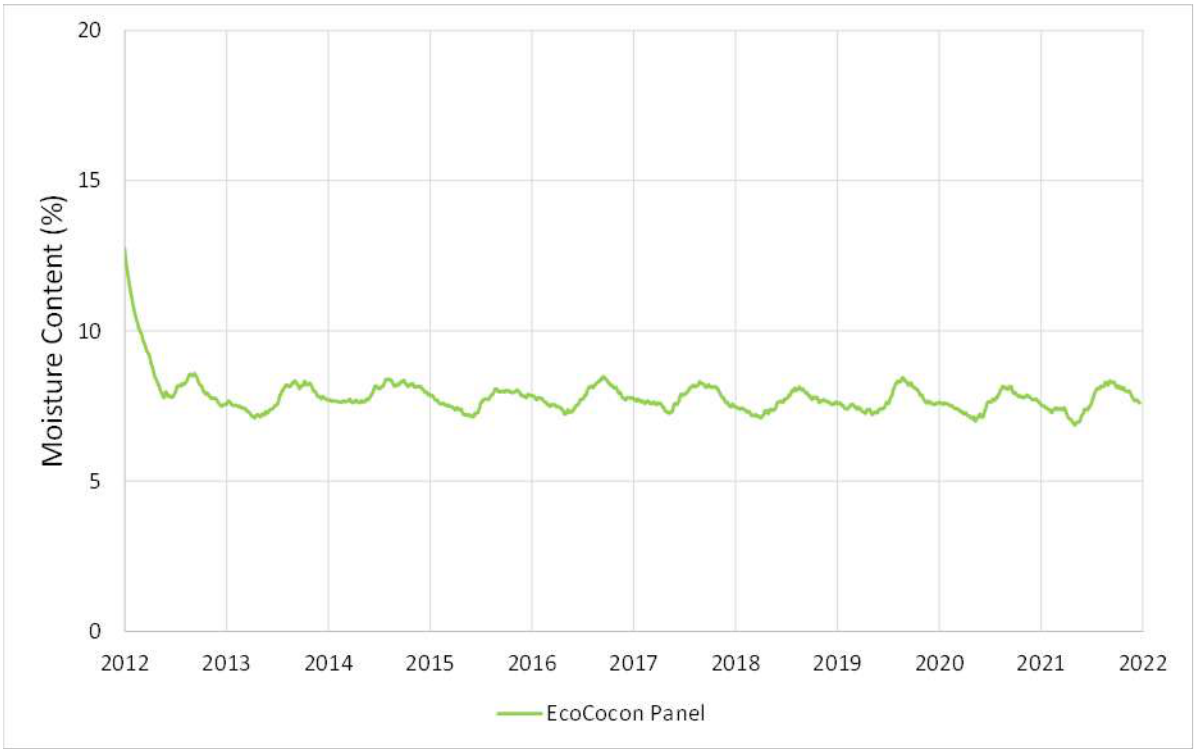


Figure 4.7 – Moisture content graph for EcoCocon panel: southeast oriented, no rain leak.

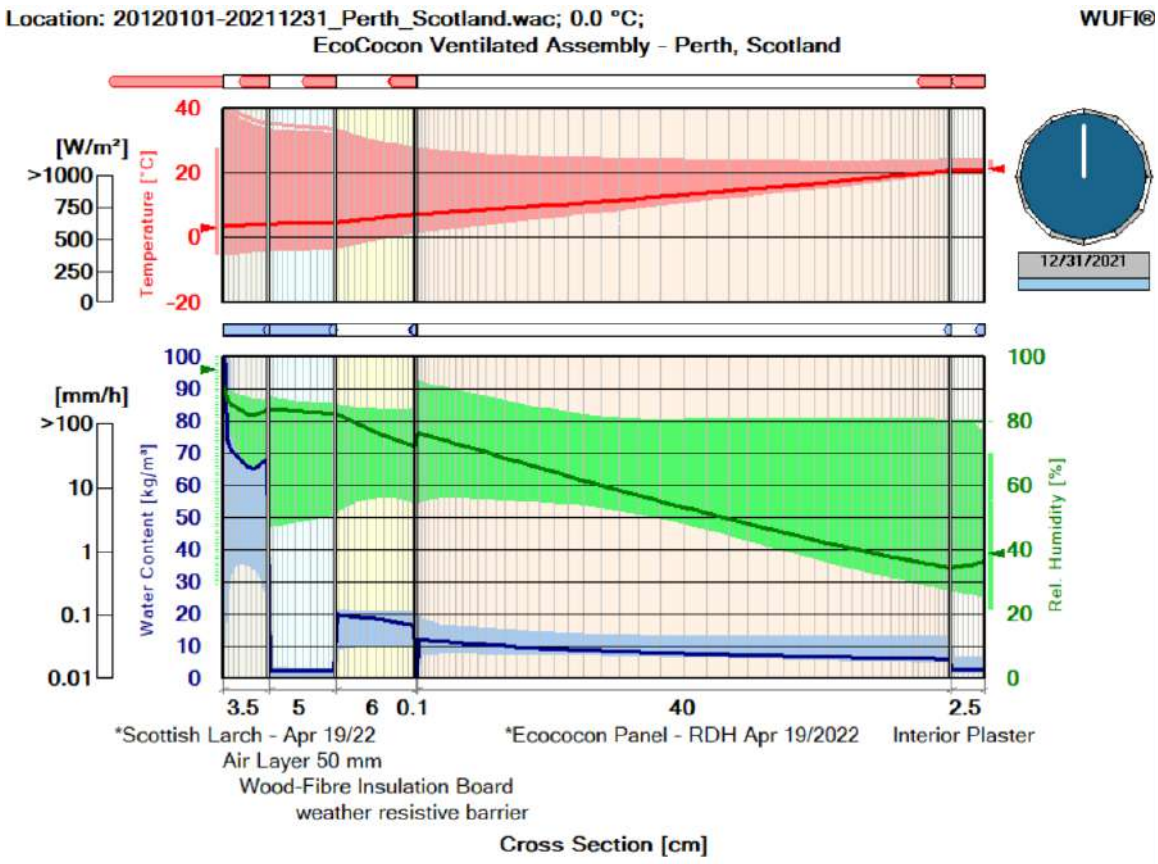


Figure 4.8 – WUFI model video: north oriented, no rain leak.

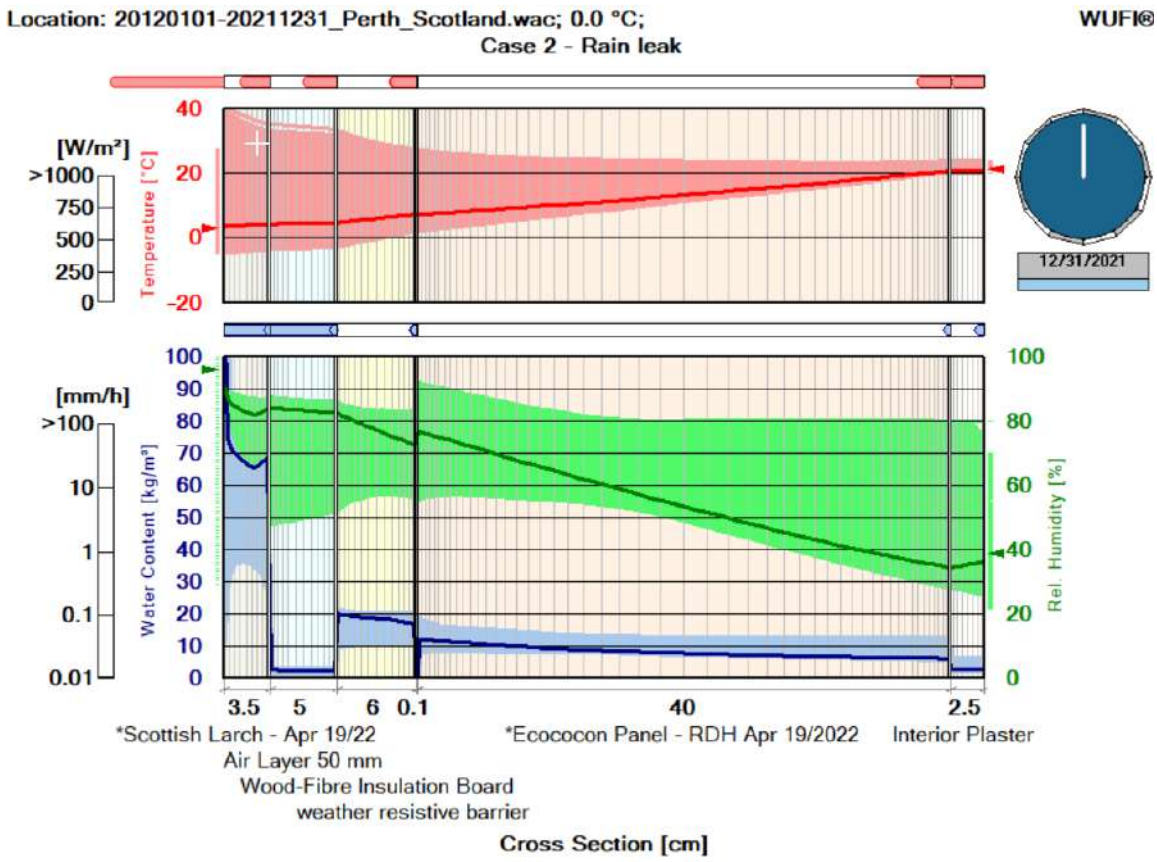


Figure 4.9 – WUFI model video: north oriented, 1% rain leak.

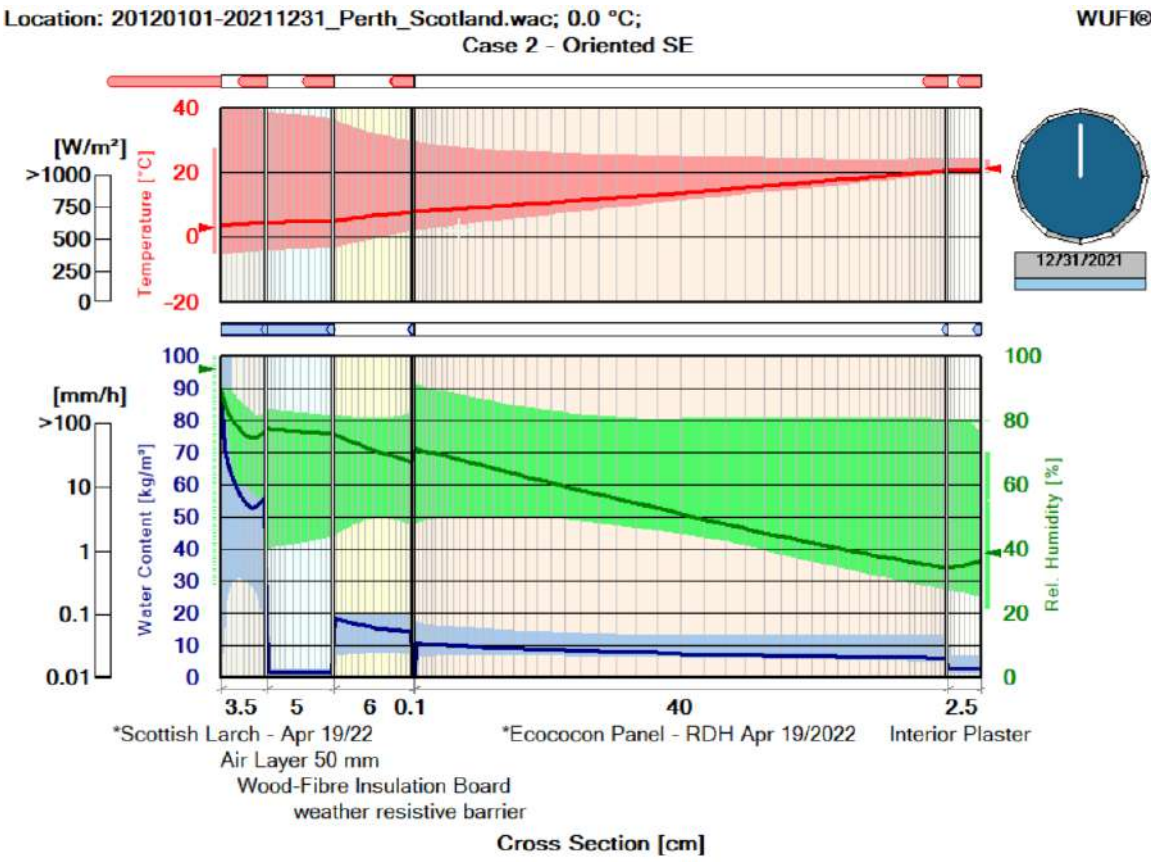


Figure 4.10 – WUFI model video: southeast oriented, no rain leak.

Appendix C

Mold Risk Analysis:

Mold Index Graphs

Figure 4.11 - Mold index graph: north oriented, no rain leak.

Figure 4.12 - Mold index graph: north oriented, 1% rain leak.

Figure 4.13 - Mold index graph: southeast oriented, no rain leak.

Report

Vienna
Hygrothermal Analysis (WUFI)

Version 1.0 - Updated 08.08.2013

eco cocon

Schäden an Gebäuden
Euro Zert Certification
Überwacht durch: SVG office GmbH
Alfred-Herrhausen-Straße 44 in 58455 Witten
Jörg Brandhorst
Sachverständiger
DIN EN ISO/IEC 17024:2012
Zertifizierungs-Nr.:
ZN - 20120928 - 0262
Gültig bis 10/2017
Personen-zertifizierter Sachverständiger

Bjorn Kierulf
Createrra s.r.o.
Hruby Sur 15

90301 Senec
Slovak Republic

Zertifizierter Sachverständiger
nach DIN EN ISO/ISC 17024:2012,
Zertif.-Nr : ZN – 20120928-0262
für Schäden an Gebäuden,
Innenraumschadstoffen,
Bauphysik, Fenstermontagen,
energetische Bewertung von
Gebäuden und Energieeffizienz

Bonn, den 28.08.2013

Straw Bale House

Dear Mr. Bjorn Kierulf,

the calculations with WUFI have been done under the following conditions:

- **climate data: Wien, Hohe Warte**
- humidity of the materials: straw < 17%
- indoor climate: high humidity loads (bathrooms or similar as maximal humidity)
- exterior wall: west (main wheater side)

1) Wall construction with 4mm plaster

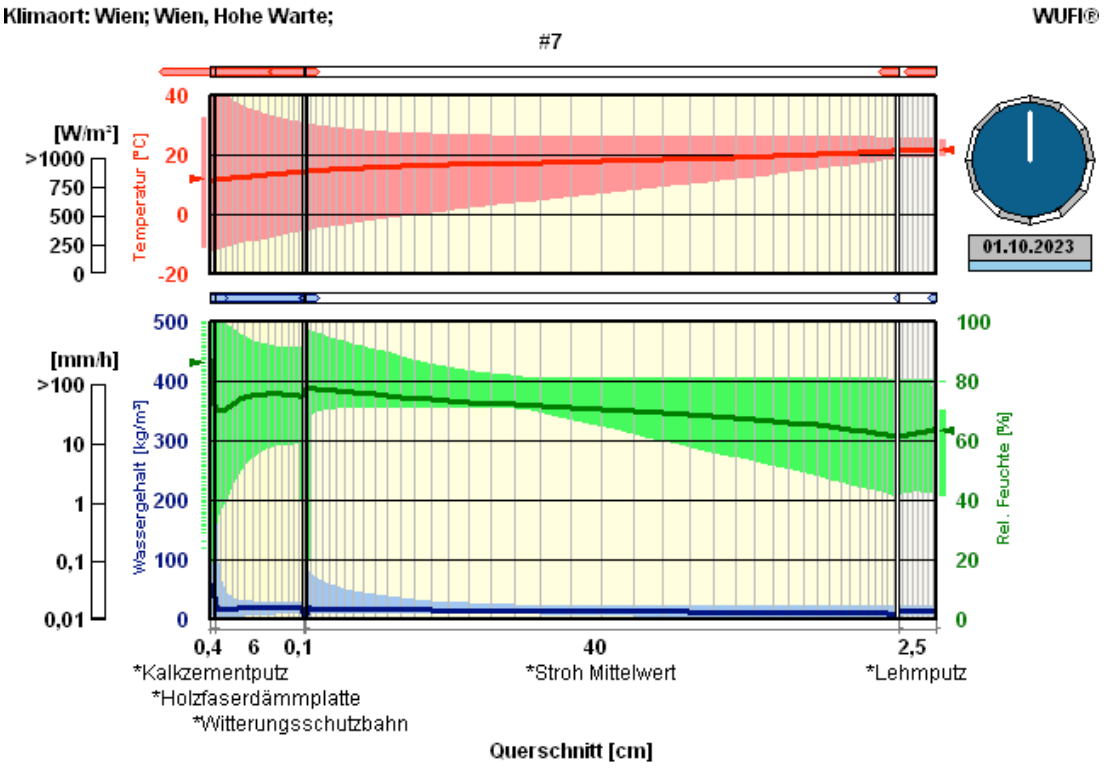
Construction from inside to outside:

clay plaster 25mm
straw 400mm
roofing membrane SD: 0.2 m
wood fibre insulation board 040 60mm
exterior plaster 4mm

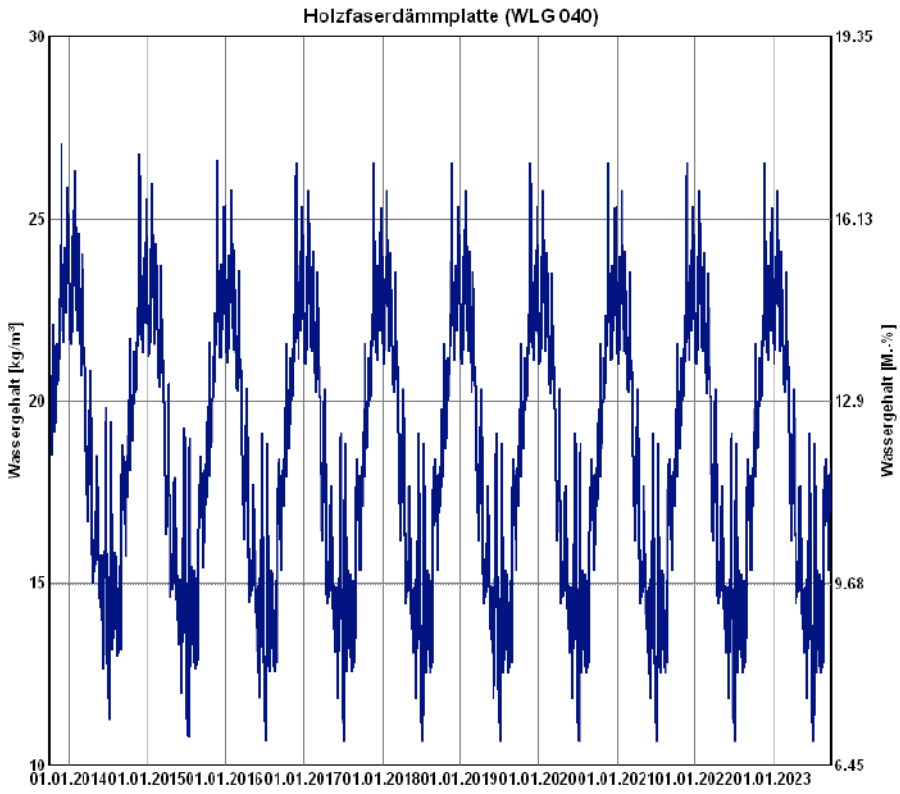
The exterior plaster with a w-value (coefficient of water absorption) of <0.1 kg/m2 * h.

Under these conditions, the calculations for the relevant components have revealed the following:

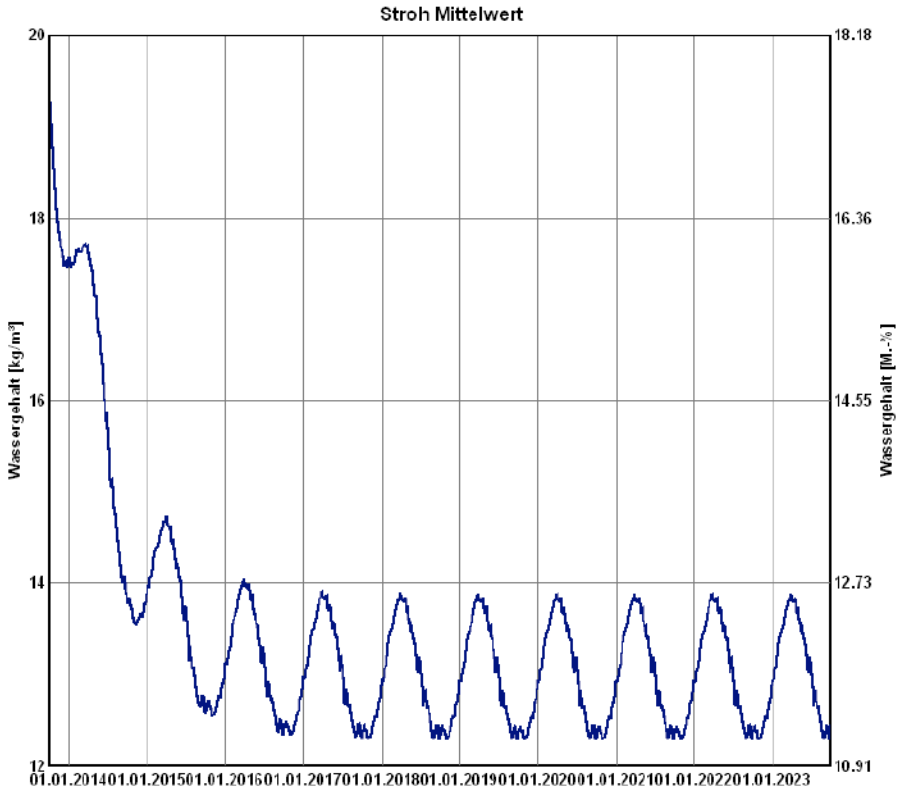
Whole construction:



Wood fibre insulation board:



Straw bale:



This construction can be realised under the following conditions:

- The exterior plaster must have permanently a w-value of <0.1 kg/m2 * h.
- The w-value must be frequently controlled. If the value increases over 0.3 kg/m2 * h the construction is not longer realisable

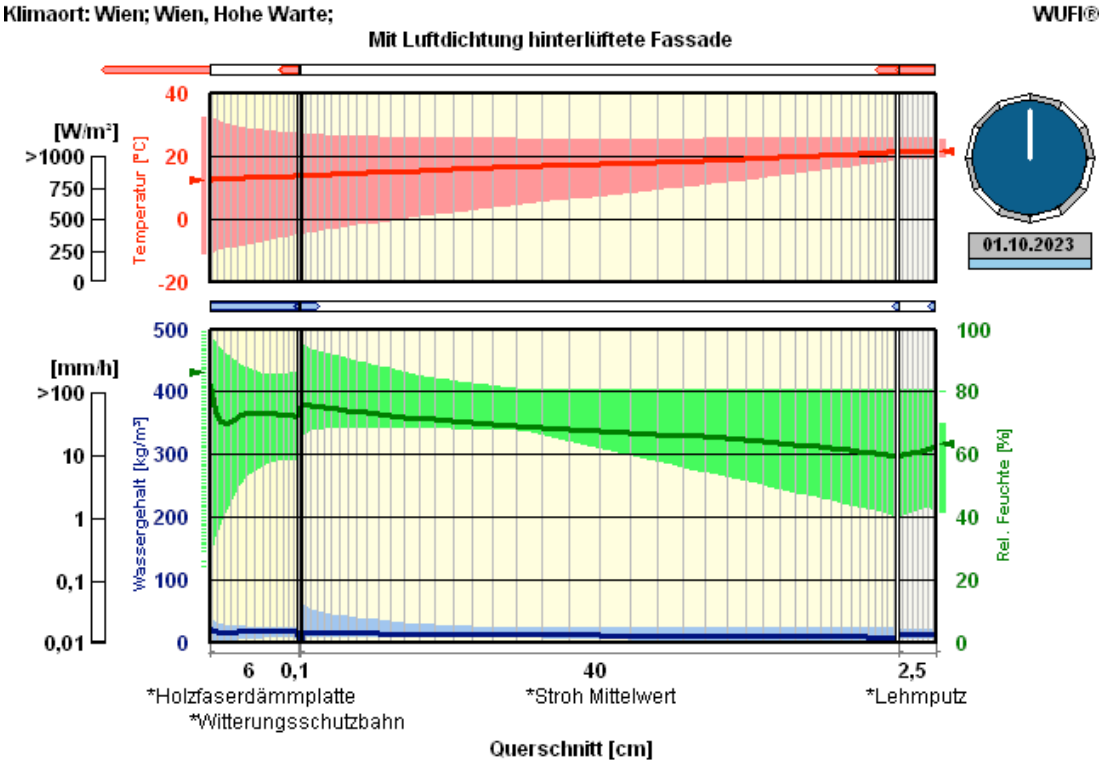
2) Construction with ventilated facade:

The construction with the ventilated facade, without rainfall on the wood fibre insulation board, has the following results:

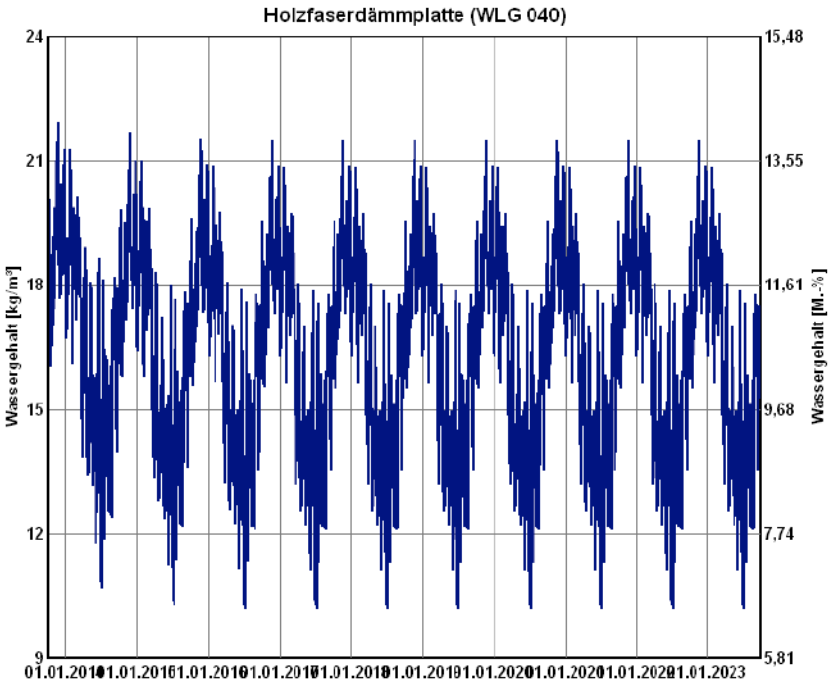
Construction from inside to outside:

clay plaster 25mm
straw 400mm
roofing membrane SD: 0.2 m
wood fibre insulation board 040 60mm
ventilated facade

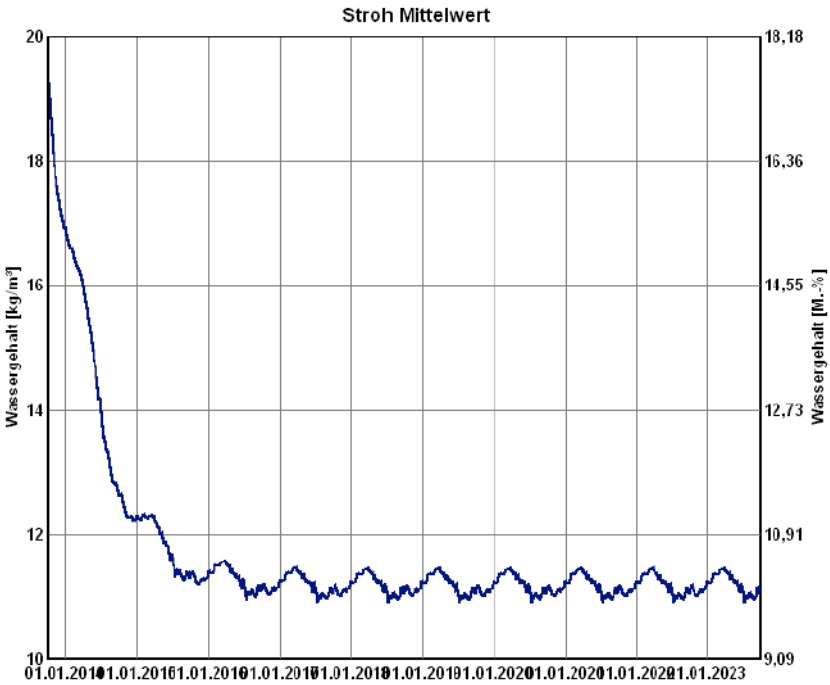
Whole construction:



Wood fibre insulation board:



Straw bale:



The construction can be realised.

The same construction could also be realised without the roofing membrane, if the vapor tightness is ensured on the inside.

Kind regards

Michael Brandhorst

Annotation:

The values for the Straw bale are average values, of all existent analysis. The following values has been used for the calculations:

raw density	100,0	kg/m^3
porosity	0,9	m^3/m^3
thermal capacity	2000	J/kgK
thermal conductivity	0,045	W/mK
diffusion resistance coefficent	1,3	-

Due to their inhomogeneity exact values for straw bales are not definable. The above-mentioned calculations present only refenrence values.