Group1
The impact of climate change on cultural heritage buildings

Hygrothermal performance of building materials in historic buildings and structures under various climate change scenarios

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ABSTRACT

It is known that climate change causes drastic changes all over the world and the average temperature is continually increasing, along with other various disasters. This directly affects the building materials, making them vulnerable to any kind of damages, specially biodeterioration. This European Project Semester investigates the hygrothermal performance of two timber historic buildings in Tønsberg, a city located in Norway, considering different climate scenarios. These constructions are mainly damaged by biological degradation of the wooden building parts, so the study focuses on the parameters related to mold risk. The main goal of this research is to use these two case studies as a small scale to predict the future of the deterioration of the construction materials. This investigation entails an inspection in situ, analyzing samples, working with hygrothermal simulation software, between other different kinds of tools. The project is part of Hyperion, a research and investigation program funded by the European Union in 2020.

PROJECT SUMMARY

It is known that climate change causes drastic changes all over the world and the average temperature is continually increasing, along with other various disasters. This directly affects the building materials, making them vulnerable to any kind of damages, specially biodeterioration. This European Project Semester project investigates the hygrothermal performance of two timber historic buildings in Tønsberg, a city located in Norway, considering different climate scenarios. These constructions are mainly damaged by biological degradation of the wooden building parts, so the study focuses on the parameters related to mold risk. The main goal of this research is to use these two case studies as a small scale to predict the future of the deterioration of the construction materials. This investigation entails an inspection in situ, analyzing samples, working with hygrothermal simulation software, between other different kinds of tools. The project is part of Hyperion, a research and investigation program funded by the European Union for the period 2019-2022 under the Grant Agreement 821054.

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1. INTRODUCTION

Human activity has an increasing influence on the climate and the temperature of the earth. Burning fossil fuels, farming livestock and cutting down rainforest add large amounts of greenhouse gases to the atmosphere. Greenhouse gases are known to trap the sun's heat and stop it from leaking back into space. Many of these gases occur naturally in the atmosphere. However, the actions of humans are raising the concentrations.

An increasing concentration of these gases leads to a number of consequences such as risks for human health, melting ice and rising seas, risks for wildlife, extreme weather and shifting rainfall and costs for society and economy. Norway will mostly be affected by higher temperatures, rising seas and an increase in rainfall. The rising temperature in Norway will slowly turn the snow-covered winters into rainy winters (European Union, n.d.).

It is not only the humans that are in danger due to climate change but also cultural and historical buildings. Through time the construction materials of these buildings start to deteriorate. This is a natural phenomenon of time, however, the increasing temperature, air pollution, and other human-related actions are speeding up the process of deterioration. In time the climate crisis will make it more difficult to preserve the cultural heritage.

To understand the specific effects of climate change on the cultural heritage buildings in Norway two different buildings, located in Tønsberg, were investigated; the Heierstad loft and the Fadum Storehouse. During the first stage of the project, the buildings were mapped. Afterward, climate risk scenarios were analyzed. The last stage was the investigation of the biodeterioration of old building materials. The main goal of this research is to use these two case studies as a small scale to predict the future of the deterioration of the construction materials.

Figure 1. Venice

Figure 2. Tonsberg

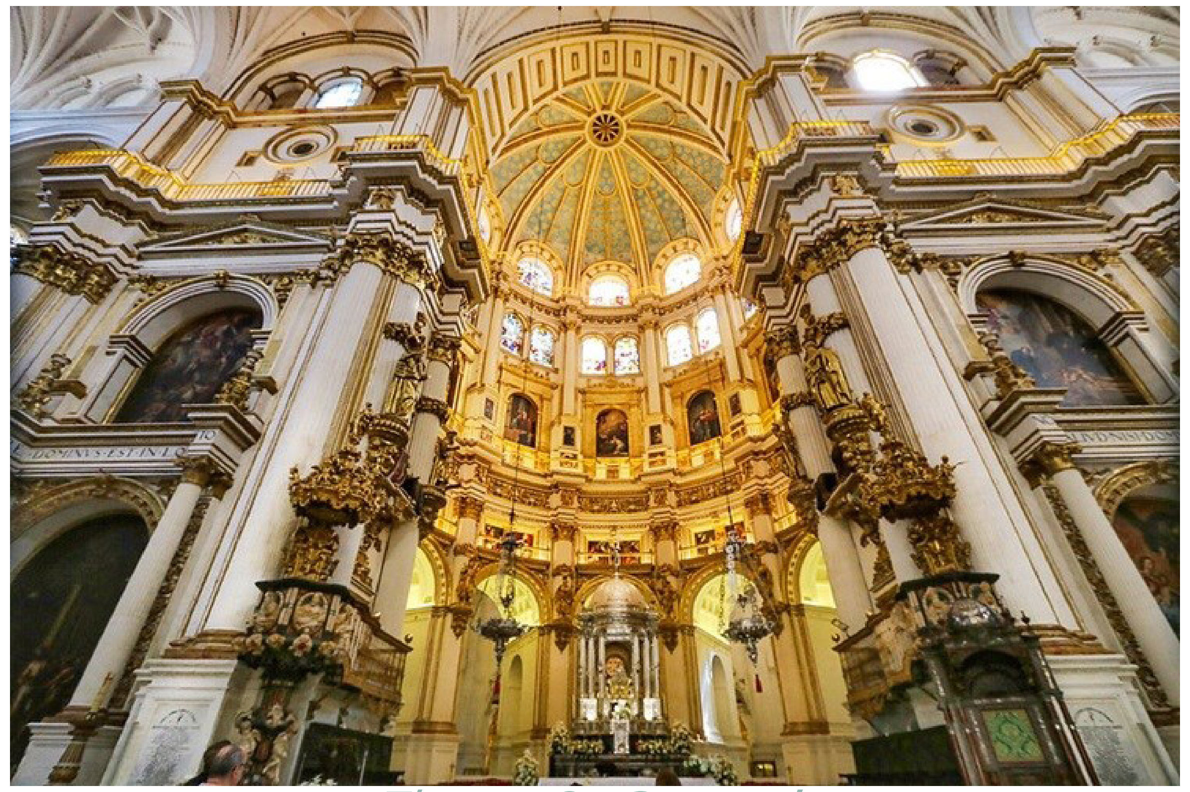


Figure 3. Granada

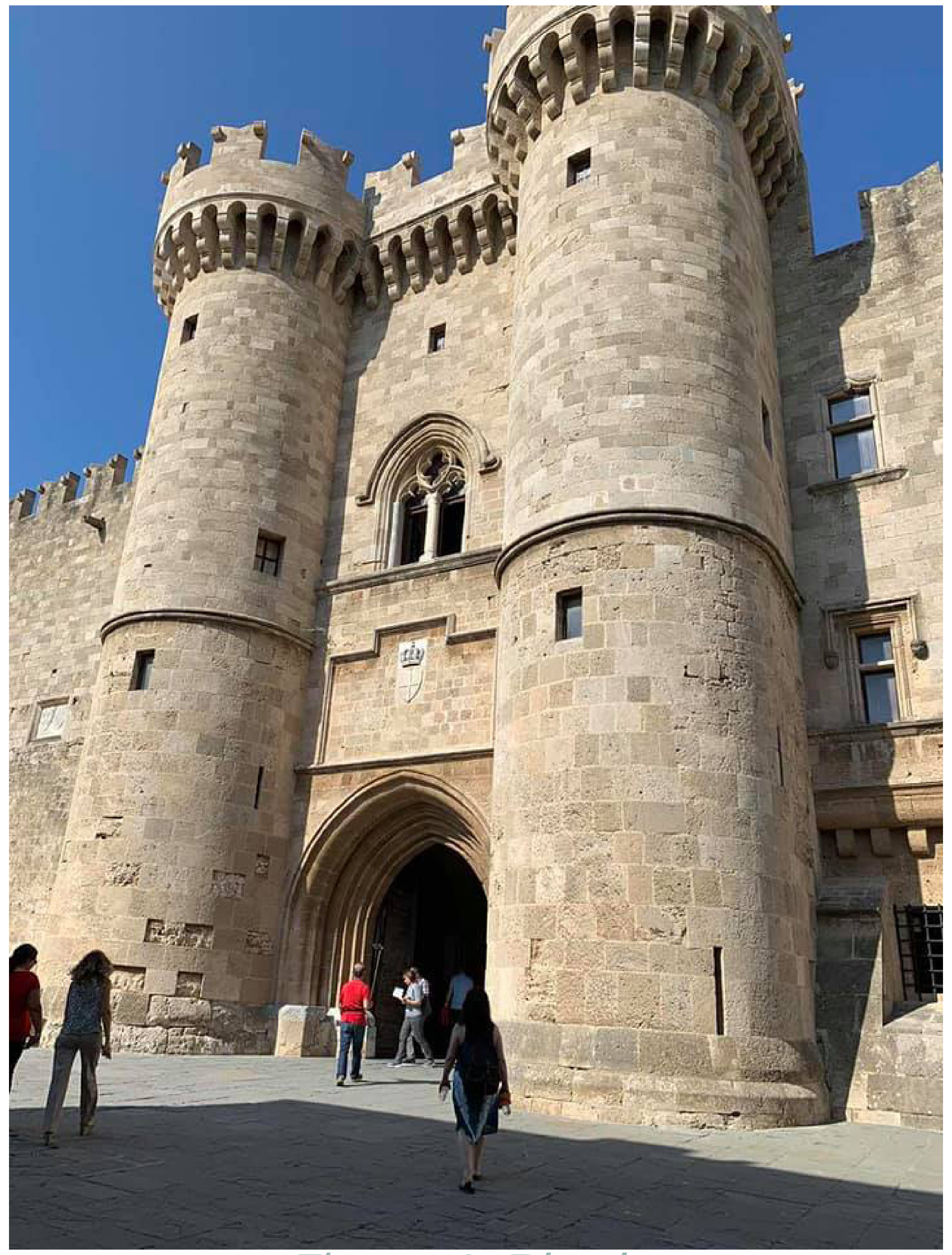


Figure 4. Rhodes

1.1. VISION

Hyperion is a European project of particular importance for the preservation of Europe's tangible cultural heritage. Accordingly, the program began its research activities in early June 2019, coordinated by the Institute for Communications and Computer Systems Research at the National Technical University of Athens (NTUA).

The main objective of HYPERION project is to offer appropriate tools for a better understanding of the impact of climate, weather ravages, intense geological phenomena and accidental and extreme weather conditions in archaeological sites and cultural monuments heritage.

Hyperion therefore focuses on four iconic locations: the medieval city of Rhodes (Greece), Albaicín and Realejo in Granada (Spain), the Castrum Tunsbergis in Tønsberg (Norway) and the City of Venice (Italy). Each of the cases have its own particular climate, different building materials and specific deterioration problems. This will provide a wider view of how the impact of climate change affects the historic buildings differently in Europe.

This EPS project is a part of Hyperion and it focuses on the cases studies in Tønsberg. The climate in Norway is very different from the other three investigated areas, and also the typology of the researched buildings variates. They are medieval timber structures vulnerable to biodeterioration and degradation caused by the extreme weather of Northern Europe. To analyze how these buildings will be affected by climate change, several simulations and physical inspections were carried out during the process. Eventually, after the results were discussed, some conclusions were made which might help to understand the behavior better of these two wooden structures, now and in the future.

1.2. PROBLEM FORMULATION

Building materials are exposed to potential damages due to various phenomena. One of these phenomena is the biological deterioration of materials. It is a natural process and therefore cannot be stopped. The climate has a direct impact on biodeterioration. Since the information for past and current climate conditions are available, the rates of biodeterioration for historic and current climate situations are well known. By the experiences from the recent years and the evaluation of climate data from the past century, a significant change of climate for many parts of the world is expected. Therefore, the prediction of future biodeterioration is fairly difficult. Other types of damage can be caused by extreme weather phenomena such as heavy storms or heat periods. Such weather phenomena will increase due to climate change in the next years (Austigard & Mattsson, 2019). Those types of damage can occur in every building. However, especially old cultural heritage buildings have a high risk of taking damage because their building materials already became much weaker during the life of those buildings. Cultural heritage buildings are witnesses to history and tradition of countries all around the world. It should be in the interest of those countries to preserve their heritage and secure it for the future generations.

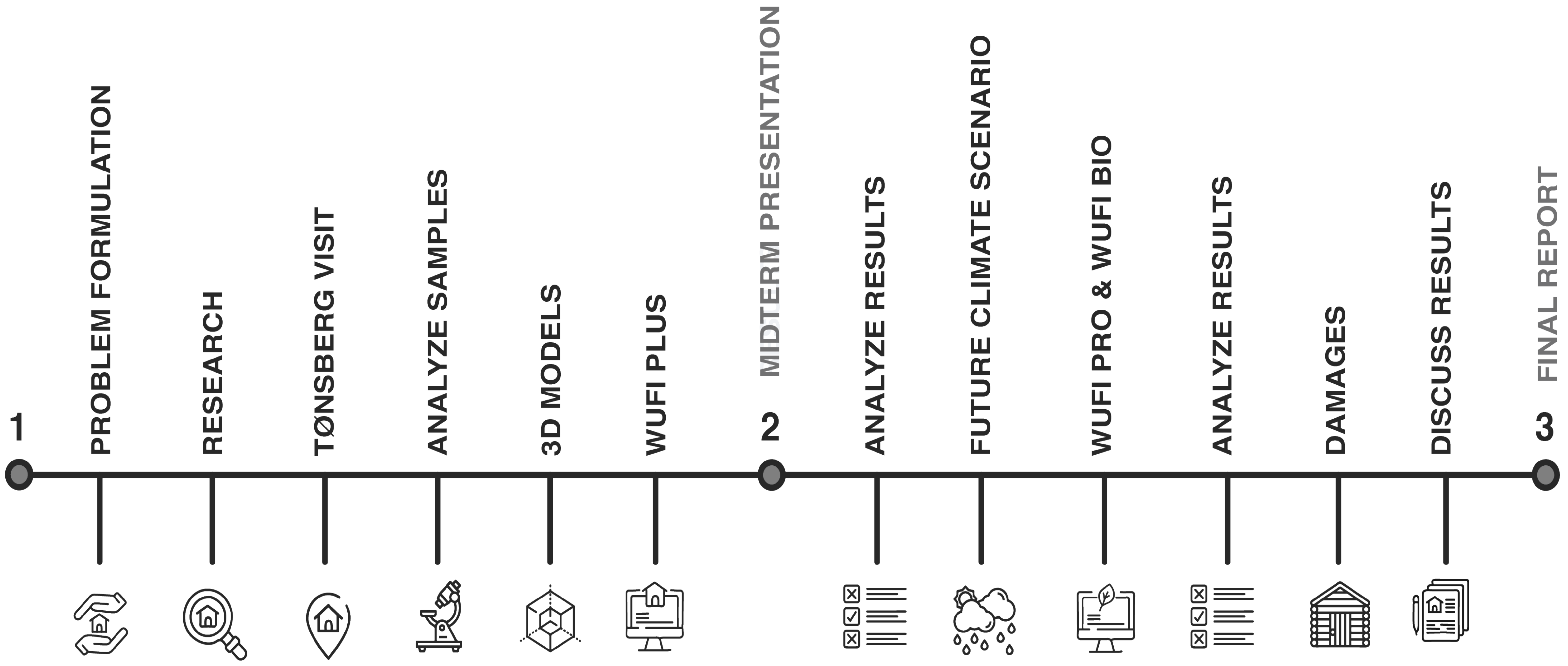


Figure 5. Project Timeline

This timeline shows the different tasks needed to reach the goals set at the beginning of the project. The first steps were very theoretical and based on research to get a better understanding of the purpose. Moreover, a visit to the pilot area, Tønsberg, took place early in the semester to collect some samples and to do a physical inspection of the two buildings. WUFI plus is a hygrothermal energy simulation software that was introduced in the first stage of the period and helped to understand how the buildings studied behave in different climate situations.. During the second part of the project, the focus was on the development of a new climate scenario which was used for the hygrothermal simulations in WUFI pro, WUFI plus and WUFI bio. An analysis of the actual damages was carried out at the same time as the running of the simulations. Eventually, the results were discussed to finalize the final report.

2. THEORY

2. 1. CLIMATE CHANGE: GENERAL INFORMATION

The term climate describes the atmospheric conditions for a specific area and is measured over a long period of time. While the weather can change from day to day or seasonally, climate refers to a stable situation for a long period of time. Climate change is the long-term alteration of those climate conditions (National Geographic Society, 2019). It has occurred throughout the Earth's history and is caused by imbalance in the energy exchange between the Earth and space. The energy exchange is influenced by the greenhouse gases. The main greenhouse gases are carbon dioxide, carbon monoxide, chlorofluorocarbons, nitrogen oxide and methane. They occur naturally in the Earth's atmosphere and causes the greenhouse effect, which indeed is needed to make our planet habitable.The gases work as a mirror and reflect some of the infrared radiation back to the Earth's surface. Because of the reflection of the heat, we have a stable temperature on Earth. Changes in the concentration of those gases lead to an imbalance in the energy exchange between the Earth and space and therefore, leads to changes in the weather. Changes of the concentration occurred throughout the Earth's history and were caused by natural phenomena as volcanic eruptions. However, the change of concentration since the begin of industrialisation were mainly caused by human activities (NCSS, 2017).
As figure 6. shows, the burning of fossil fuels for energy production and the large remove of vegetation caused a drastic increase of the concentration of greenhouse gases in the Earth's atmosphere since 1900.

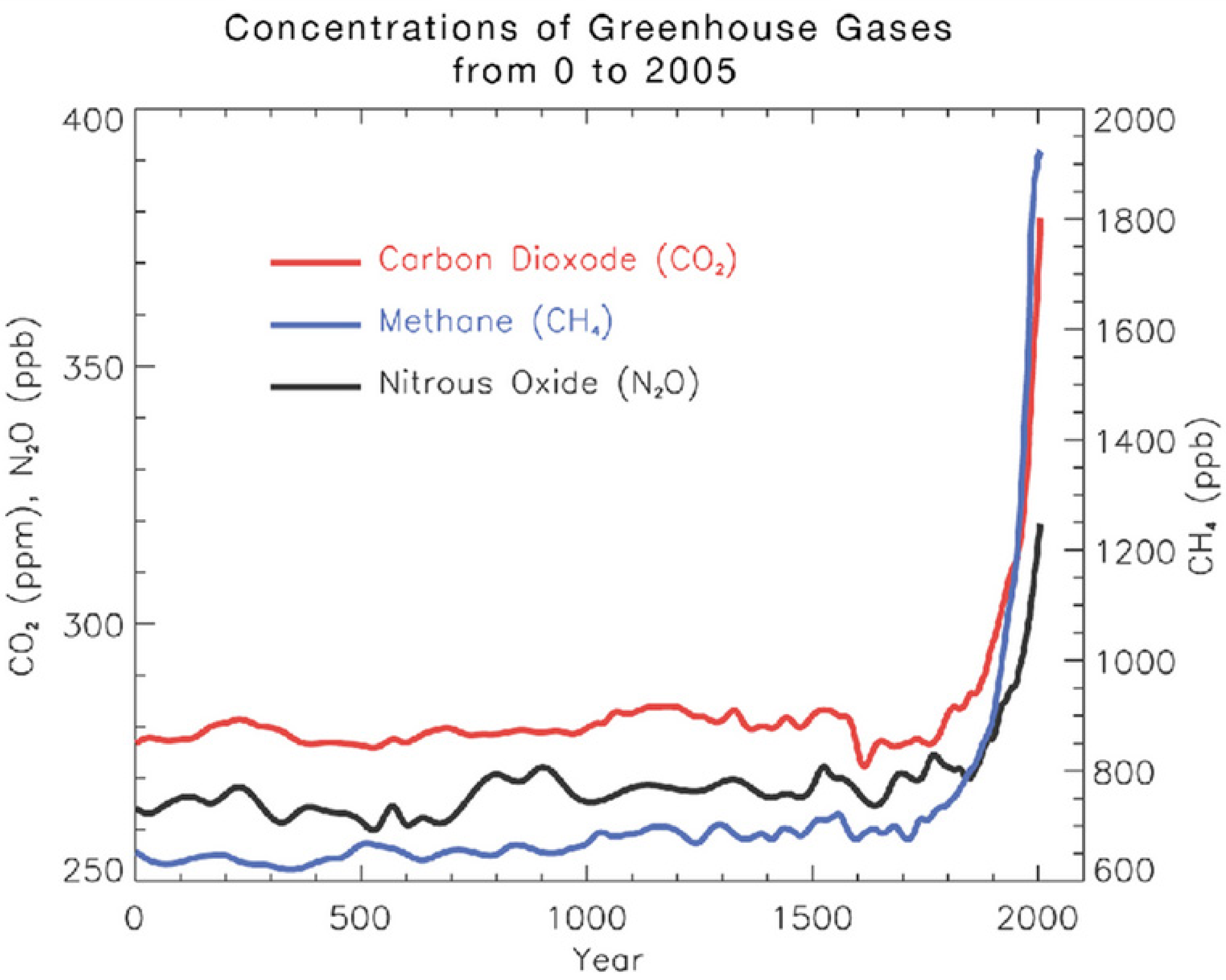


Figure 6. Greenhouse gases concentration from 0-2000

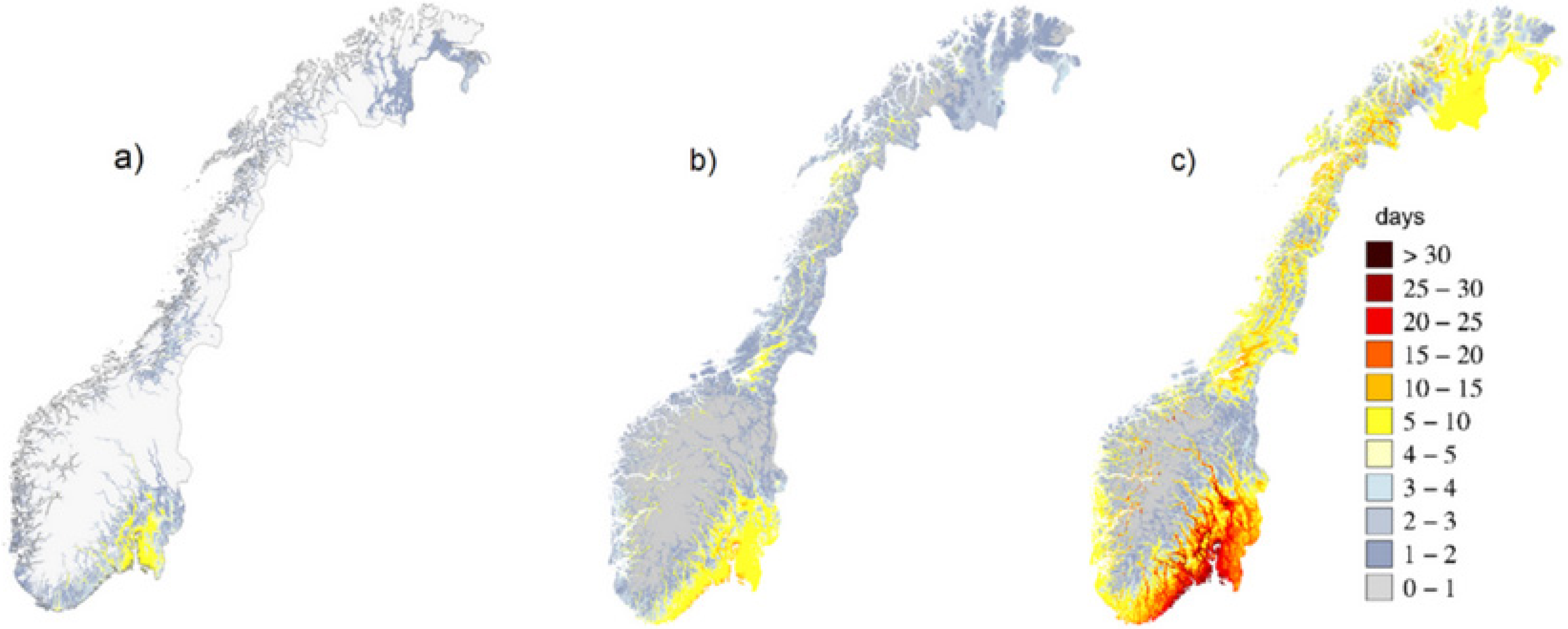


Figure 7. Number of “warm days” per year in a) 1971-2000, b) RCP4.5 and c) RCP8.5

2.2. CLIMATE CHANGE IN NORWAY

The past, present and future climate situation in Norway is presented in the NCCS report “Climate in Norway 2100”. This report is a basis for climate adaptation in Norway and uses the climate scenarios presented in the latest report from the Intergovernmental Panel for Climate Change. The worst case of these scenarios is the RCP8.5. RCP is the acronym of Representative Concentration Pathways, what will be discussed in the next chapter. Several changes are expected for the climate in Norway till the end of the century. For instance, the annual temperature will increase by ca. 4.5°C. This increase becomes clear when considering the “warm days”, days with a daily mean temperatures above 20°C. As can be seen in figure 7. (NCSS, 2017, p.19), in the period from 1971-2000 the number of warm days lies within the interval of 4-10 days/year. For the end of this century the number of warm days shall increase to around 30 days/year.

The increase of temperature will reduce the number of glaciers and the remaining glaciers will be substantially diminished. In addition, the increase in temperature will boost the evaporation process and as a consequence more humidity will be concentrated in the atmosphere. As a result of the latter rainfall will be more intensive and will occur more frequently which leads to more floods induced by rainfall. Furthermore, the amount of winter snow cover will decrease and may disappear in some regions. For reduced greenhouse gas emission scenarios, the changes will be less significantly. A precise list of all expected changes for the climate in Norway can be found in the report (NCSS, 2017).

2.3. CLIMATE SCENARIOS

Established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC) developed climate emissions scenarios to get a understanding about how the future might look. The information related to those emissions scenarios are published in the IPCC assessment reports. There are different types of future climate scenarios. The most used scenarios in literature are “Special Report on Emissions Scenarios” (SRES) and more recently, the “Representative Concentration Pathways” (RCPs). All these future scenarios have in common that they focus on the greenhouse gas emissions and concentrations throughout the 21st century.

SRES were used in the third and fourth IPCC Assessment Reports. The figure 8. (IPCC Working Group 3, 2000, p.4) shows the subdivision of the different scenarios. They are divided into four scenario families, the A1, A2, B1 and B2 storyline. Each scenario determinants a certain storyline and builds up the simulation on this base. The simulation calculates the changes in greenhouse gas emissions and concentration. With this information, all the other climate parameters are predicted.

The four scenario families are divided into six scenario groups, one group each in A2, B1 and B2, and three groups in the A1. Within the set of scenarios, some share “harmonized” assumptions on global population, gross world product and final energy. These scenarios are marked as “HS” for harmonized scenarios. “OS” describe scenarios that explore uncertainties in driving forces beyond those of the HS.

The A1 scenario family describes a future world of very rapid economic growth, global population that peaks mid-century and declines after that, and the rapid introduction of new and more efficient technologies. The A1 scenarios develop into three groups that have their own energy system: fossil intensive (A1F1), non-fossil energy sources (A1T) or a balance across all sources (A1B). The A2 scenario family describe a heterogeneous world. The underlying theme is self-reliance and preservation of local identities. It is characterized by an continuously increasing global population and slow and fragmented technologie change and economic growth.

The B1 storyline describes a convergent world with the same global population as in the the A1 storyline. The economic structures change rapidly toward a service and information economy with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability. The B2 scenario family describes a world with a focus on local solutions to economic, social and environmental sustainability. It has a similar population as the A2 storyline, but the increasing rate is lower. Technological changes are less rapid and more diverse compared to the B1 and A1 storylines and it has intermediate levels of economic development (IPCC Working Group 3, 2000).

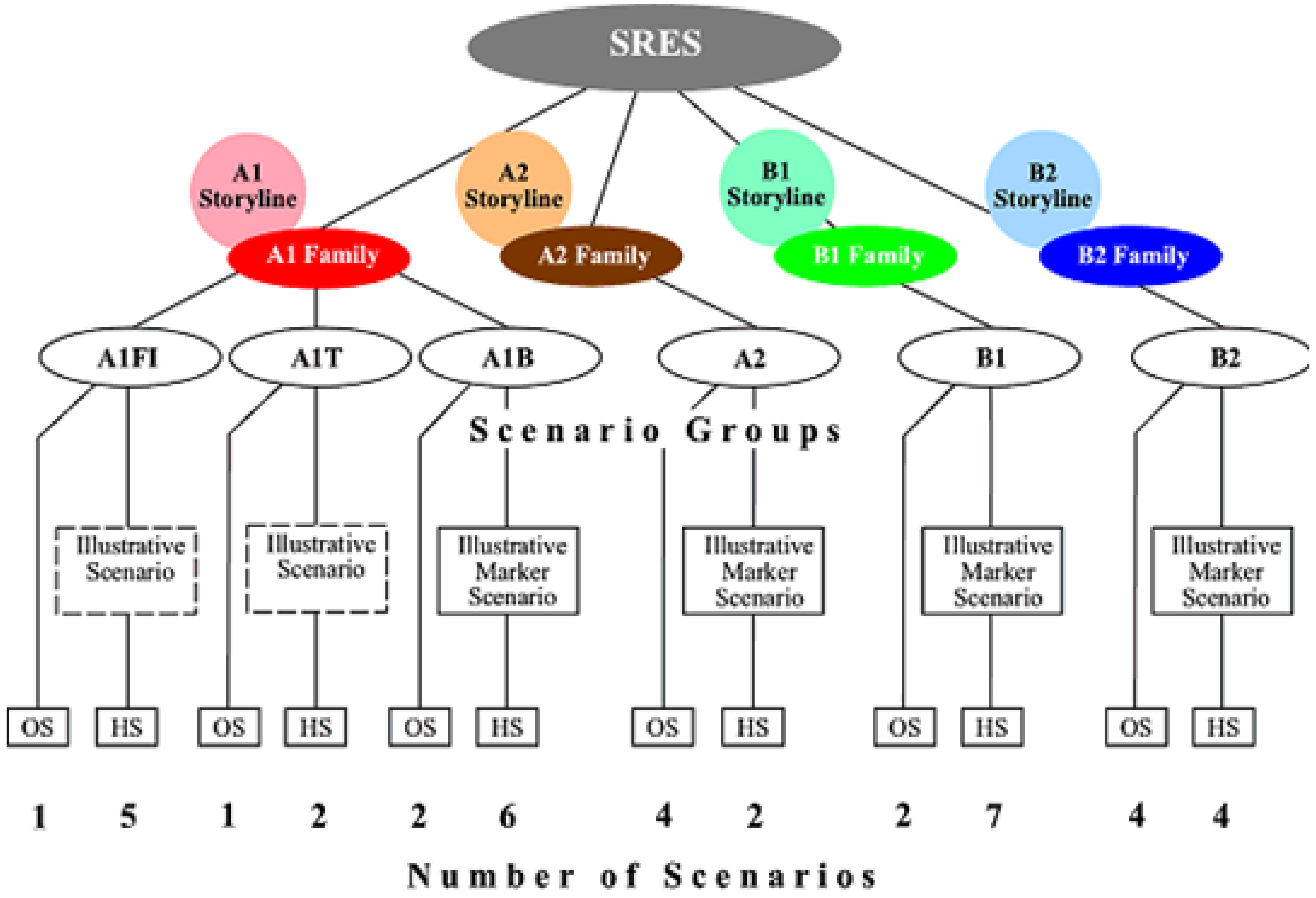


Figure 8. Illustration of SRES scenarios

Figure 9. (IPCC Working Group 3, 2000, p.9) shows the expected total global emissions of CO2 from 1990 to 2100 related to the different scenarios. The SRES scenarios can also be grouped into four emissions categories: low, medium-low, medium-high and high. Other greenhouse gases have a similar curve course. The significant high emission of the greenhouse gases will lead to a large increase of global and local temperature.

Since the Fourth Assessment Report important improvements in climate models have been made. Therefore, a new generation of climate scenarios were used for the Fifth Assessment Report, the RCPs. RCPs are time and space dependent concentration curves of greenhouse gases and pollutants resulting from human activities, including changes in land use. While SRES first set a specific storyline and determine the development of the concentration of greenhouse gases, RCPs are using radiative forcing to express their simulations. As figure 10. shows (Wayne, 2013), RCPs can be divided into four groups of radiative forcing levels: 2.6, 4.5, 6 and 8.5 W/m² in the year 2100.

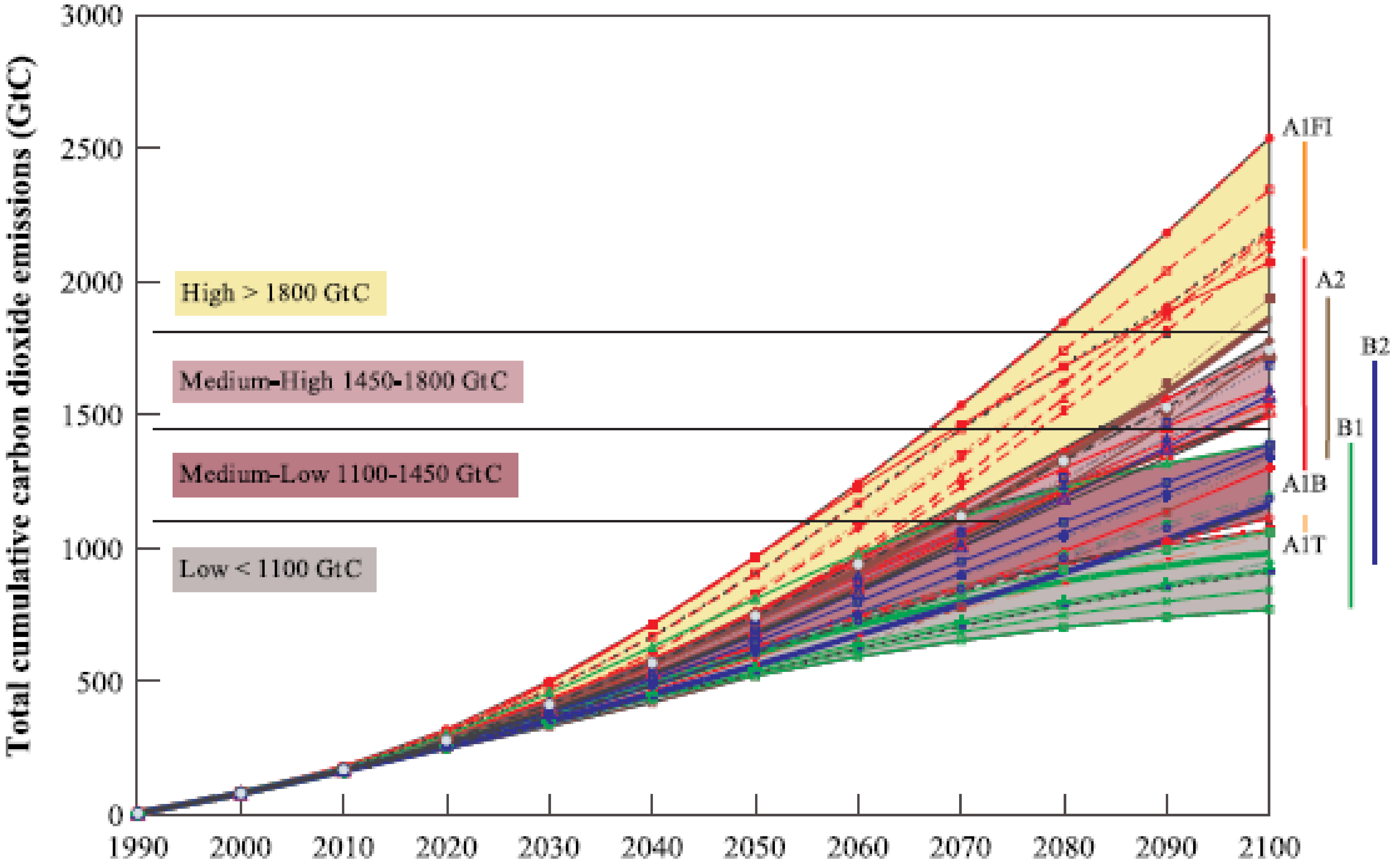


Figure 9. Total global cumulative CO2 emissions from 1990 to 2100

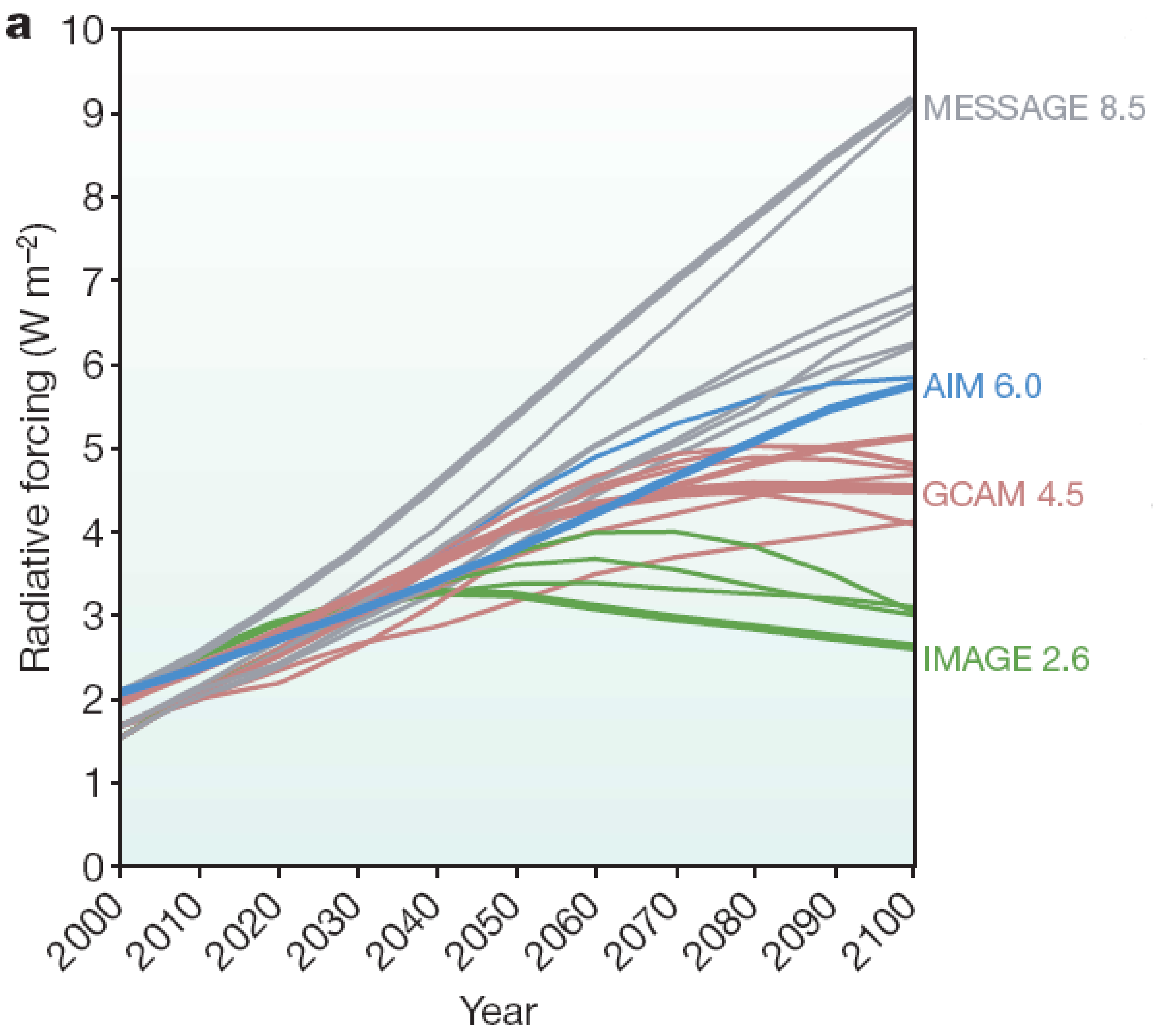


Figure 10. Changes in radiative forcing

Radiative forcing is the additional energy taken up by the Earth system. It can be defined as the difference in the balance of energy that enters the atmosphere and the amount that is returned to space.Radiative forcing is influenced by positive forcing from greenhouse gases and negative forcing from aerosols. As the radiative forcing increase, the global temperature rises.
A key difference between the RCPs and SRES is that there are no fixed storylines to reach the different values of radiative forcing. Many different socio-economic futures can lead to the same level of radiative forcing. Therefore, one RCP is only one possible way of development throughout the 21st century. This provides much more opportunities for the researcher as they can be more flexible with the different parameters such as global population or economic development.

The RCP 8.5 is a high emission scenario comparable to the SRES scenario A1F1. It describes a future with no policy changes to reduce emissions. It has a heavy reliance on fossil fuels, high energy intensity and a low rate of technology development.
The RCP 6 describes a world comparable to the B2 SRES scenario. There is still a heavy reliance on fossil fuels. However, it has a intermediate energy intensity and and consists the application of a range of technologies and strategies for reducing greenhouse gas emissions.
The RCP 4.5 consist a future with relatively ambitious emissions reductions. There are stringent climate policies, lower energy intensity and strong reforestation programmes. It can be compared with the B1 scenario.
The RCP 2.6 is a low emissions scenario. Radiative forcing would reaches 3.1 W/m² before it returns to 2.6 W/m² by 2100. This future would require low energy intensity, declining use of oil and a high decrease of greenhouse gas emissions. It has no comparable SRES scenario and can be described as a “best case” scenario (Bjørnæs, 2015).

Figure 11. (Wayne, 2013) shows the development of greenhouse gas concentrations across the RCPs. It is clearly to see that the concentrations raise as higher the radiative forcing becomes.

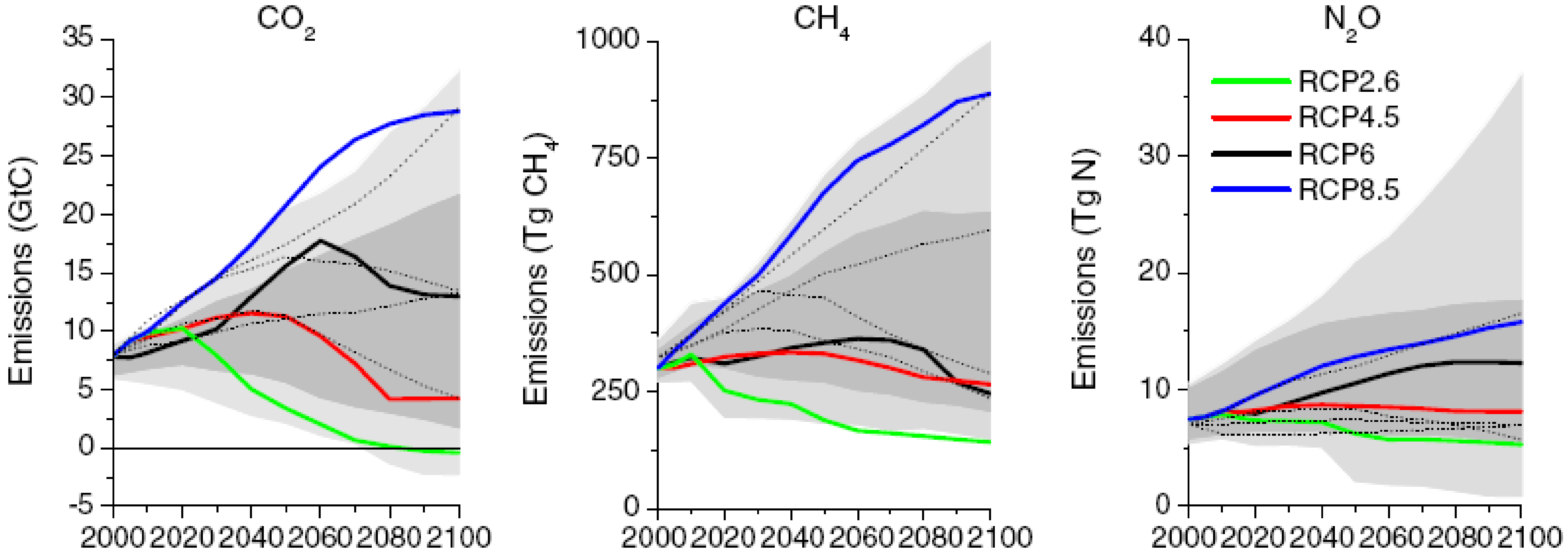


Figure 11. Greenhouse gases emissions across the RCPs

Figure 12. The great pyramids of Giza in Egypt

Figure 13. The Taj Mahal in India

2.4. HISTORIC BUILDINGS

Historic buildings
A historic building is a built structure that is considered to hold some historical significant and value. It may hold a specific historic interest because of its importance with respect to a particular historical event or period. It may hold a specific historic interest because of its importance with respect to a particular historical event or period. The word historic refers to something preserved from a past time or culture, whose first known use was in 1594. Continuing with the origin of the terms, the etymology of the word build comes from late Old English word ‘’byldan” and means «construct a house».

Some examples of historic buildings are the Great Pyramids of Giza in Egypt or the Taj Mahal in India. These well-known buildings have become a symbol of the countries and besides, they play an important cultural role in cultivating pride in our heritage. Apart from its cultural significance, they have significant economic value due to the fact that it creates workplaces for local people because of tourism. In addition, they are environmentally friendly considering those buildings a sort of recycling since they reduce construction waste and save the energy spent on manufacturing building materials.

Hyperion includes the analysis of four very different historic buildings. Each of them owns its specific problems and it is affected by climate change in distinct ways. These are the four case studies: the medieval city of Rhodes (Greece), Albaicín and Realejo, two old neighborhoods in Granada (Spain), the Castrum Tunsbergis in Tønsberg (Norway) and Venice (Italy). Accordingly, the climate differs significantly in every case, giving, as a result, a complete analysis of varied sorts of historic buildings. This analysis might be helpful for future studies and it can be extrapolated to other old buildings in danger of damage.

DAMAGES IN BUILDINGS

Climate change has many effects on human life. In this investigation, one of the four case studies is two timber buildings in Norway. It is known that for that kind of constructions, one of the most harmful effects is the vulnerability to biodeterioration, such as the germination of fungi. According to that, in order for fungi to grow, three conditions must be in place: a certain temperature, high relative humidity and time to let the fungi develop. To predict how fungi will affect the buildings in this study, those three conditions must be analyzed (Huijbregts, 2012).

Relative humidity (RH) is partial vapour pressure of humid air expressed as a percentage relative to the vapor pressure of the same air, saturated, and at the same temperature (Díaz-Pérez, 2019).
Higher relative humidity levels, due to inclement weather, will intensify the decay of the building materials in historic structures resulting in significant damages.
Harmful relative humidity can be divided in four types, which may cause the deterioration of the building materials: 1) damp; 2) RH above or below a critical value; 3) RH fluctuations. Mechanical, biological, and chemical deterioration all rise sharply beyond 60% RH, and increase significantly for every increment to 100% RH. The corrosion (in steel) takes place for RH > 60%, while mold growth for RH > 80%, and condensation, for surfaces or interstitial, for RH = 100%.
60-80% of all damage to the buildings is due to moisture or its effects. For example, fluid flow in water leaks, water transport due to capillary forces in the pores of the material, air leaks, or steam diffusion due to different water vapor contents in indoor and outdoor air (Michalski, 1993).

Mould growth on organic materials as wooden building materials is a major risk in historic buildings in Northern Europe, due to generally high indoor relative humidity values, and can cause significant damages. To set off a mould growth process in a building, a certain minimum temperature and relative humidity have to be exceeded: the temperature should be between 0 and 50 ºC and the relative humidity should be higher than approximately 70% for a certain period. Aside from that, the nutrient content of the substrate on which the mould growth occurs is a very significant factor (Sedlbauer, 2001).

Figure 14. Green Algae on the Heierstad Loft

Figure 15. Mold growth on the Heierstad Loft

Figure 16. Loss of material in the Heierstad Loft

Tønsberg (Norway)

This EPS project is focused on the case study in Tønsberg, which belongs to the region of Vestfold. The investigation consists of three different timber buildings situated in Slottsfjellet, a small hill in the town with a height of 63 meters above sea level. Some typical features of this area are the cold climate and the usage of wood as the main building material.

Tønsberg is located on 22m above sea level, the climate is mild, generally warm and temperate. It is an area where rainfalls are very common, even in the driest month. According to Köppen and Geiger, this climate is classified as Cfb. The average temperature in Tønsberg is 7.2 °C | 44.9 °F. About 728 mm | 28.7 inch of precipitation falls annually (Kottek, 2006).

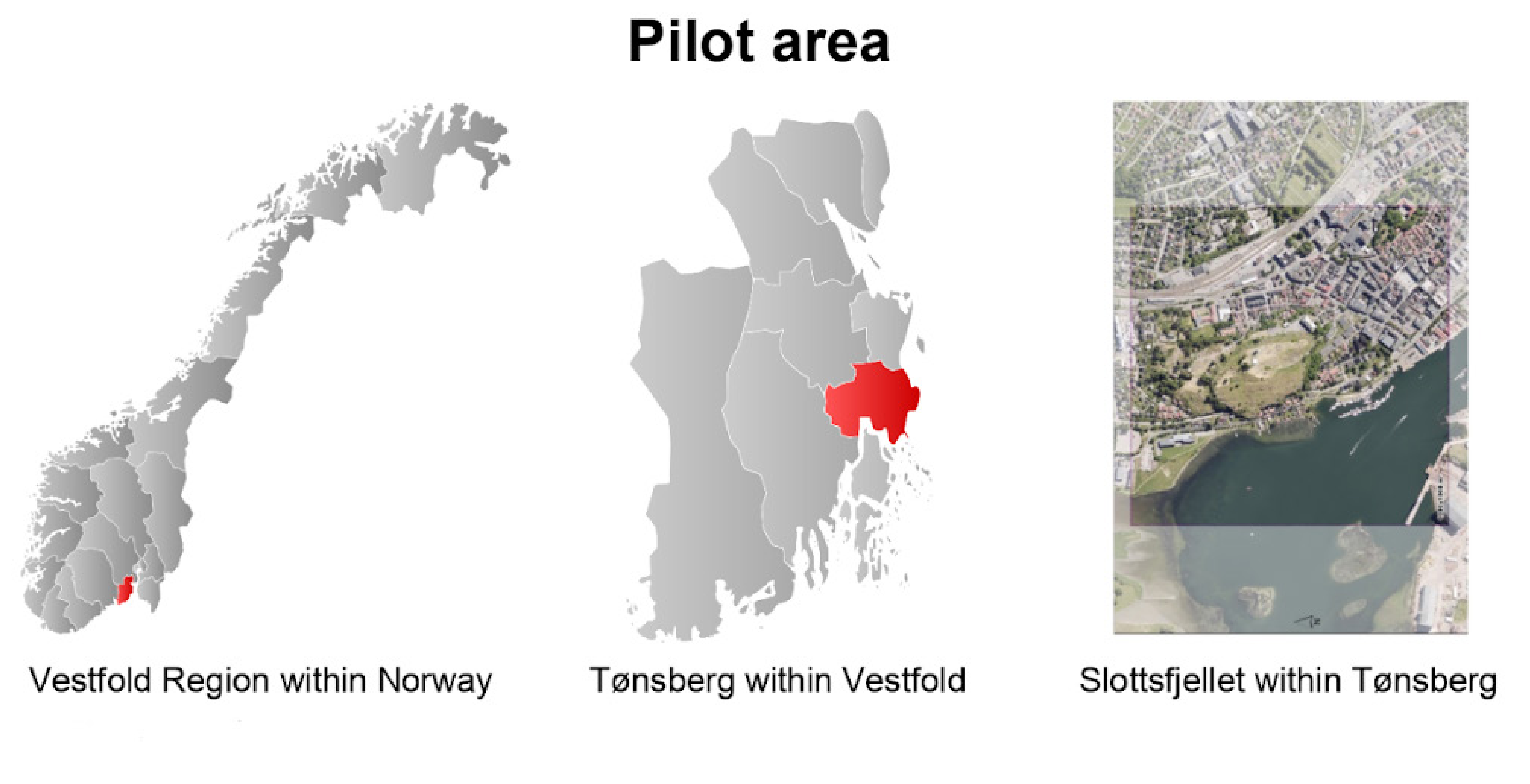


Figure 17. The pilot area

3. METHODS

3.1. PILOT AREA TØNSBERG

On February 7th a visit to Tønsberg was carried out. The buildings studied are located at Slottsfjellsmuseet, a Viking museum that owns medieval exhibitions and ancient ruins. Museum managers facilitated the way to the hill where the buildings were placed, inside the garden of the museum. Once there, the activities were executed in situ. Some of the tasks were to analyze the actual damage of the components, to take pictures of the buildings, to collect air samples in order to analyze them in the laboratory or to take small amounts of fungi directly from the wooden boards. These activities provided very useful information for the investigation and data that were subsequently analyzed in the next steps.

3.1.1. Heierstad Loft

The Heierstad Loft is a storage building, which moved from the Heierstad farm, 50 km north of Tønsberg, to the Slottsfjell Museum, where it was rebuild in 1957. The original ground floor is still intact and dates from 1407, while the attic floor is partially rebuild. The plan of the building is rectangular and has measurements of 8 x 9 meters, the height is around 9 meters. The building materials consist of large pine or spruce logs. On top is a simple gable roof construction, the roof material are thick wooden boards, a layer of birch bark and grass. The exterior is superficially treated with tar.

3.1.2. Fadum Storehouse

The Fadum Storehouse was built in the region of Fadum and dates from ca. 1820. In 1958, the building was moved approximately 5 km south-east from Sem to the Slottsfjell Museum in Tønsberg. It is a two-storey building, the ground floor was used as a storehouse while the first floor may have served as a bedroom. The building has a rectangular plan that measures 7.5 x 9 meters and a height of ca. 5.5 meters. The Fadum Storehouse is built of pine or spruce logs, with a simple gable roof construction. The roof is covered by bricks. The storehouse is overall in good condition however, it requires continuous maintenance. Typical for this building are the 8 wooden pillars the building stands on.

Figure 18. Heierstad Loft

Figure 19. Fadum Storehouse

3.2. TOOLS

This EPS project focuses on the impact of climate change on the future deterioration of cultural heritage buildings. Multiple tools are used in order to predict and calculate these results. The toolset consists mostly of an in-situ inspection, analysis of micro fungi, 2D and 3D modeling programs, and heat and moisture simulation programs.

3.2.1. SAS-ISO 100: Microbiological Sampler

A microbiological air sampler captures contaminants in a known volume of air. The contaminants are airborne and are compared and measured against the volume of air. The results are expressed as a concentration, normally as milligrams per cubic meter (mg/m3) or parts per million (ppm) (Napoli,2012).

During the visit in Tønsberg, the area monitoring method was executed. Area monitoring measures the concentration of a substance in a given area. The SAS-ISO 100 microbiological air sampler draws a known volume of air through a substance. The fungi get stuck in the substance while the air is able to pass through. Two different substances, DG18 and Malt, were used in order to receive more accurate results.

3.2.2. Revit

Autodesk Revit is a Building Information Modeling (BIM) software that allows users to design with drafting elements and parametric modeling. BIM is a new Computer Aided Design (CAD) paradigm for object-based design. An advantage of Revit is that this program provides bidirectional associativity, which means that a change anywhere appears directly everywhere. A model made with BIM contains the full life cycle of the building, starting from concept to construction to end with decommissioning (Whitleygroup, 2017).

The Revit files of the Fadum Storehouse and the Heierstad Loft were already provided by the supervisors. These files are consulted as a tool to determine the dimensions of the floor plan of the buildings. However, AutoCAD will be used to function more efficiently.

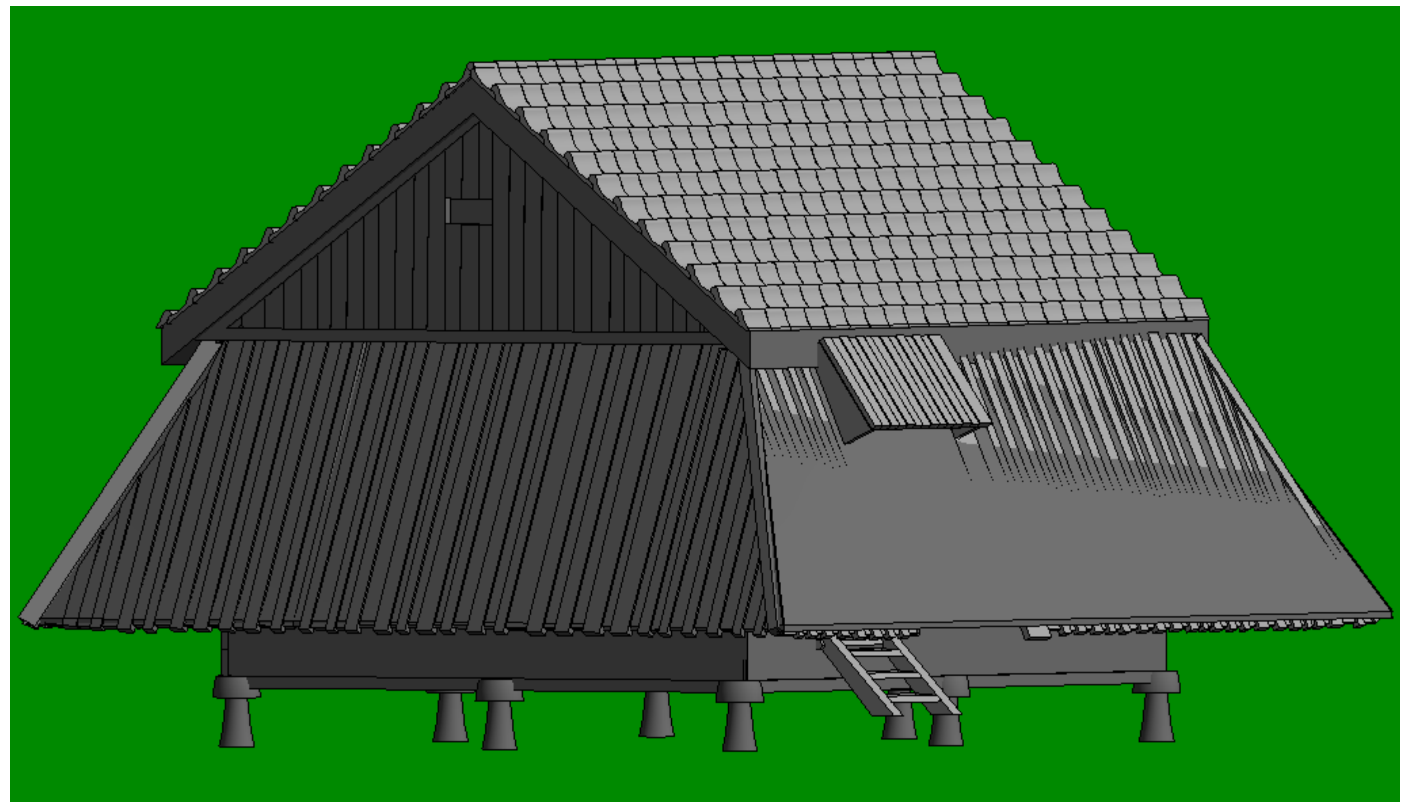


Figure 20. Revit model Fadum Storehouse

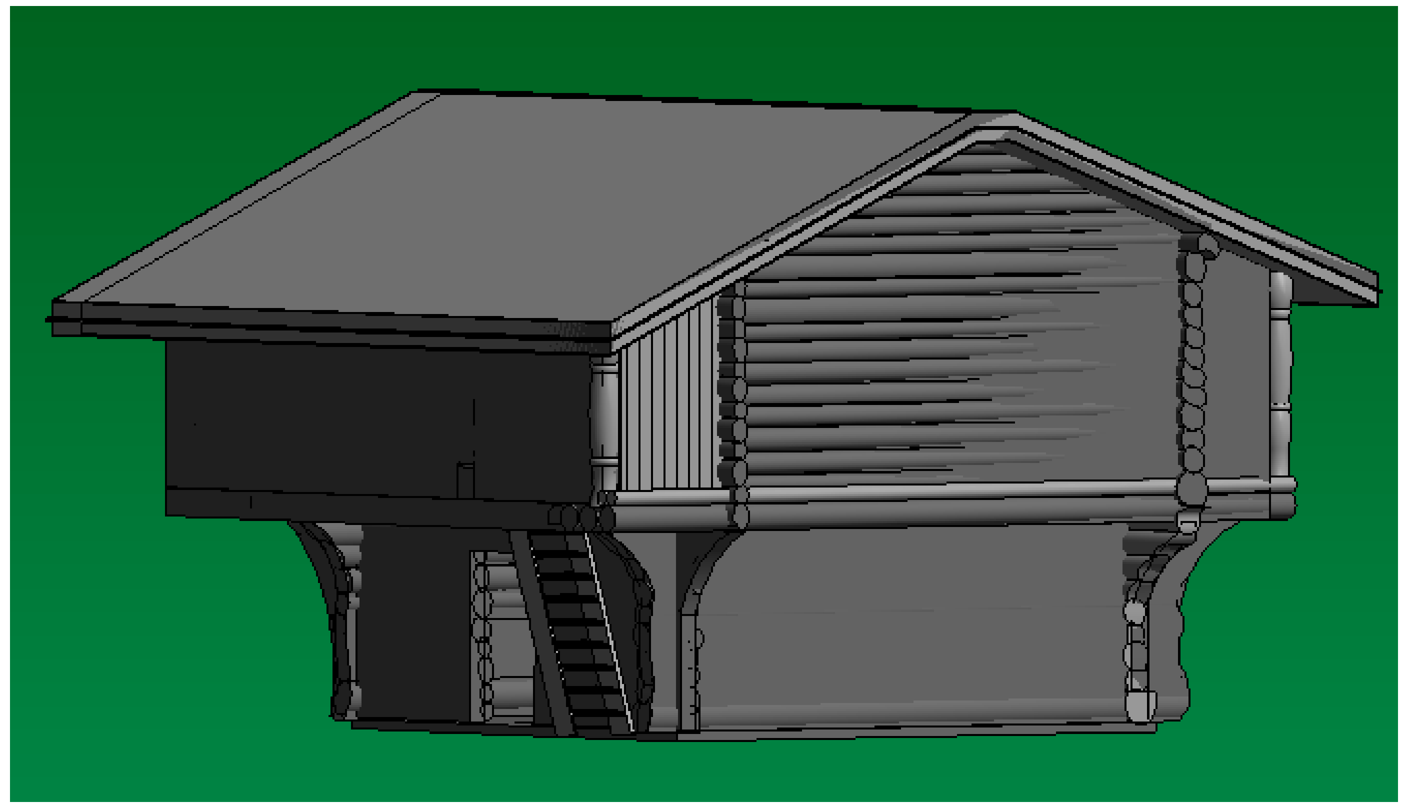


Figure 21. Revit model Heierstad Loft

3.2.3. AutoCAD

AutoCAD is a computer-aided design (CAD) software used to create precise 2D and 3D drawings. With AutoCAD architects, engineers and construction professionals can draft, annotate, and design 2D geometry and 3D models with solids, surfaces, and mesh objects (Fraunhofer, 2019).

The AutoCAD files implemented in this EPS project were provided by the supervisors. During this project the CAD files are adopted as a measuring tool to analyze the different dimensions of the building components. These component dimensions are necessary for the creation of the 3D models in WUFI Plus.

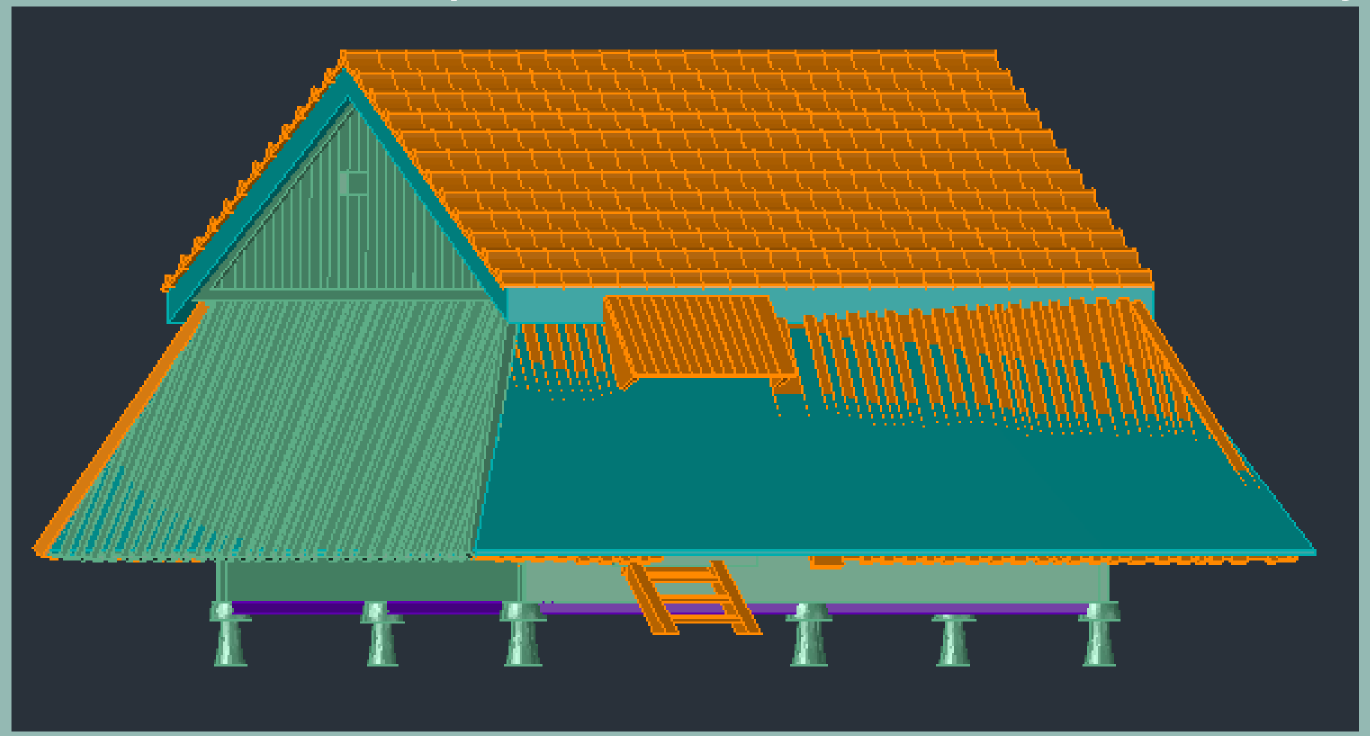


Figure 22. AutoCAD model Fadum Storehouse

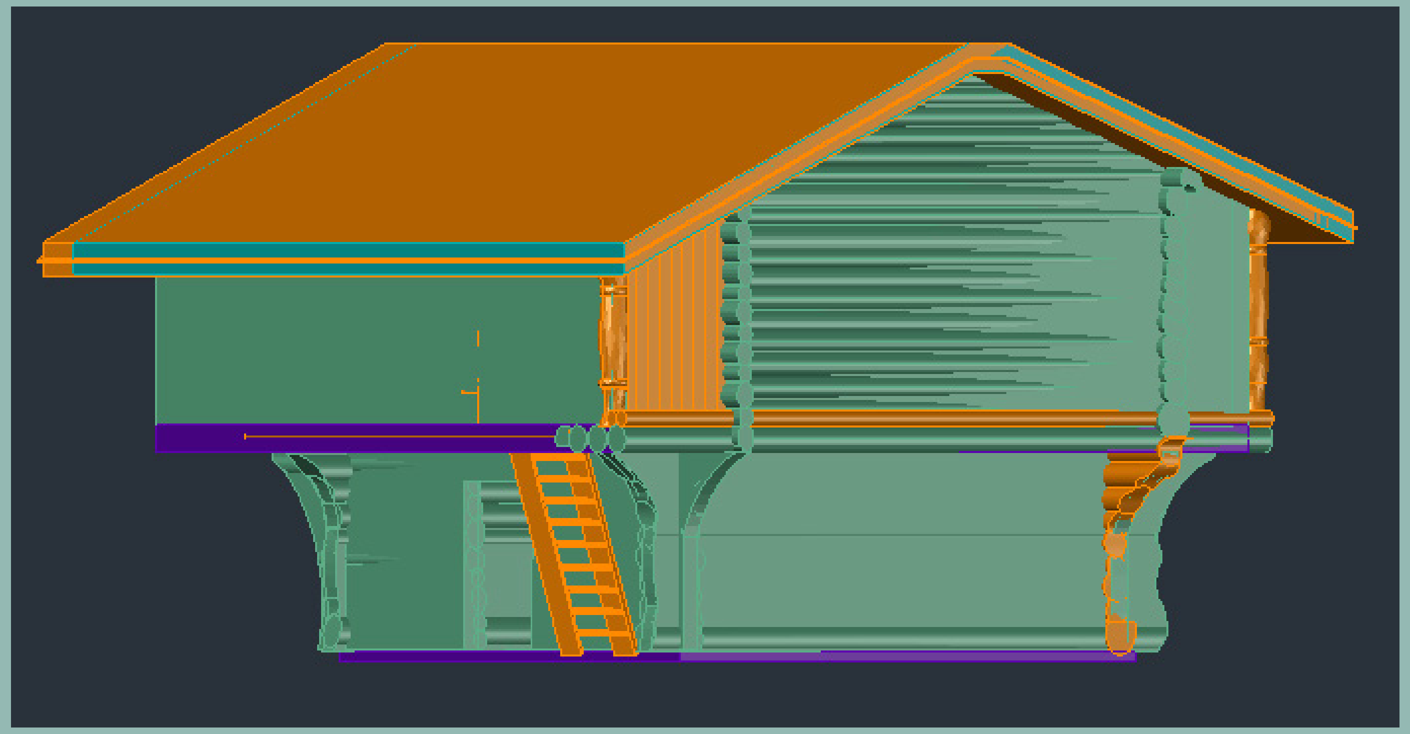


Figure 23. AutoCAD model Heierstad Loft

3.2.4. WUFI Plus

WUFI Plus is a heat and moisture simulation tool that simulates not only the hygrothermal conditions in building components but also the indoor environment. The simulations are based on user-specified settings which makes the situation at hand accurately represented.

WUFI Plus is a crucial tool in this project since we can digitally model the Fadum Storehouse and Heierstad Loft in order to simulate the current situation and to predict to future situation. The climate files implied to create these simulations are both from a weather station close to Tønsberg. The current climate is a typical year between 1991 and 2010 for the different types of radiation and cloud cover fraction. For the parameters of air temperature, percipation, relative humidity and wind speed and direction, the typical year is calculated between 2000 and 2009. The future climate, a prediction, is from 2100. Both the A2 and the RCP8.5 scenario were used in the WUFI Plus simulations.

The results from the simulation consist of temperature, relative humidity, and water content. Every zone of the building has its own results which makes it possible to see the transportation of these factors through the building components. The indoor climate of the zones created in WUFI plus will be used in WUFI Pro (Fraunhofer, 2019).

It was decided to divide the Heierstad Loft building in three different zones, in order to simulate the individual indoor climate present in the construction. This will help to analyze in a more precise way the hygrothermal performance of the structure. The first level corresponds to the ground floor and it has only one room, which accords to Zone 1. In the second level are differentiated two different zones according to their own characteristics: Zone 2 represents the corridor and Zone 3 the two rooms, whose spaces are separated by inner walls. The corridor was intentionally assigned into a different zone due to the fact of possessing the openings of the staircase and certain small windows.

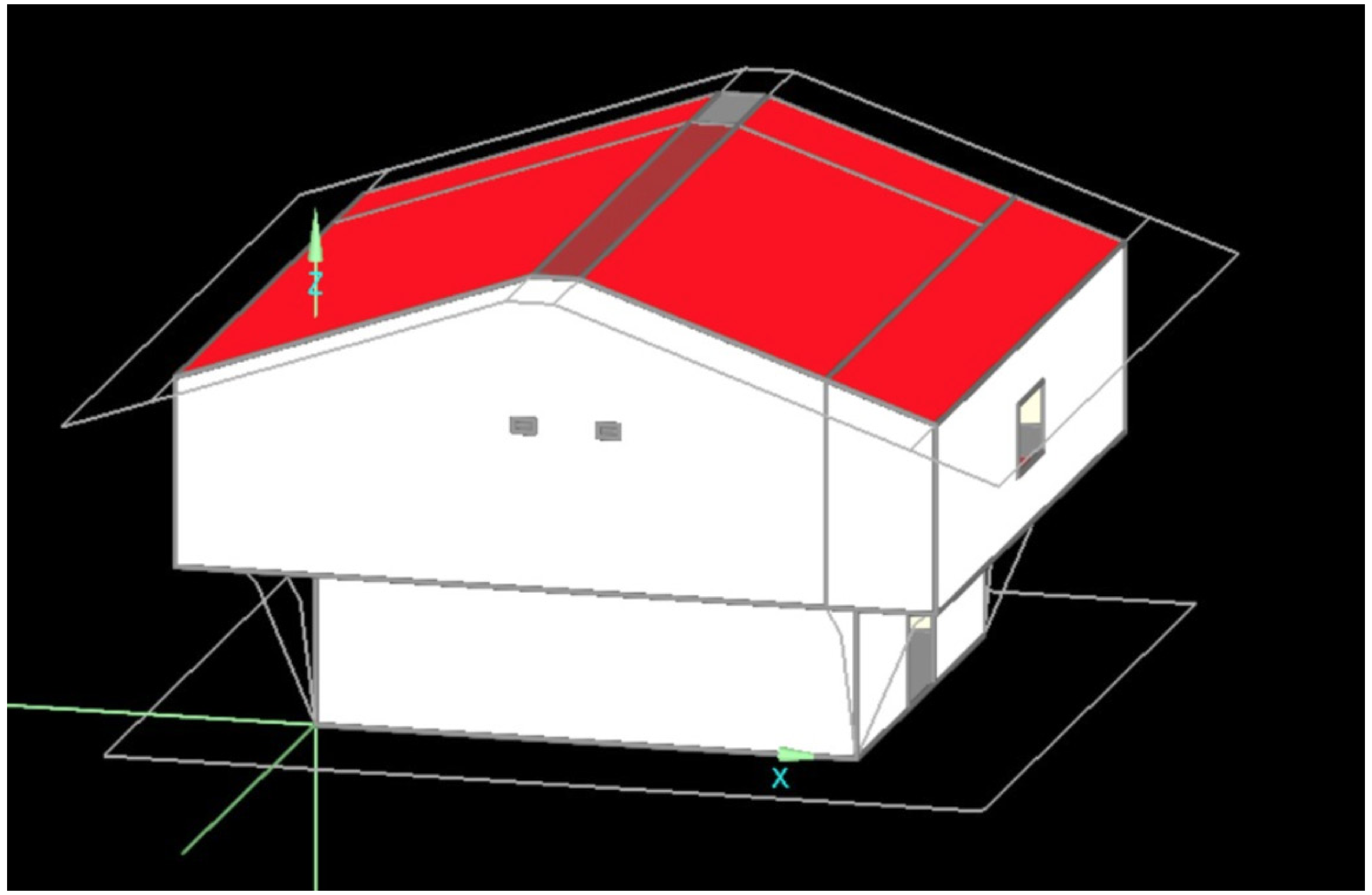


Figure 24. WUFI Plus model Heierstad Loft

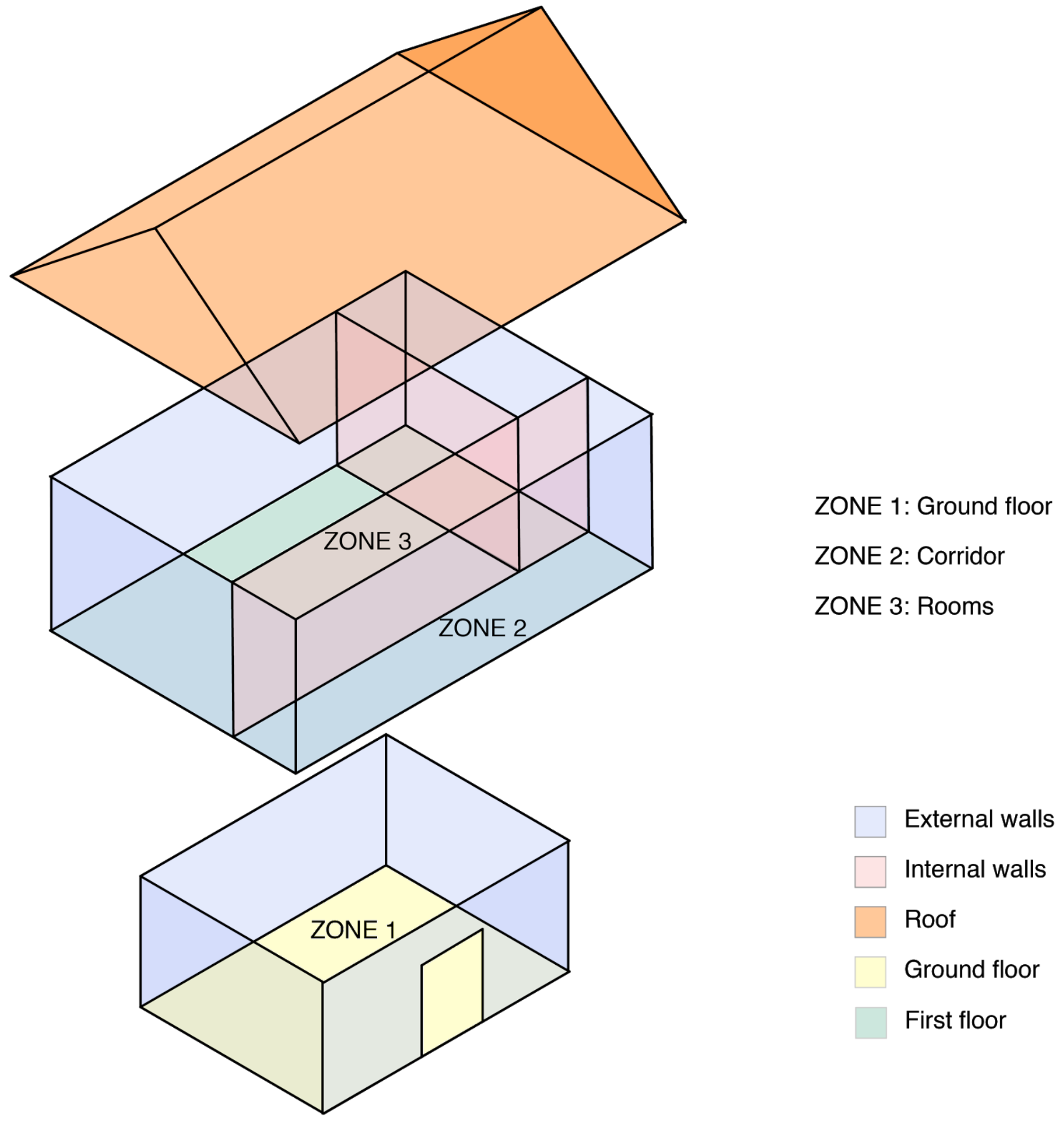


Figure 25. Exploded view Heierstad Loft

In contrast to the Heierstad Loft, the Fadum Storehouse only needed two different zones. Zone 1 corresponds to the only room that construction owns, access by a few stairs due it is lifted by pillars. Unlike the previous building, whose external wall were completely exposed to the outer climate conditions, the Fadum Storehouse has slanted roofs which cover the walls, protecting the building from wind, rain and solar radiation. Zone 2 accords to the space between the roof and the ceiling of the room.

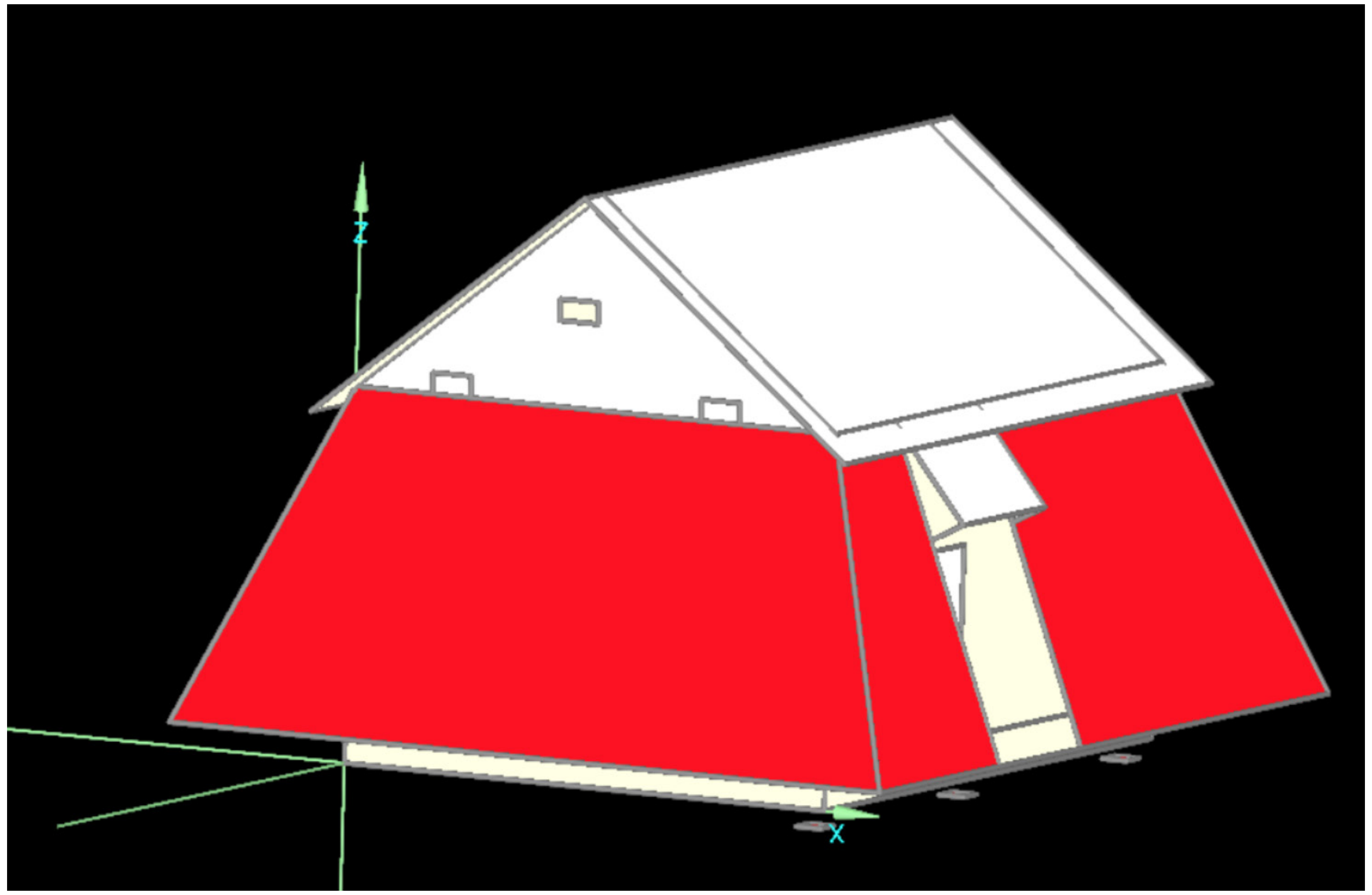


Figure 26. WUFI Plus model adum Storehouse

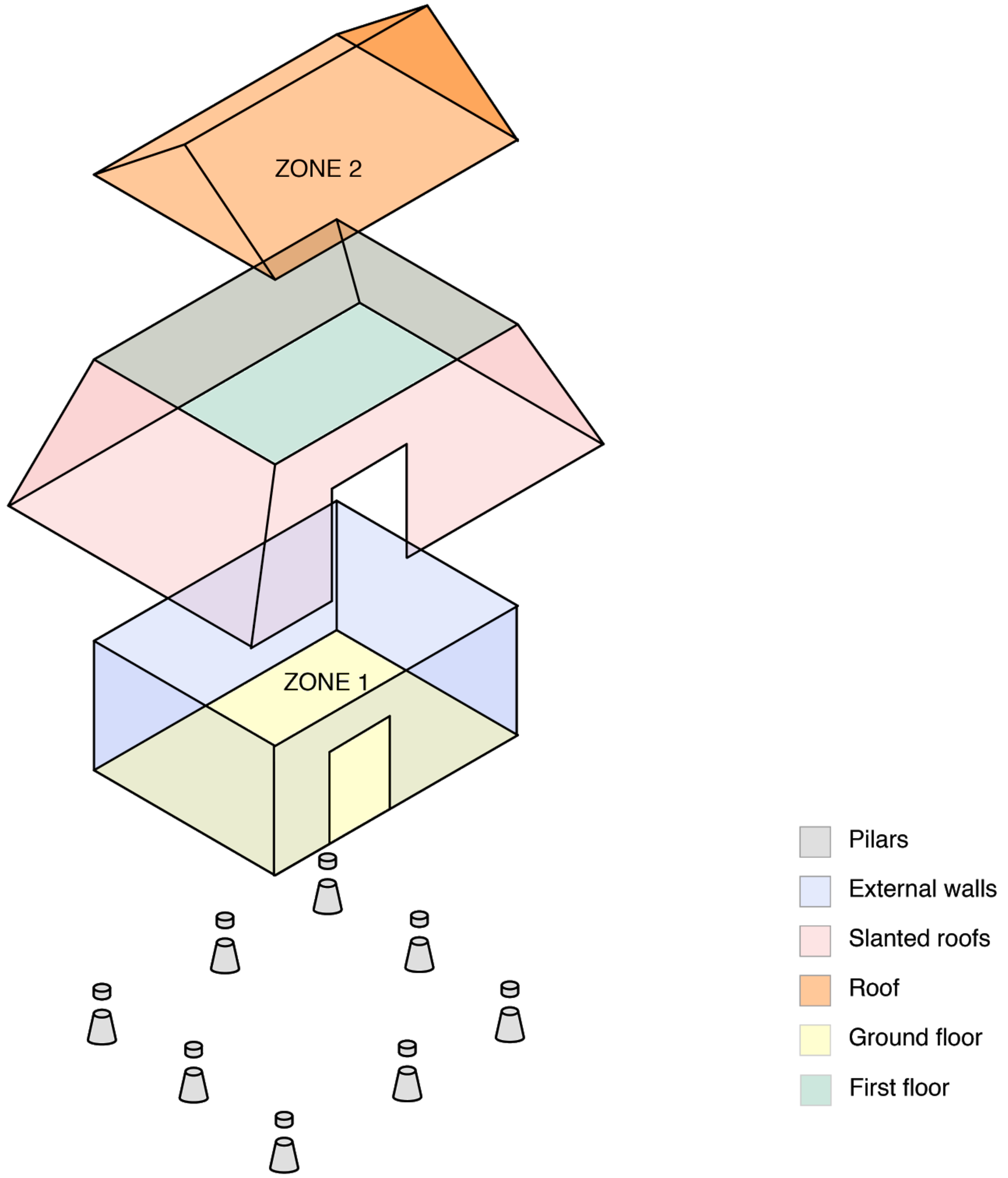


Figure 27. Exploded view Fadum Storehouse

3.2.5. Photogrammetry

Agisoft Photoscan is a stand-alone software product that performs photogrammetric processing of digital images and generated 3D spatial data. These images and data are used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales (Agisoft,n.d.).

During the visit in Tønsberg, around 100 pictures were taken of both Fadum Storehouse and Heierstad Loft. When all the pictures of one building are assembled in Agisoft Photoscan, this program manages to process all the images and offers a very precise and detailed model of that building. This image-based 3D model makes it possible to observe the building conditions and damages.

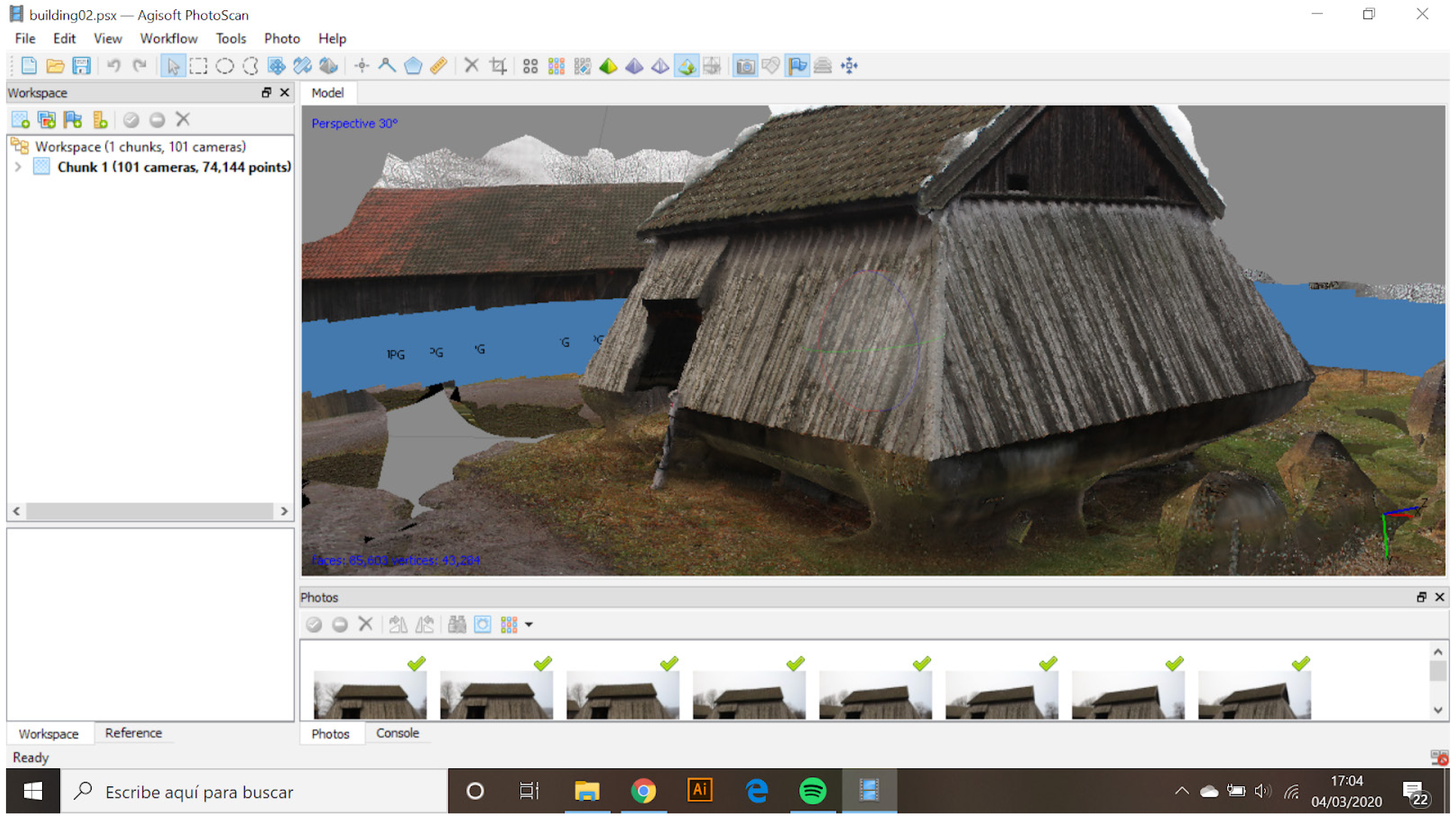


Figure 28. Photogrammetry model Fadum Storehouse

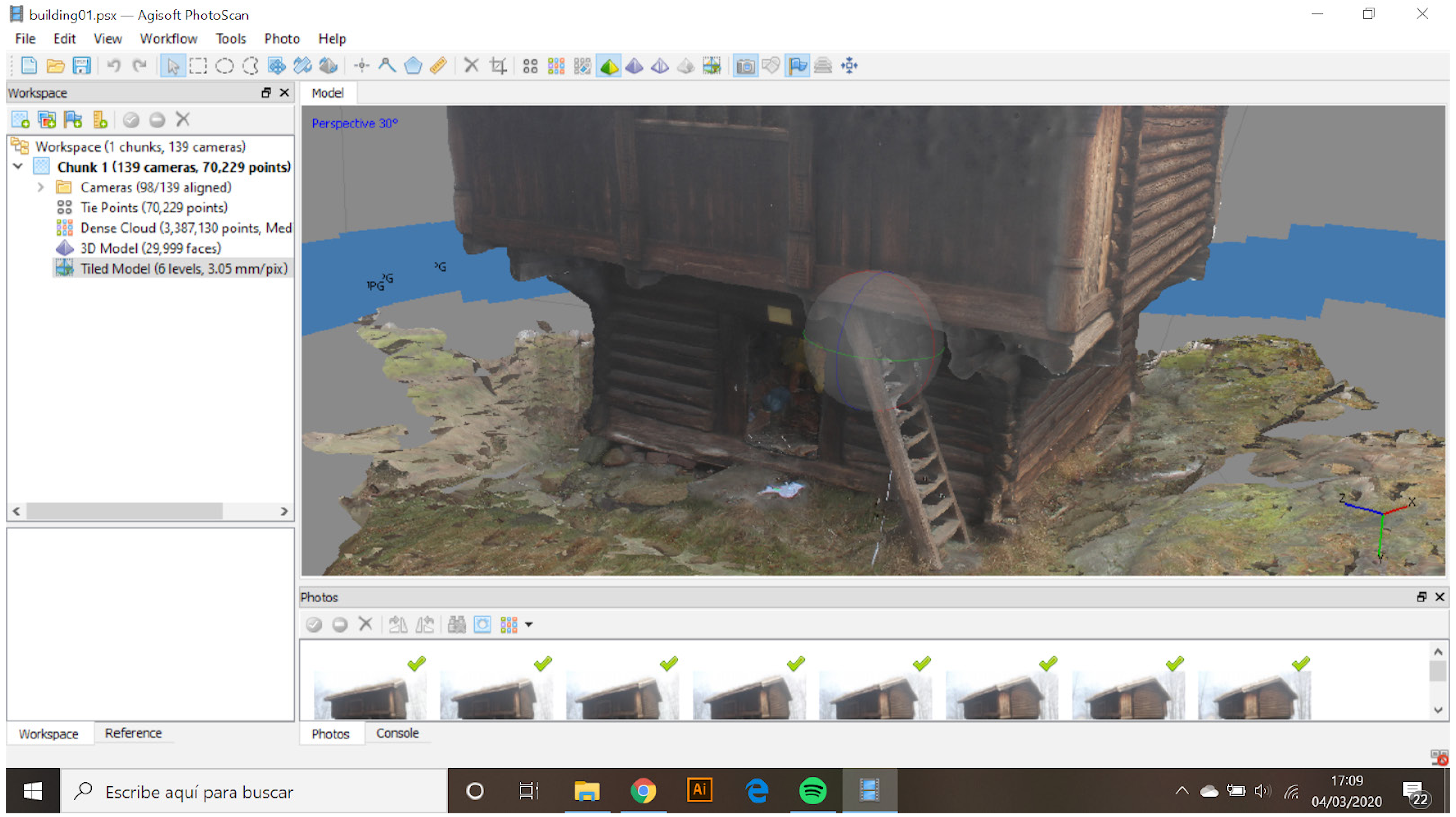


Figure 29. Photogrammetry model Heierstad Loft

3.2.6. WUFI Pro

Wufi Pro is the standard program for evaluating moisture conditions in building envelopes. The aim of Wufi Pro is to perform one-dimensional hygrothermal calculations on cross-sections of building components. The hygrothermal calculations consider factors such as built-in moisture, solar radiation, driving rain, long-wave radiation, summer condensation, and capillary transport. Wufi Pro applies real climate conditions to establish the hygrothermal performance of the different building components (Fraunhofer, 2019).

This project implements Wufi Pro for the analysis of the hygrothermal condition of the case studies in Tønsberg. The case studies, The Heierstad loft and the Fadum Storehouse, are divided into cross-sections to obtain more precise and detailed results. The results of the hygrothermal simulation will be compared by the current and future climate in Tønsberg. Once the results are achieved, they will be transferred to WUFI BIO to get a more specific outlook.

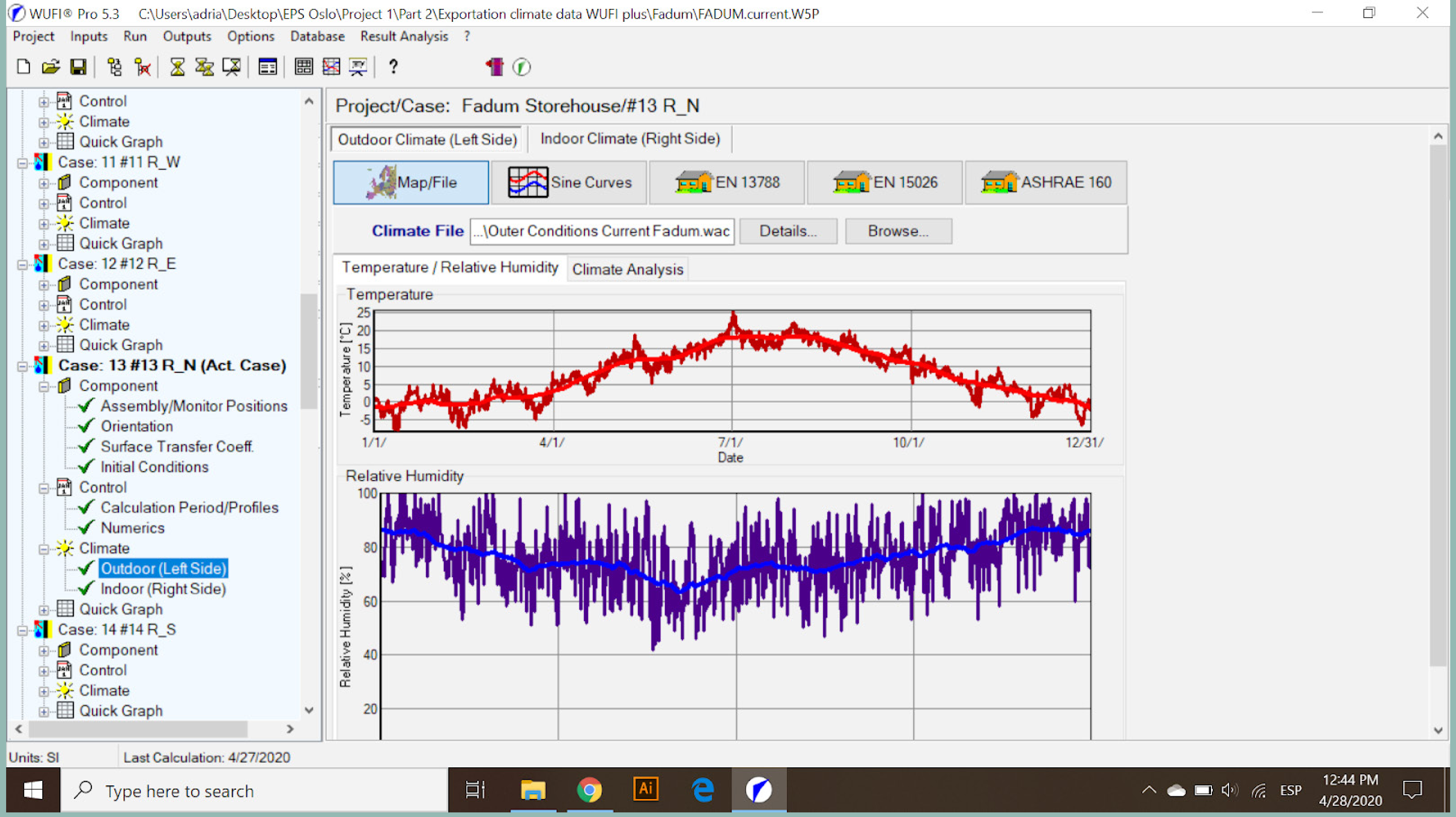


Figure 30. Assembly Fadum Storehouse, current climate data, North Roof

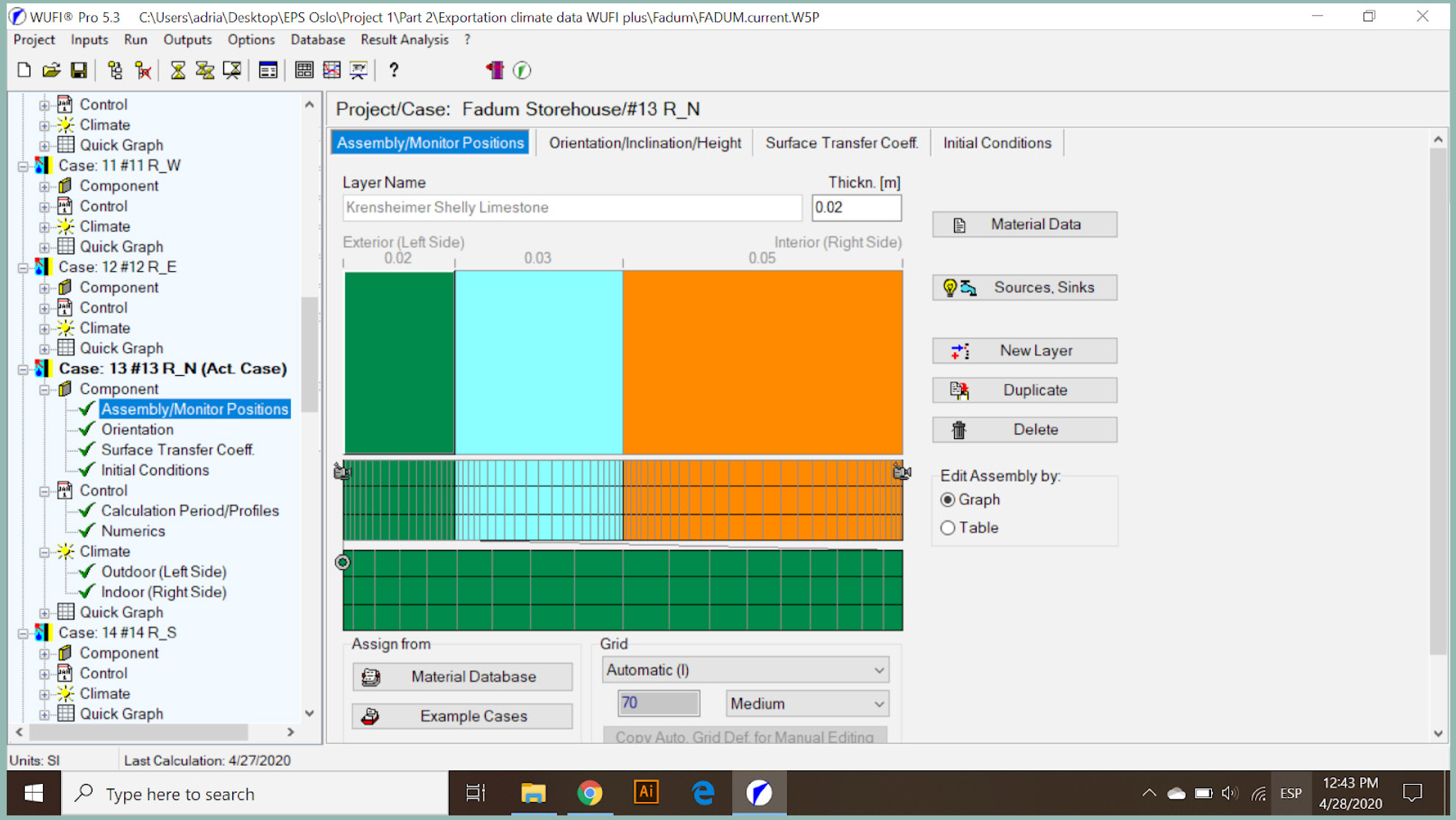


Figure 31.Climate Fadum Storehouse, current climate data, North Roof

3.2.7. WUFI Bio

WUFI Bio is a biohygrothermal model that assesses mold growth under transient hygrothermal boundary conditions. The method is based on comparison of the measured or calculated transient boundary conditions with the growth conditions for typical molds found on building materials. WUFI Bio does not accurately simulate the actual growth processes, however, it presents an assessment of the risk for mold growth (Fraunhofer, 2019).

By implementing WUFI Bio the mold index can be analyzed for the different cross-sections of the buildings.

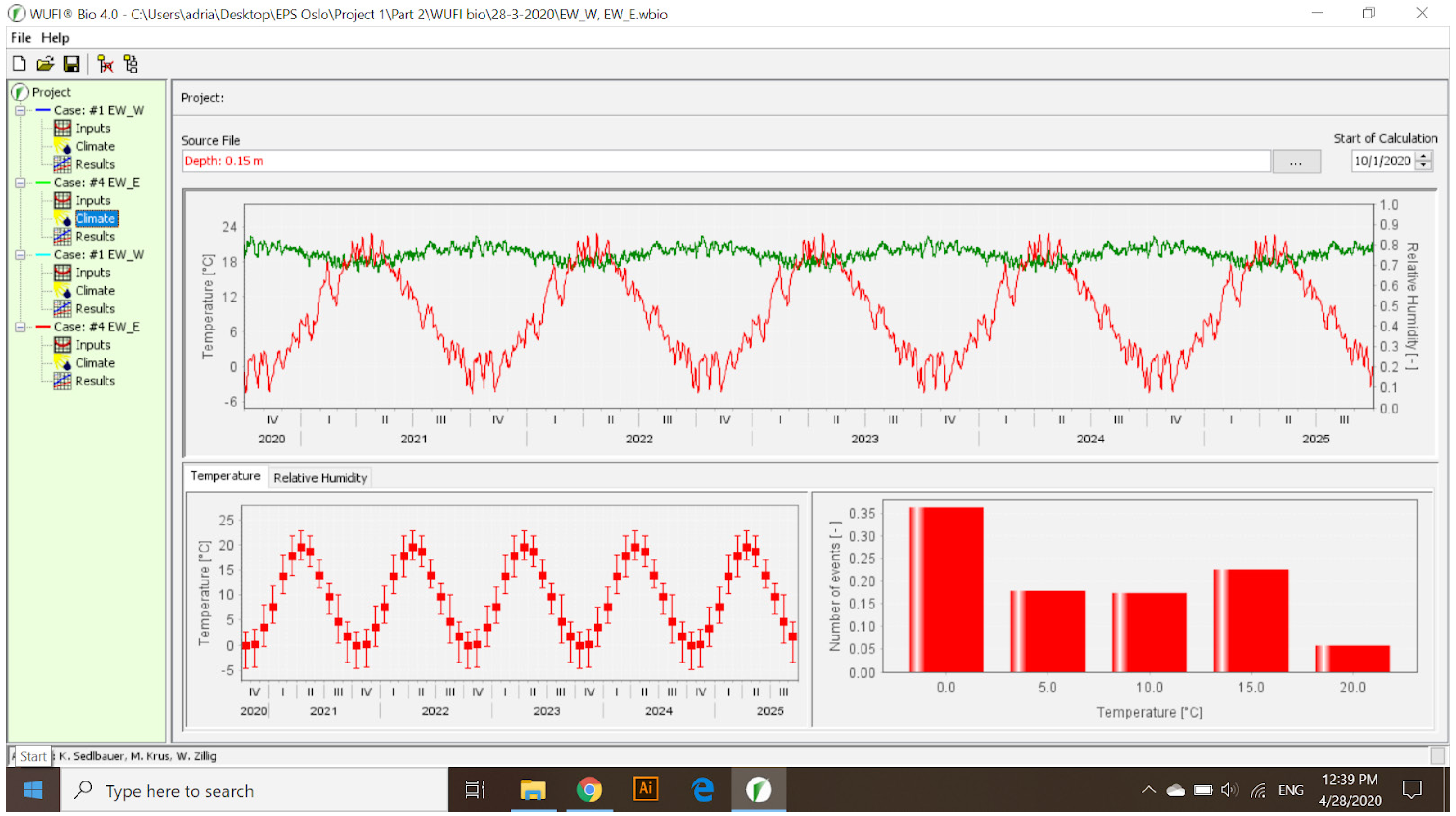


Figure 32. Climate Fadum Storehouse, current climate data, Exterior Wall East

Figure 33. Results Fadum Storehouse, current climate data, Exterior Wall East

3.3. CLIMATE SCENARIOS

To be able to make statements about the hygrothermal performance of a building, several hygrothermal simulations have been run using WUFI plus, pro and bio. Within the first set of simulations the SRES A2 has been taken into account. The climate file derived from the Meteonorm software. Considering that the prediction of the future climate is very difficult and is influenced by different dynamic meteorological factors, an additional climate file has been created. The defined climate file includes data for the RCP 8.5 scenario. All simulations have been repeated using the new climate file as an input. Finally a comparison has been made between the results from the two different climate change scenarios.

There are various projects that provide data on wide variety of climate models. One of those projects is the CORDEX initiative, sponsored by the World Climate Research Program (WRCP). The climate data are stored on the ESGF website https://esgf-data.dkrz.de/search/cordex-dkrz/, the Earth System Grid Federation, and most of them can be downloaded for free. The CORDEX initiative provides model data for several regions around the world with an 0.11x0.11 degrees horizontal resolution. This means that one grid point describes the average conditions over a 0.11x0.11 degrees grid box (Euro-Cordex, n.d.). The values do not describe the microclimate of the pilot area. The climate file that has been created corresponds to the RCP 8.5 scenario. Since it is also a worst case scenario, results can be compared to the results of the A2 scenario. Within the CORDEX project there are several different regional climate models. One of these models is REMO 2015. Originally developed at the Max-Planck-Institute for Meteorology, the model is nowadays further developed and maintained by the Climate Service Center Germany (GERICS).

This model was selected because it provides climate data with a temporal resolution of one hour for most of the parameters (The regional climate model REMO, n.d.). High temporal resolution data are best suited for hygrothermal simulations. When it comes to hygrothermal simulation, at least data for temperature and relative humidity are necessary. However, a modeling process with a climate file which only contains temperature and relative humidity is not very detailed and the results may be inaccurate. Therefore, a large amount of different parameters should be chosen (Creating weather files, n.d.). The Figure 34. shows all the parameters that are used in the climate file.

Variable	Variable in REMO	Unit	Unit WUFI	Time frequency
Temperature	Near-Surface Air Temperature	°K	°C	1h
Relative Humidity	Near-Surface Relative Humidity	%	%	1h
Rain	Precipitation	kg/m^2s	mm/h	1hr
Wind Speed	Near-Surface Wind Speed	m/s	m/s	1hr
Longwave Radiation	Surface Downwelling Longwave Radiation	W/m^2	W/m^2	1hr
Shortwave Radiation	Surface Downwelling Shortwave Radiation	W/m^2	W/m^2	1hr
Cloud Fraction	Total Cloud Fraction	%	0...1	1hr
Northward Wind	Northward Near-Surface Wind	m/s	°	6hr
Eastward Wind	Eastward Near-Surface Wind	m/s	°	6hr

Figure 34. Table of chosen variables .

In order to eliminate the influence of the initial conditions in the simulation results data for a period of five years, from 2096-2101, has been used. The required data were downloaded from the ESGF website. They are provided in netcdf files. One file contains data for one climate parameter for a one-year period for several grid points in Europe. This means for each parameter five files have been downloaded. For every single file the data for only one grid point have been extracted. Specifically, the grid point that is closer to the pilot area. In order to do so the software MatLab has been used. Using Matlab it is possible to read data from netcdf files and write them, for example, into an excel sheet.

Figure 35. shows the interface of MatLab as it was used to extract the data. Some lines of coding were necessary to extract the data from the netcdf files. In particular the following commands have been used:

```
nc = netcdf.open('filename.nc');
ncdisp('filename.nc');
var = netcdf.getVar(nc,9);
data = var(224,293,:);
data_m = reshape(data_v,8760,1);
writematrix(data_m,'Pr_2096-2101.xlsx','Range','A2');
```

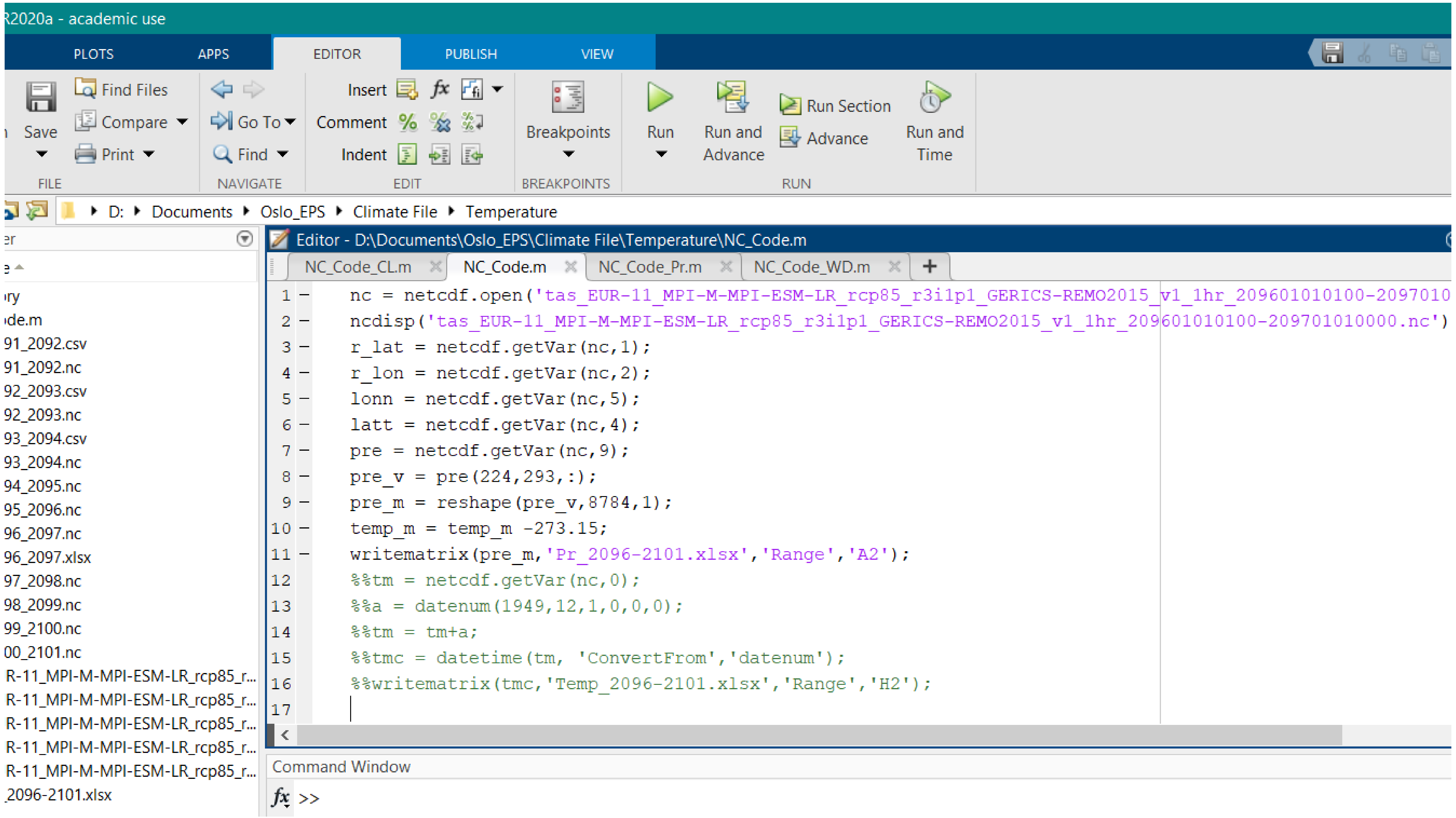


Figure 35. MatLab Interface with some lines of coding.

The coloured parts vary based on the file name. The function “netcdf.open” loads the netcdf file into the worksheet of MatLab. With “ncdisp” the information, which are stored in the netcdf file, are displayed in the command window of MatLab. The desired variable is placed in a buffer and then the data for the specific grid point are extracted. The data matrix needs to be reshape into a useful size and can then finally be written into an excel sheet. In this case, a fix grid point was selected which refer to 59.3 °N and 10.54 °E.

Not all parameters had the correct unit as it is needed for the WUFI software. Therefore, some equations had to be made. In particular this concerned temperature, rain, cloud fraction and wind direction. Temperature had the unit °K and WUFI requires °C. To transform the values into the correct one, following relationship has been used:
temp (C°) = temp (K°) - 273.15;
For rain the units have been transformed from kg/m²s to mm/h. For that purpose the following equation have been used: rain in mm/h = rain in kg/m²s * 3600;
The data for cloud fraction were available in percentage. WUFI requires the unit 0…1. The coding line for this transformation would be: cf = cf/100;
The REMO 2015 model provides data for the wind direction in terms of wind speed towards north and east. It is possible to combine these two values to get the wind direction in degrees. In WUFI wind direction starts from north = 0° and goes clockwise. This means a positive value for northward wind is blowing towards north and has a direction = 180°. An eastward wind is blowing towards east and has a direction = 270°. Therefore, following coding can be applied:
If northward<0 and eastward<0 then direction=tan-1(eastward/northward)
If northward<0 and eastward>0 then direction=tan-1(eastward/northward) + 360°
In all other cases direction=tan-1(eastward/northward) + 180°
Unfortunately the data for wind direction are only available with a time frequency of six hours. Thus it is assumed that the wind direction is stable for the hole six-hour period. The following lines of coding has been used to in order to generate the hourly values of wind direction:

```
M = readtable(‘filename.xlsx’);
A = zeros(8760,1);
B = table2array(M);
z = 1;
for c=1:1460
    for r=1:6
    A(z,1) = B(c,1);
    z = z+1;
    end
end
writematrix(A,’filename.xlsx’);
```

The WUFI software provides an excel sheet to create the climate file in an useable format. Figure 36. shows the interface of this excel sheet. All the data can be copied into this excel sheet. It provides a column for each parameter. Some settings as location, time zone or first year must be made. When all settings have been made, the data can be exported to an ".wac" file. This file can later be used for simulations with the WUFI software.

Location:	Tønsberg		
Description:	REMO2015 RCP 8.5 Scenario		
Longitude [°]:	10,54	Altitude [m]:	50
Latitude [°]:	59,30	Time Zone [h]:	1,0
		First Year [yyyy]:	2096

V5_Tonsberg_RCP85.wac

Export to .WAC file

Ver.: 2.4

Note:

	A	B	C	D	E	F	G	H	I	J	K	
8	Year	Month	Day	Hour	cumul.	Temperature [°C]	Air Humidity	Rain [Ltr/m²h]	Wind Speed [m/s]	Radiation [W/m²]	Radiation [W/m²]	Wind D
9					Hour	Air Temperature	Rel. Humidity [%]	Normal Rain	Skalar Average	Solar Global Horiz.	ounterrad. Atm. Horiz.	north = (
10	1	1	1	1	1	1,51	88,19	0,000	4,772	0	249,5965881	
11	1	1	1	2	2	1,40	88,82	0,000	4,657	0	257,474823	
12	1	1	1	3	3	1,28	89,14	0,000	4,314	0	274,5643005	
13	1	1	1	4	4	1,26	87,39	0,000	4,411	0	273,9024353	
14	1	1	1	5	5	1,24	84,40	0,003	4,374	0	287,068573	
15	1	1	1	6	6	1,08	85,75	0,000	4,072	0	254,0899658	
16	1	1	1	7	7	0,93	85,97	0,000	3,505	0	258,6280518	
17	1	1	1	8	8	0,83	86,28	0,000	3,452	0	253,842041	
18	1	1	1	9	9	0,73	86,48	0,000	3,295	1,560998201	257,7034302	
19	1	1	1	10	10	0,64	86,34	0,000	3,153	18,07094193	270,588623	
20	1	1	1	11	11	0,65	85,84	0,000	3,458	25,99286652	271,1882935	
21	1	1	1	12	12	0,66	85,76	0,000	3,386	22,86468887	278,5540161	
22	1	1	1	13	13	0,69	85,40	0,000	3,500	8,502323151	292,9477539	
23	1	1	1	14	14	0,80	84,72	0,000	4,064	3,678312778	282,7330017	
24	1	1	1	15	15	0,95	81,43	0,000	4,550	0,099847279	290,7151794	
25	1	1	1	16	16	0,91	79,92	0,000	3,991	0	292,8414612	

Figure 36. Interface excel sheet.

4. RESULTS

4.1. SAMPLES

The graphs below show the amount of fungi colonies in certain positions, each graph shows the results of a different substance. After the samples were taken, they were sent to the laboratory for further analysis. Three days later the fungi had grown to clearly visible dots. In order to calculate the fungi colonies, the dots had to be count. Afterwards a formula was used to define the amount of fungi colonies per cubic meter.

$$\frac{\mathrm{Pr}\,[col]}{250l} \times \frac{1000l}{m^3} = \mathrm{Pr}\,[col] \times \frac{4l}{m^3}$$

Formula 1. Formula to calculate fungi colonies

The reference, as mentioned in the graphs , is for comparing the values with the other measurement points. In this case the reference was taken outside of the buildings. As expected is the amount of fungi colonies outside extremely low due to the outside conditions volume. However, the amount of colonies inside the buildings is very high, because the indoor area has a significantly smaller volume.. The only exception is level 1 of the Fadum Storehouse.

This exception is due to the way the sample was collected. While all the other samples were acquired from the floor, this time the sampler stands on a table. In addition to that, a pressurization test was completed before the value of the ground floor was measured. Because of the pressure test all the dust was blown out of the building beforehand, which can also lead to the low value of the first level of the Fadum Storehouse. A pressurization test calculates the air tightness of a building, known as its ‘air permeability’ or ‘leakage’ rate. Air leakage is air that escapes the building via uncontrolled means. Leakage can occur through holes, cracks orgaps in the fabric of the building.
The results of the other positions may actually be even higher.

The exact determination by using the value table was not possible because the table did not contain enough values. The measurements showed that there is a large amount of fungi colonies in the buildings, which can have different effects on the material of the buildings. The wood decay can lead to brown discoloring, shrinkage of the timber and deep-surface cuts.

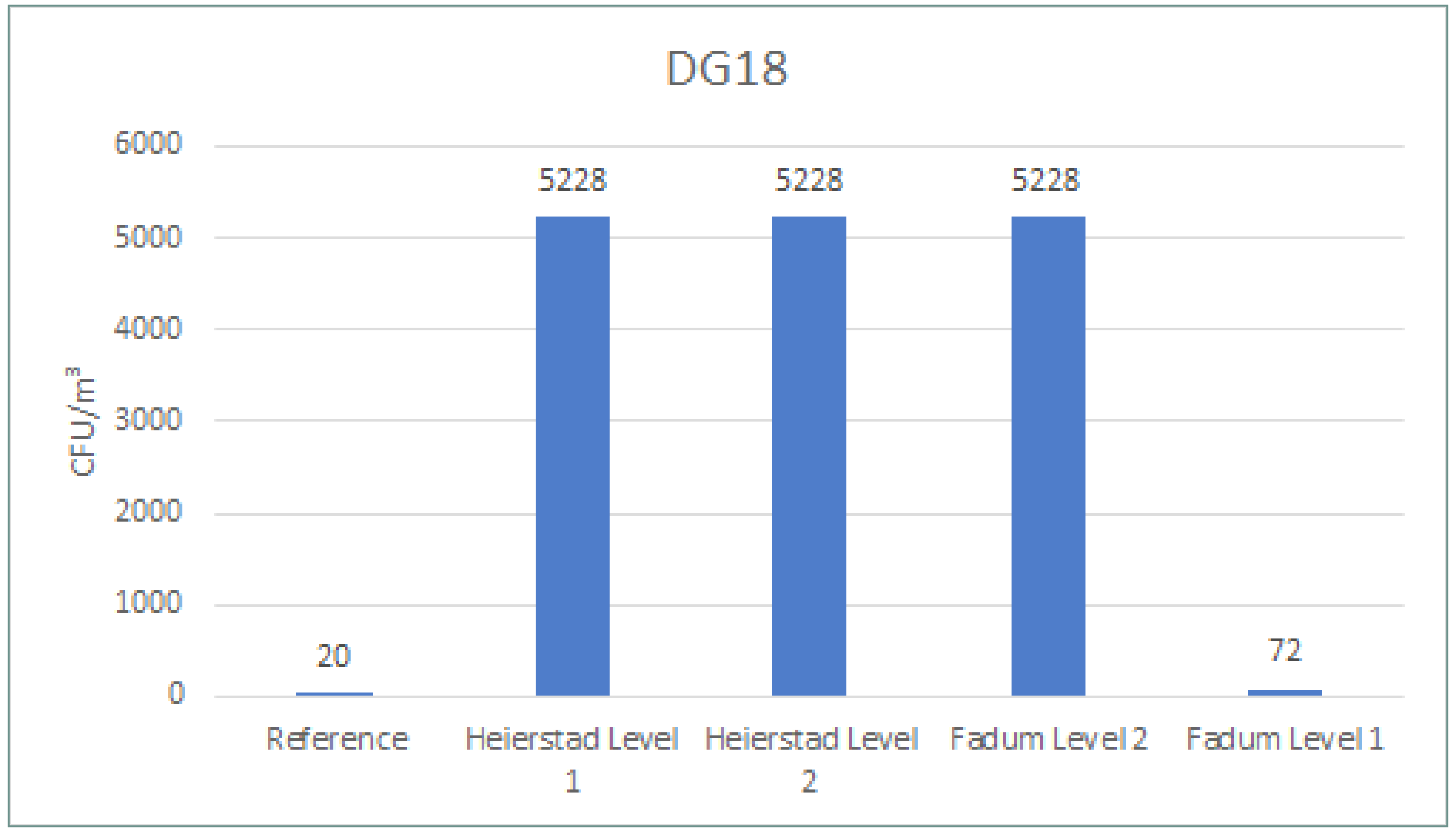


Figure 37. Results Air Samples DG18.

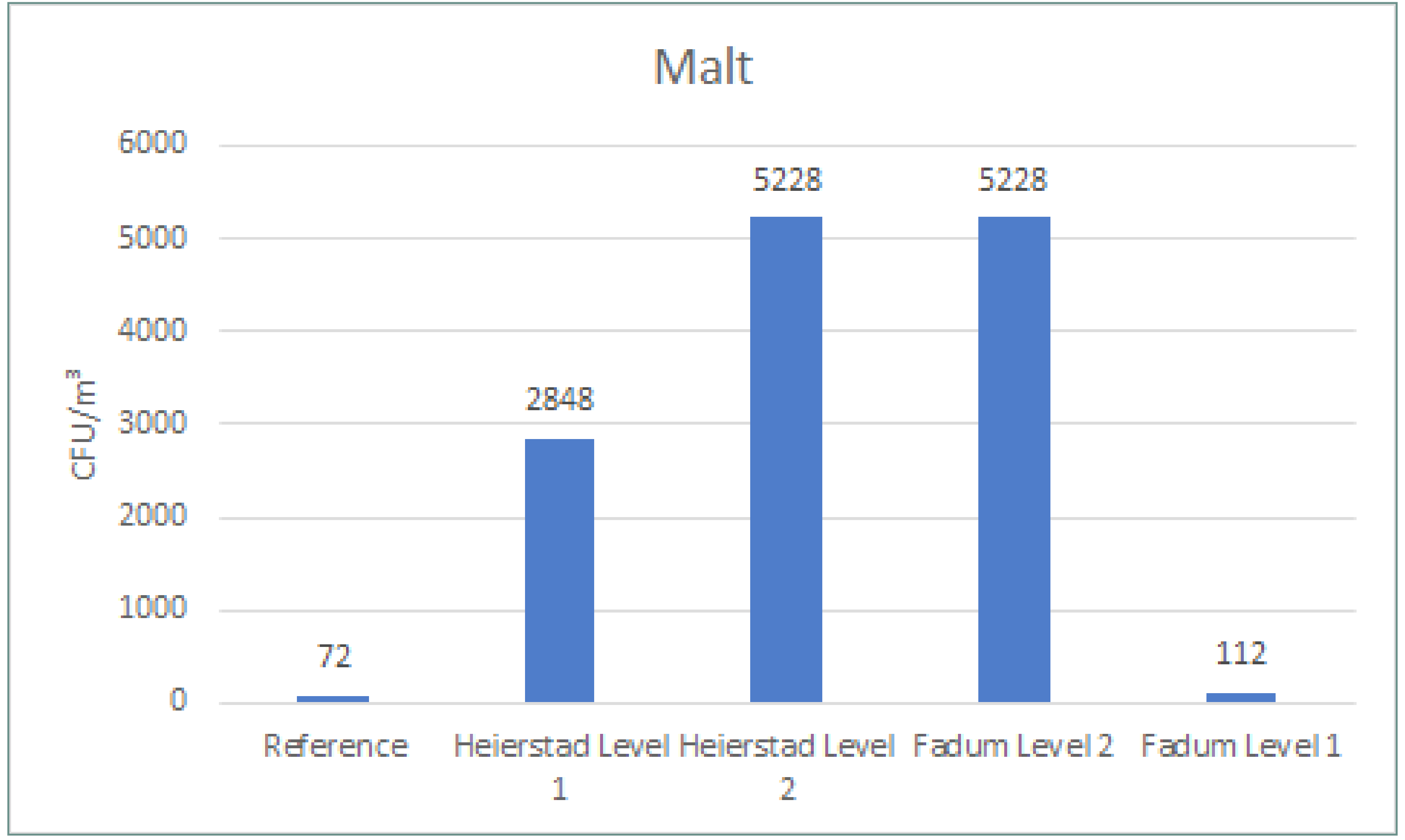


Figure 38. Results Air Samples Malt.

4.2. COMPARISON CLIMATE FILES

To get a basic overview about the differences between the climate files, the values for temperature, relative humidity and precipitation are compared. While the current situation reflects data for a typical year, the data for the A2 and the RCP8.5 scenario refer to the year 2100. Therefore, extreme events are included in these data. However, this is enough to illustrate climate changes related to this specific investigation.

Figure. 39 shows the hourly data for air temperature under the the current conditions and the future year 2100 under the scenarios A2 and RCP8.5. The minimum temperature for the current situation is -8,3 °C while the maximum temperature is 25,5 °C. Under The A2 scenario temperature ranges from -7,4 °C to 26,9 °C. For the RCP8.5 scenario, the temperature fluctuates between 1,26 °C and 23,2 °C. The change of climate is getting more clear by comparing the average values. For the current situation the average is 7,8 °C, for the A2 scenario 9,1 °C and for the RCP8.5 it is 11,5 °C. Based on the examined scenarios, the mean annual temperature may increase by 3,7 °C till the end of the year 2100.

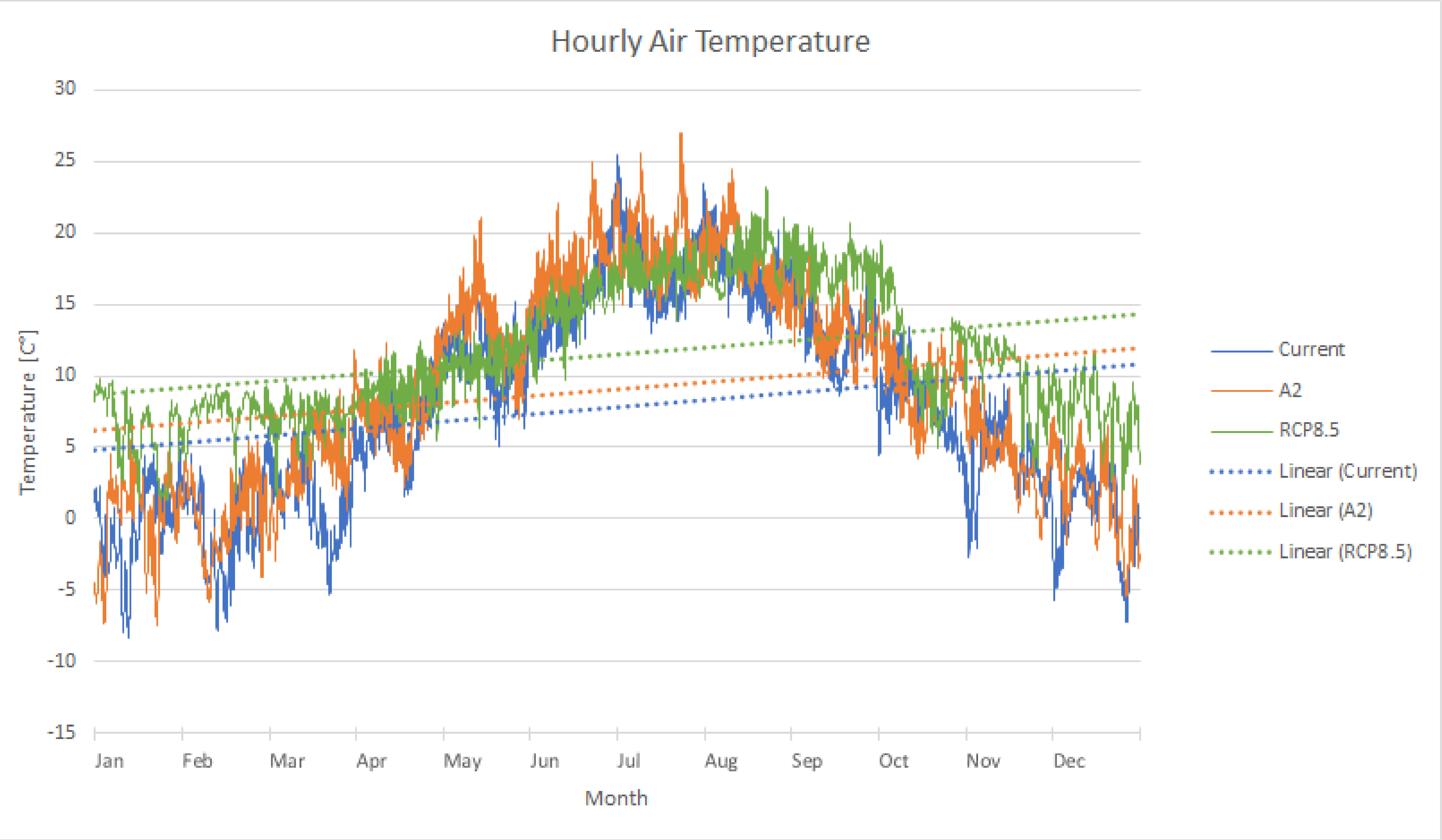


Figure 39. Hourly Air Temperature.

In Figure 39. it is observed that the relative humidity values corresponding to the RCP8.5 scenario are much higher than the other two analysed cases. While the average relative humidity for both current situation and the A2 scenario is around 75%, the average relative humidity for the RCP8.5 is 85%.

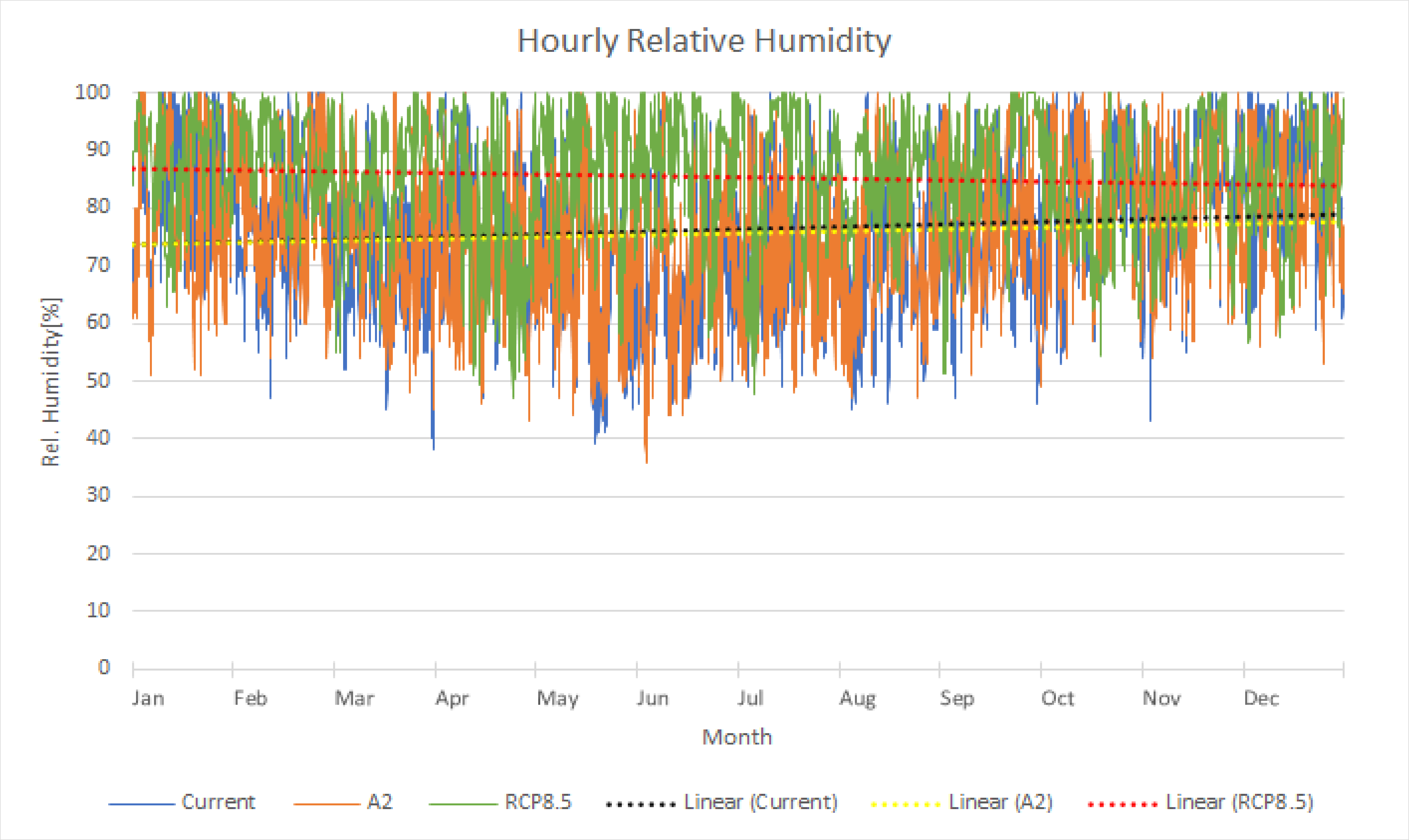


Figure 39. Hourly Relative Humidity.

The total amount of rain per year, as shown in figure. 41, increases from 680mm for the current situation to 930mm in the A2 scenario and 1630mm for the RCP8.5. Also the amount of heavy rainfalls under the future climate scenarios increase. For instance, as Figure.40 shows, under the RCP8.5 scenario the maximum rain value is up to 28 mm/h while under the A2 scenario and the current situation the maximum value is 15 mm/h.
For hygrothermal simulations it is important to take several parameters into account. For instance, not only air temperature and relative humidity have an impact on the building materials, but also parameters like solar radiation, precipitation or cloud cover can influence them. Therefore, if the climate data show large differences it has a large impact on the results of simulation processes.

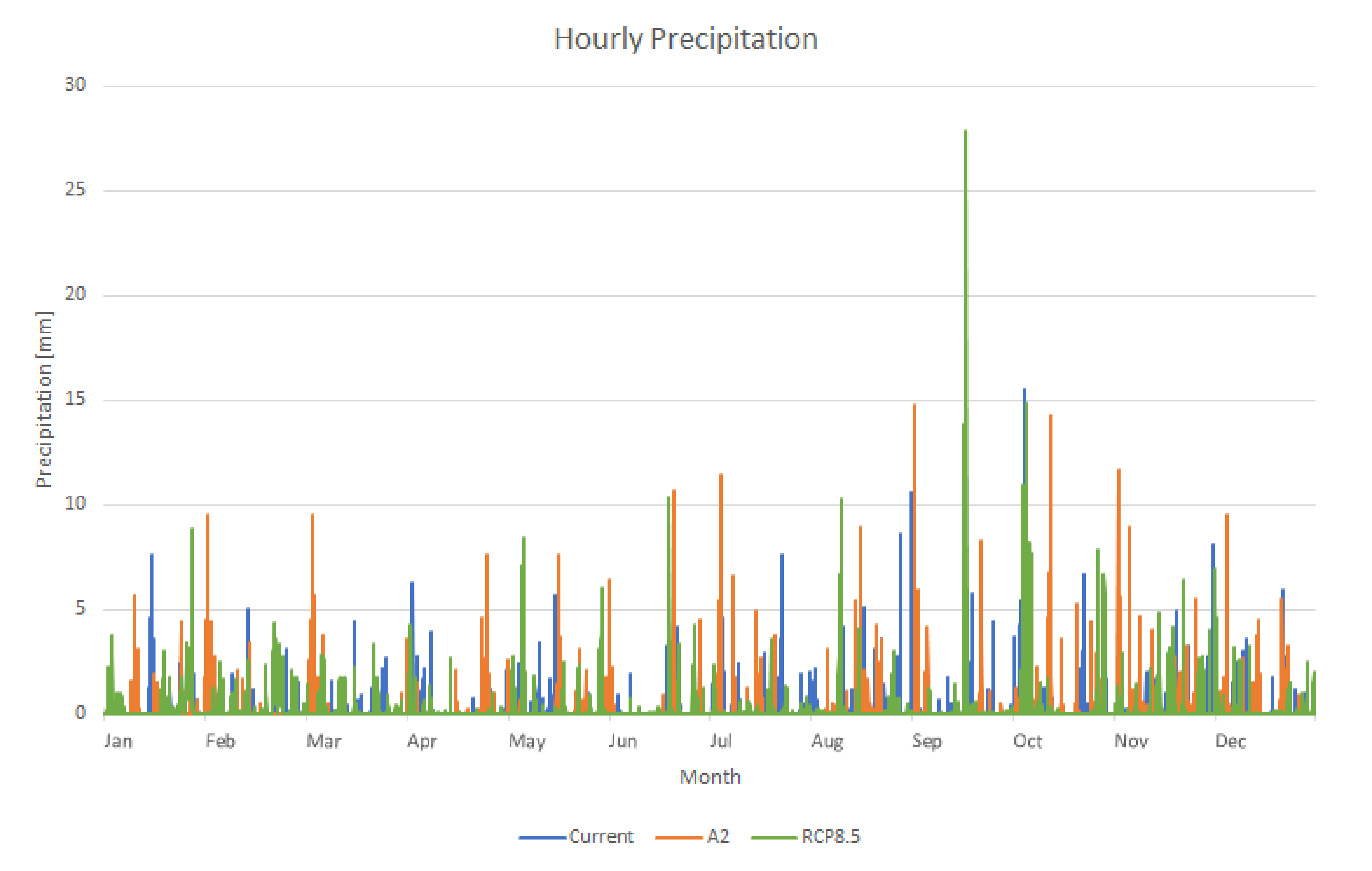


Figure 40. Hourly Percipitation

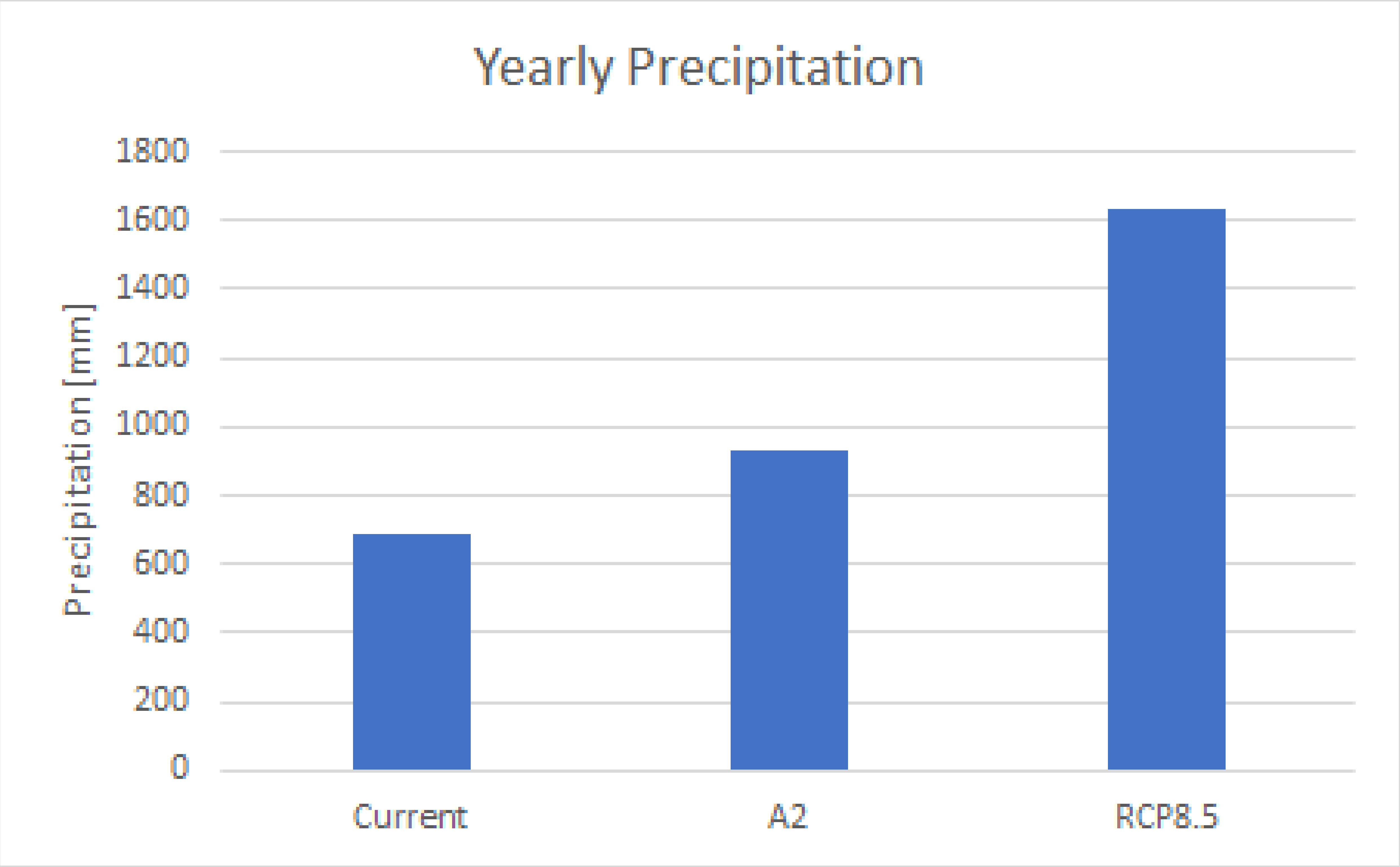


Figure 41. Yearly Percipitation.

4.3. WUFI PLUS RESULTS

The results from WUFI plus are best represented as graphs that show values of air temperature and relative humidity, either for outer conditions as indoor climate. For each aspect we have analyzed, the results are compared from a current typical year with a future situation. Alongside with the presented graphs, some conclusions, that can be drawn from the graphs, are made.

CURRENT
(TYPICAL YEAR)

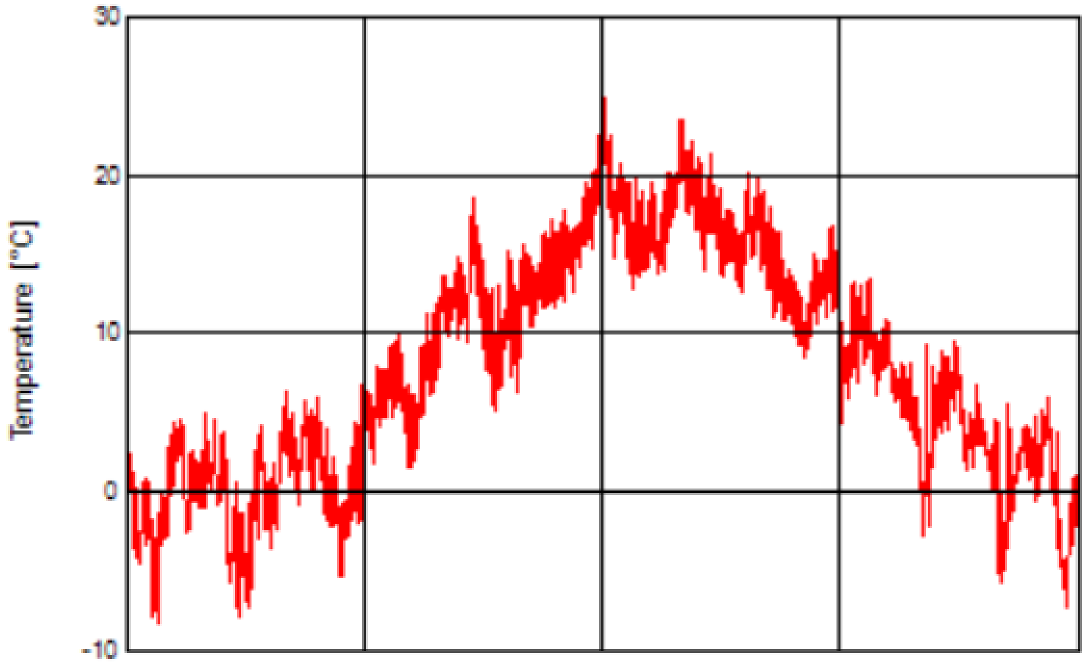


Figure 42. Ambient Air Temperature

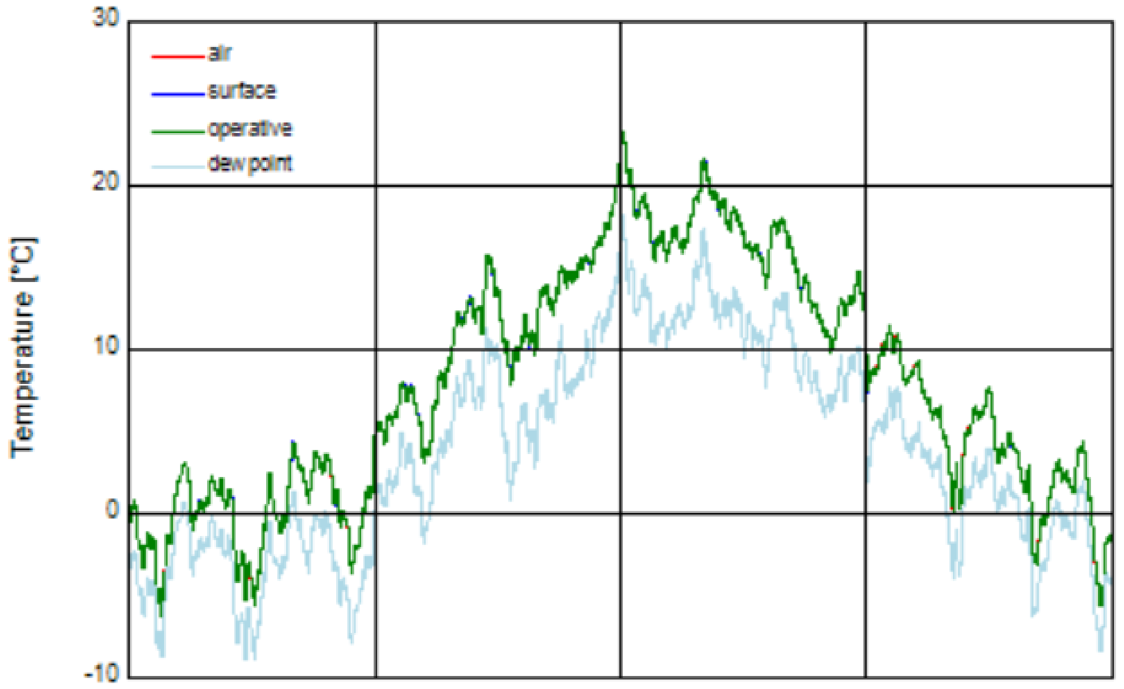


Figure 44. Air Temperature in zone 1

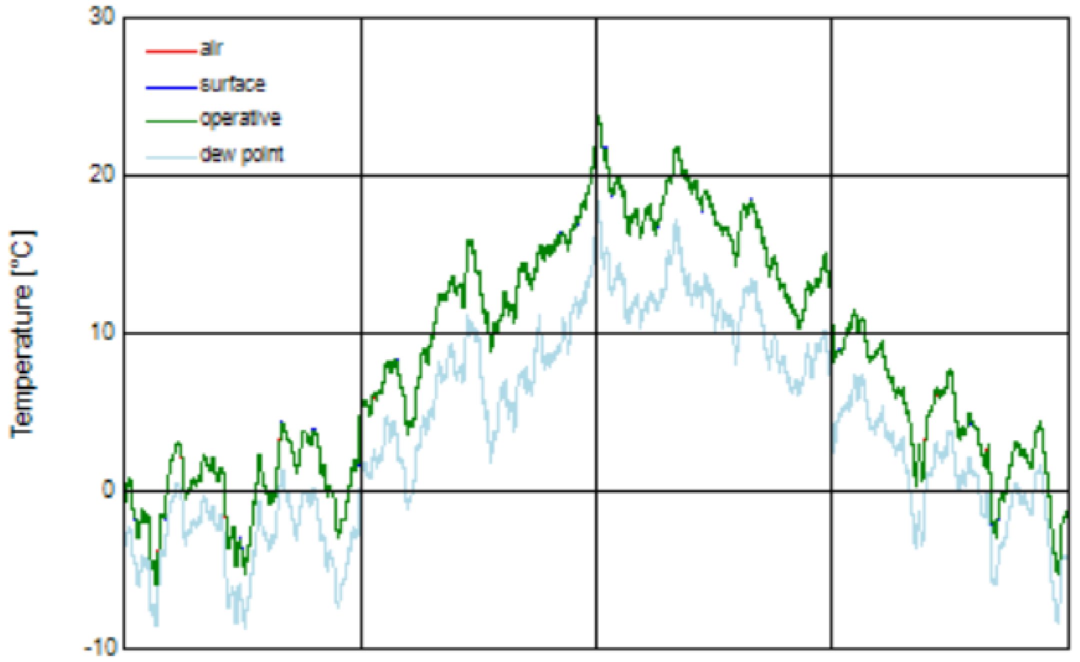


Figure 46. Air Temperature in zone 2

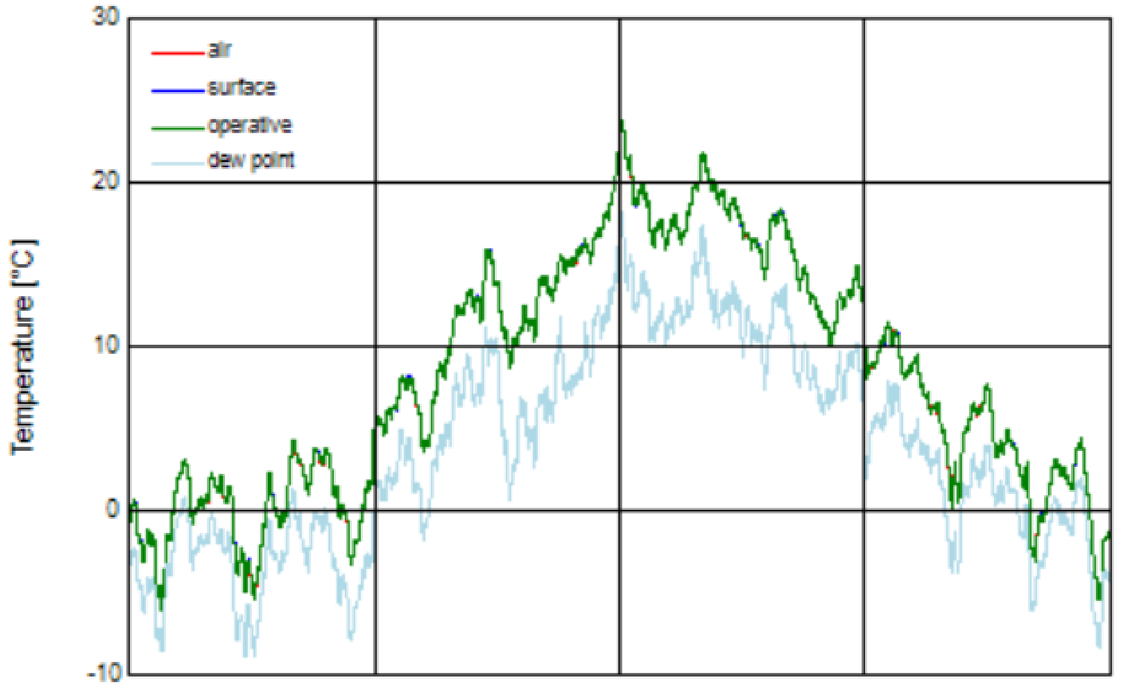


Figure 48. Air Temperature in zone 3

A2 SCENARIO
(2100)

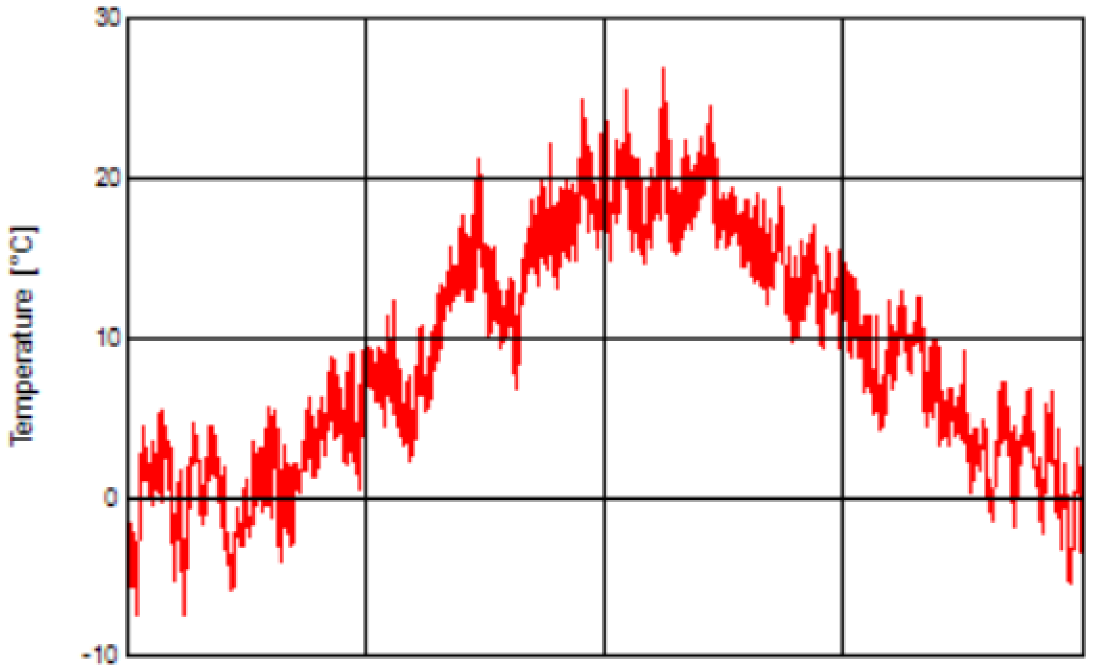


Figure 43. Ambient Air Temperature

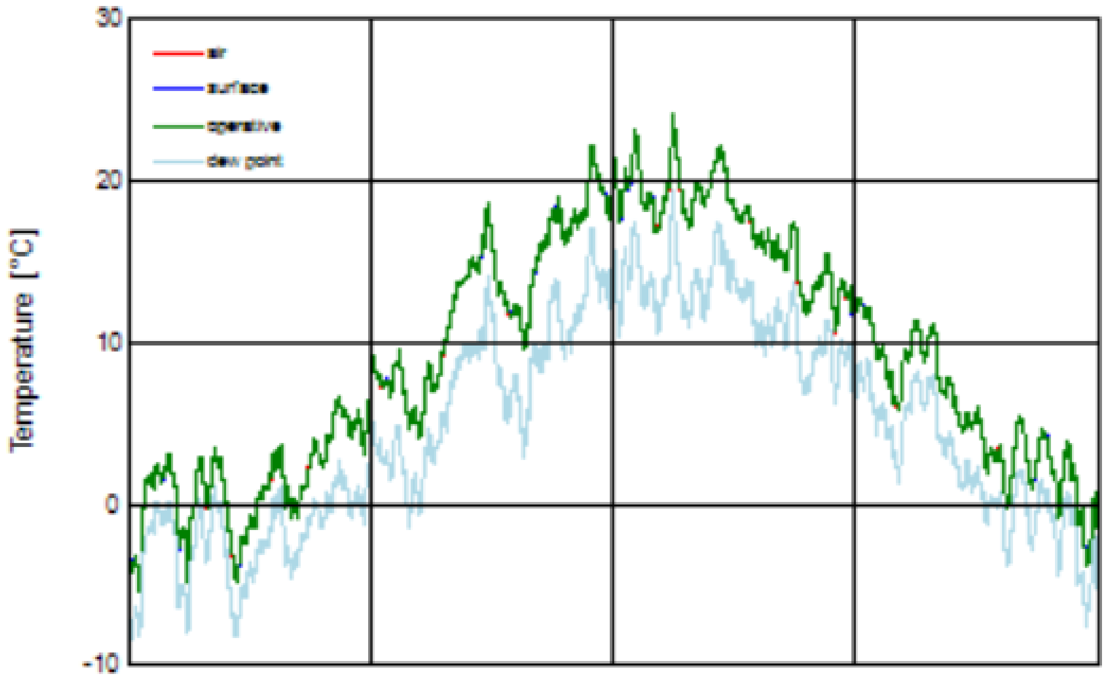


Figure 45. Air Temperature in zone 1

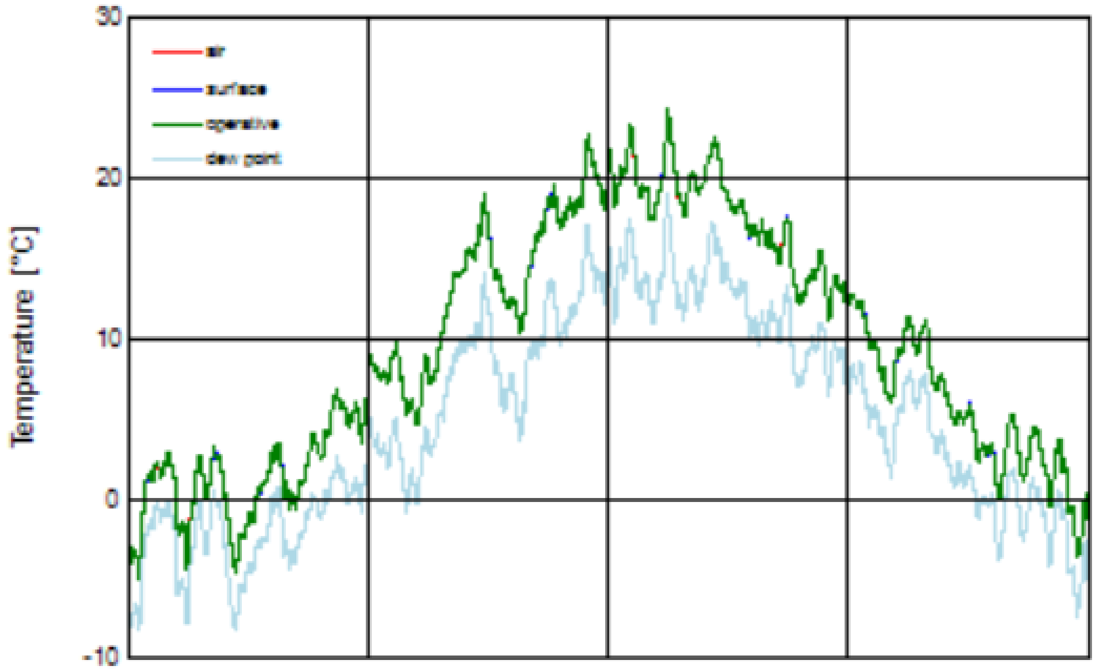


Figure 47. Air Temperature in zone 2

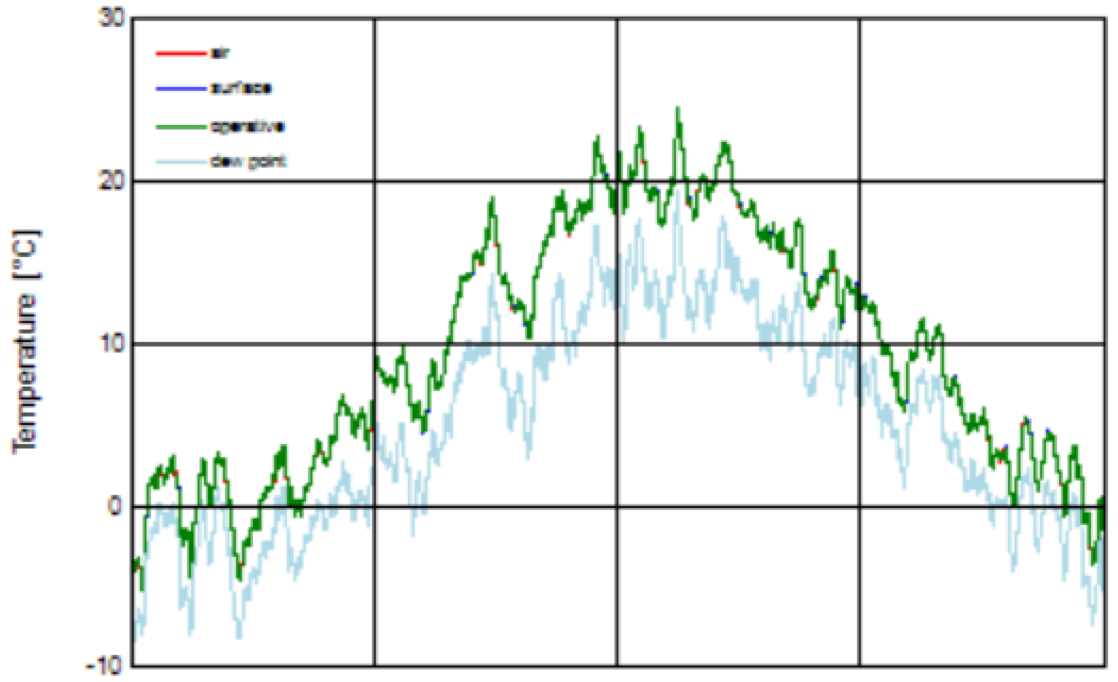


Figure 49. Air Temperature in zone 3

4.3.1. AIR TEMPERATURE

HEIERSTAD LOFT

The similarity between the eight different graphs is clearly noticeable. All the graphs have a comparable pattern, however the graphs that show the air temperature in 2100 have a slightly wider peak, reflecting the expected increase due to the GHG emissions. Comparing the ambient air temperature (Fig.42. and Fig.43.) and the air temperature indoors (Fig.44. and Fig.45.), it becomes clear that the first one is more unstable than the latter. Nevertheless, they are almost identical, which reflects the fact that the building is poorly isolated, fully ventilated and unheated. The contrast between the current typical year (Fig.42. and Fig.44.) and the future condition (Fig.43. and Fig.45.) is that the climate becomes marginally less stable in the future. A small but consistent increase in temperature is also visible in the graphs Fig.43. and Fig.45..

CURRENT
(TYPICAL YEAR)

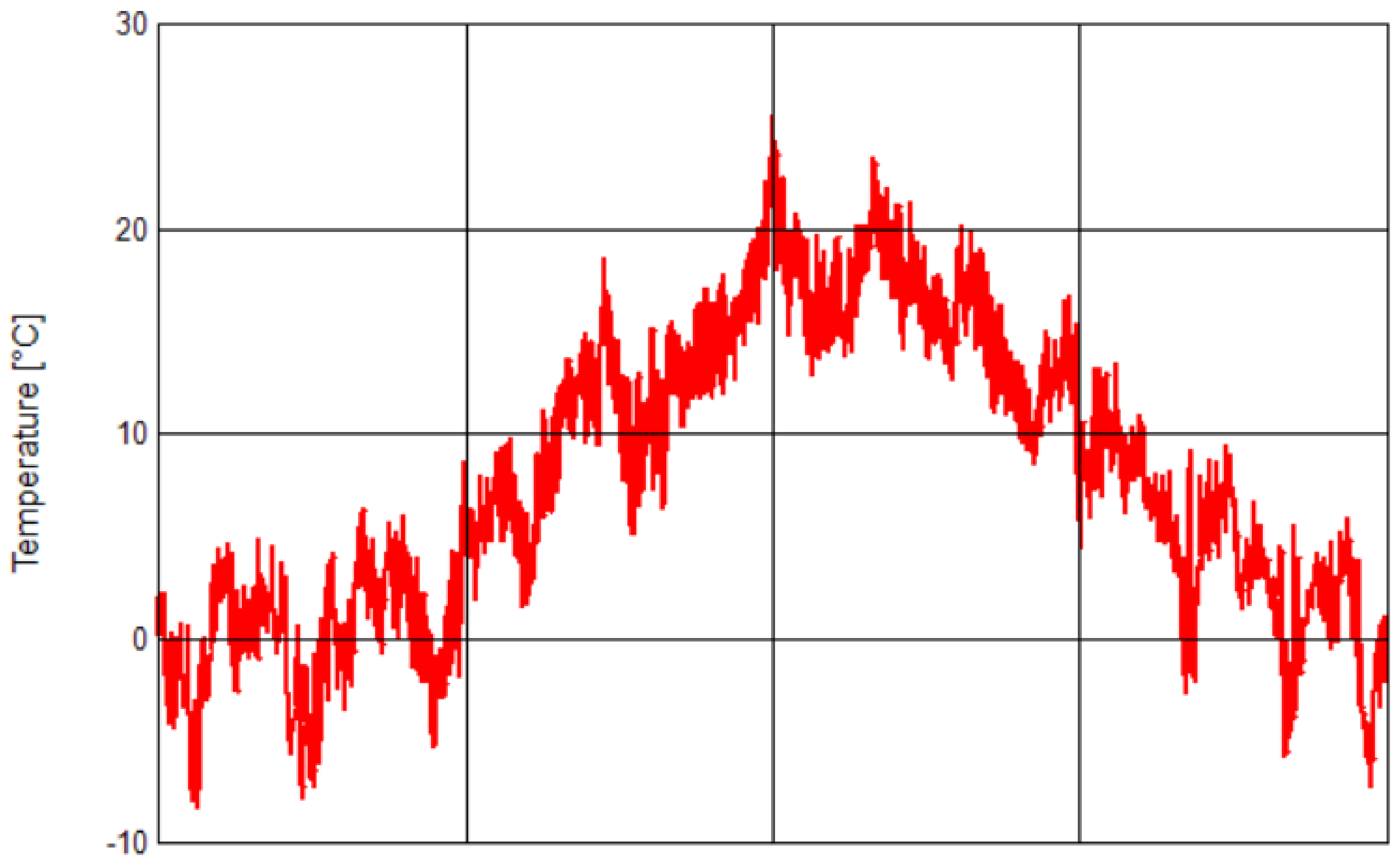


Figure 50. Ambient Air Temperature.

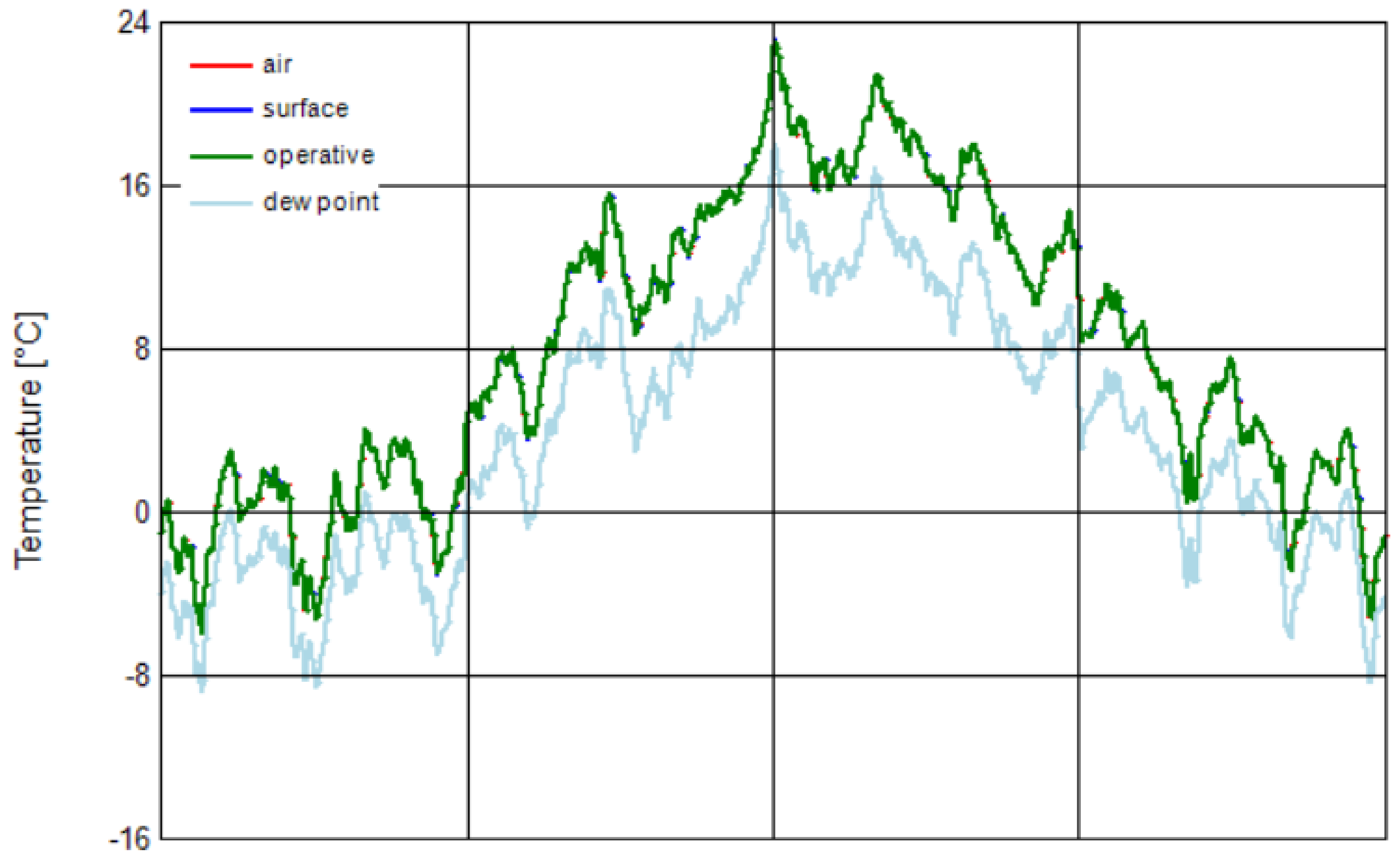


Figure 52. Air Temperature in zone 1.

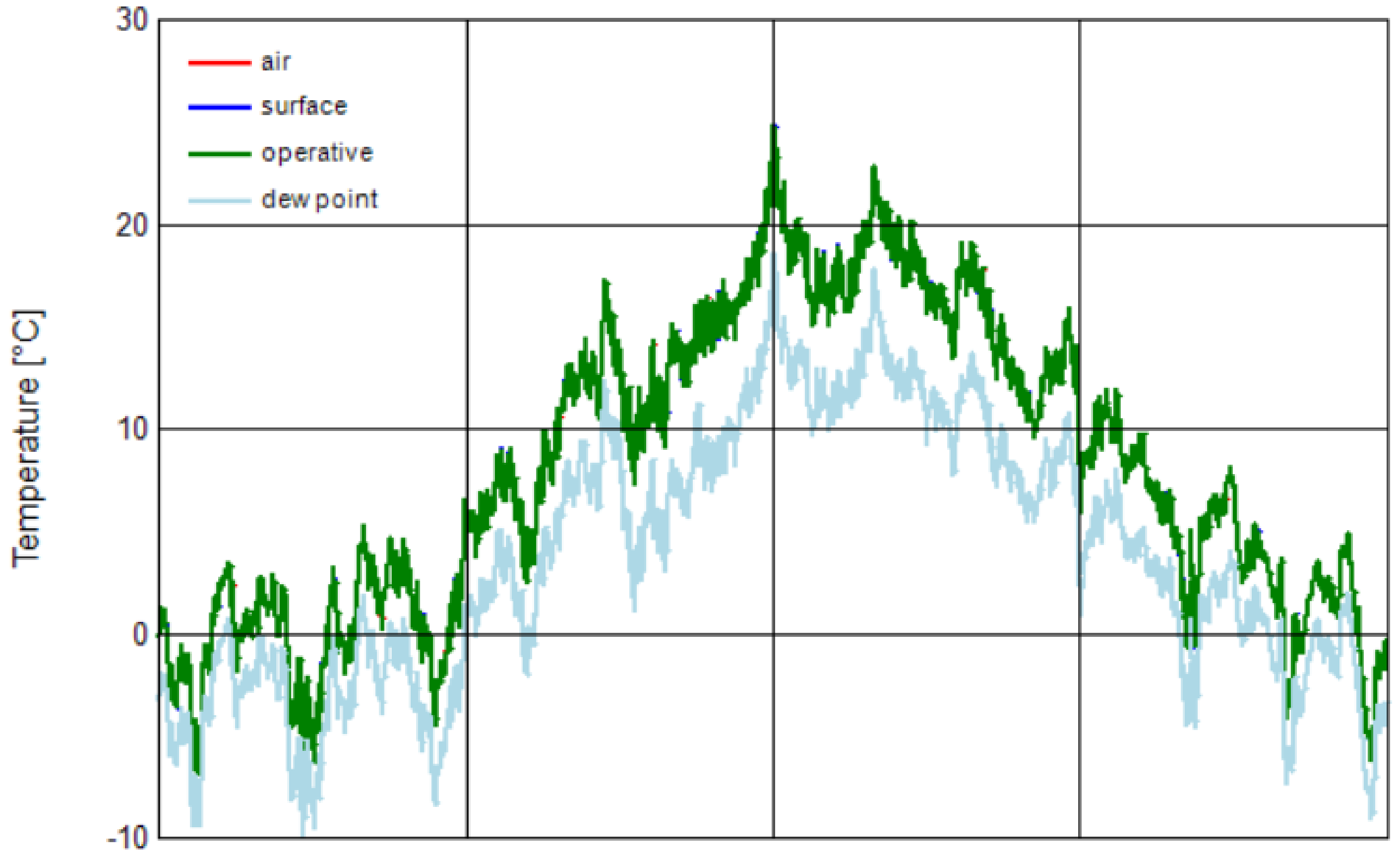


Figure 54. Air Temperature in zone 2.

A2 SCENARIO
(2100)

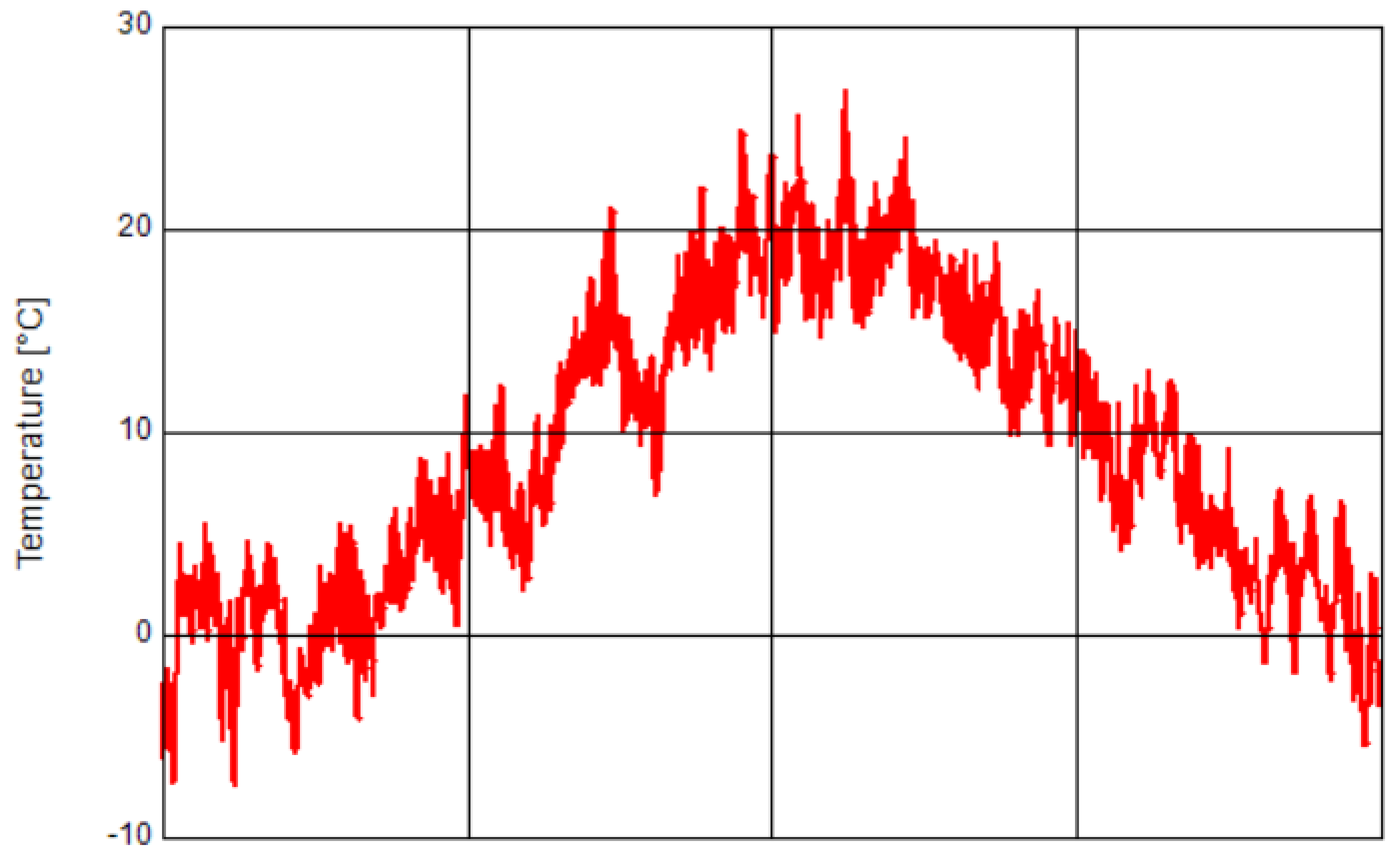


Figure 51. Ambient Air Temperature.

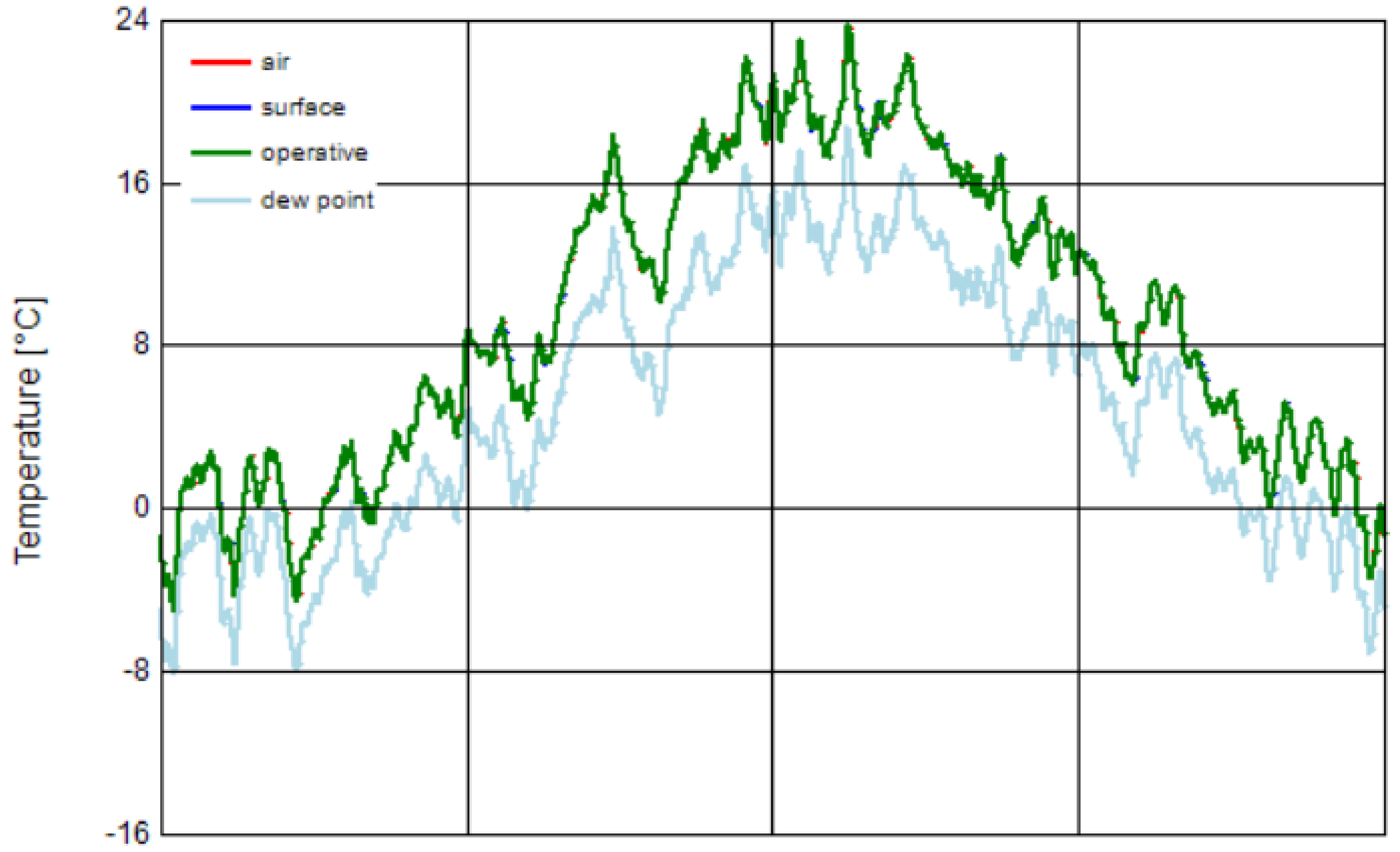


Figure 53. Air Temperature in zone 1.

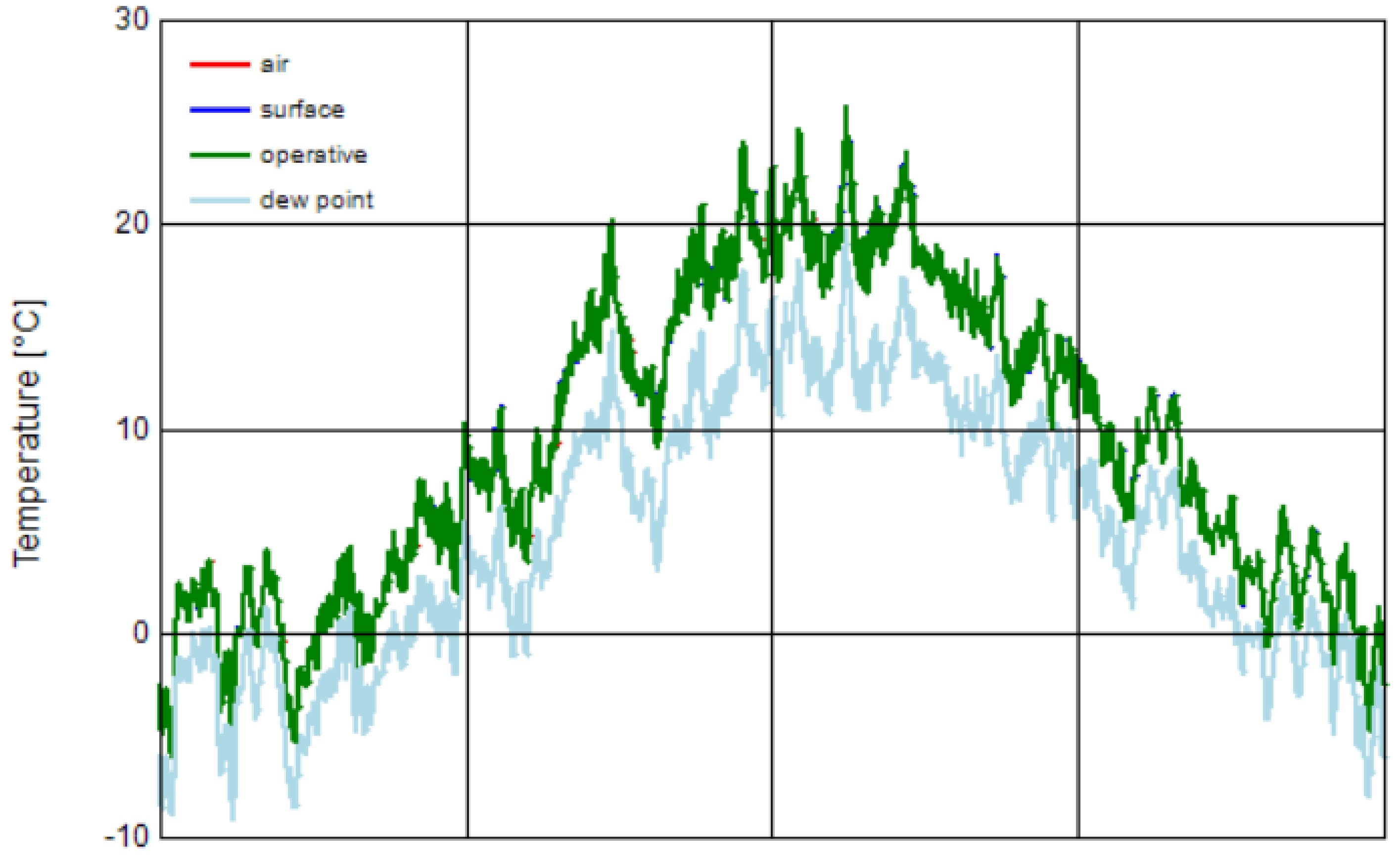


Figure 55. Air Temperature in zone 2.

FADUM STOREHOUSE

The first thing that is noticeable, is the similarity between the six graphs; all six of them follow the same pattern. The current air temperature is also very similar for both the indoor (Fig. 52. and Fig. 54.) and the outdoor (Fig. 50.) conditions. However, a difference between the graphs of the current climate is that Fig.54. and the Fig.50. are less stable than the temperature of Fig.52., which is shown through the fluctuations in the air temperature. The reason for the instability in zone 2 is that it's less protected from the outside conditions than zone 1. Zone 1 is surrounded by the slanted roof while zone 2 is directly underneath the roof and has no shelter. A comparison between the current typical year and the expected future conditions, can reveal that the temperature becomes a little higher in the latter. At first look this doesn't seem very significant. However, the consistency of the rise in temperature in Fig.51., Fig.53., and Fig.55. shows us that this isn't a coincidence and the temperature will keep rising in the future.

FADUM STOREHOUSE

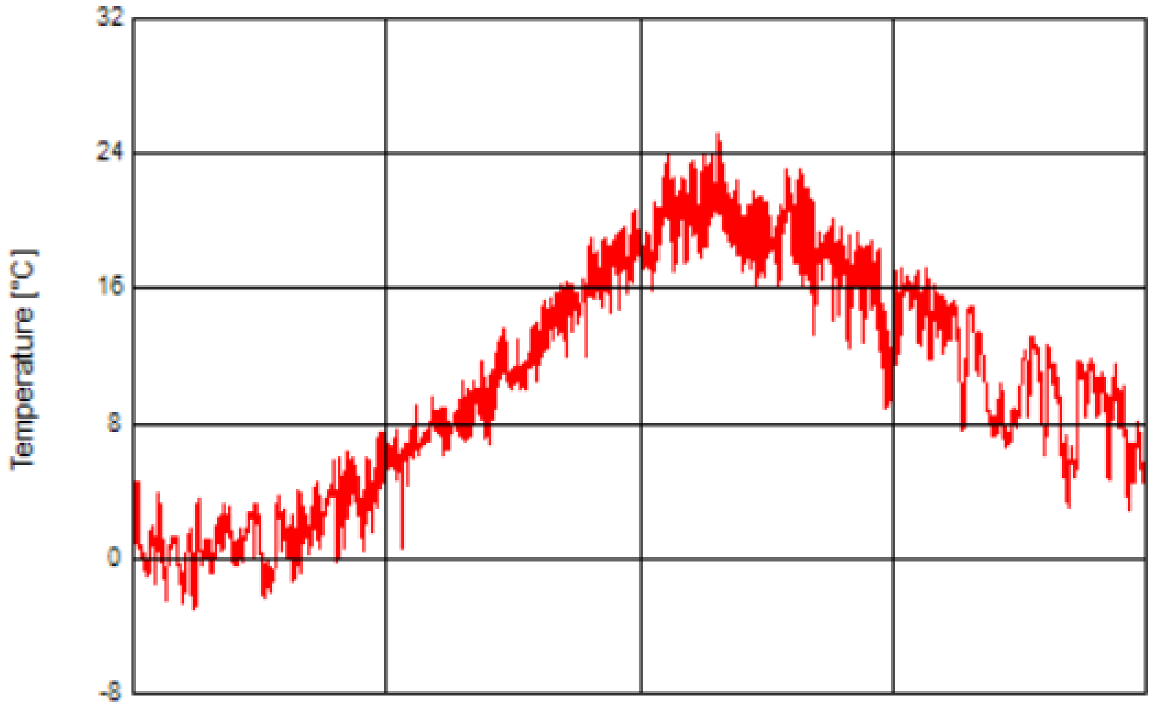


Figure 56. Ambient Air Temperature.

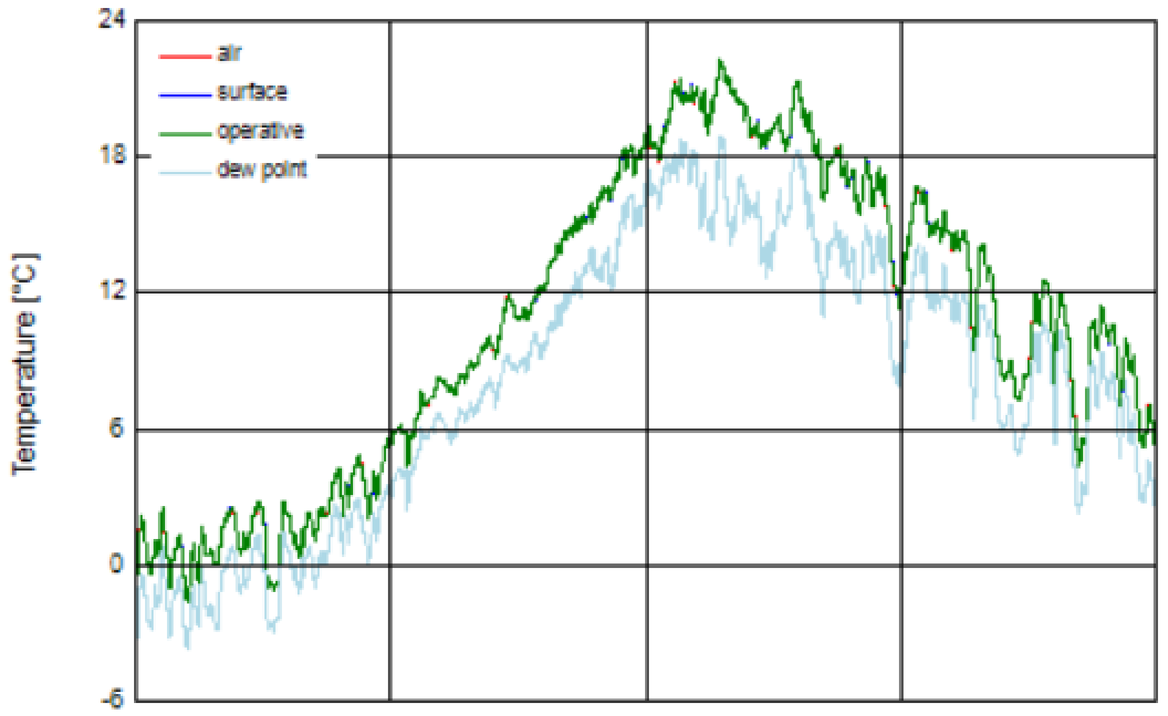


Figure 58. Air Temperature in zone 1.

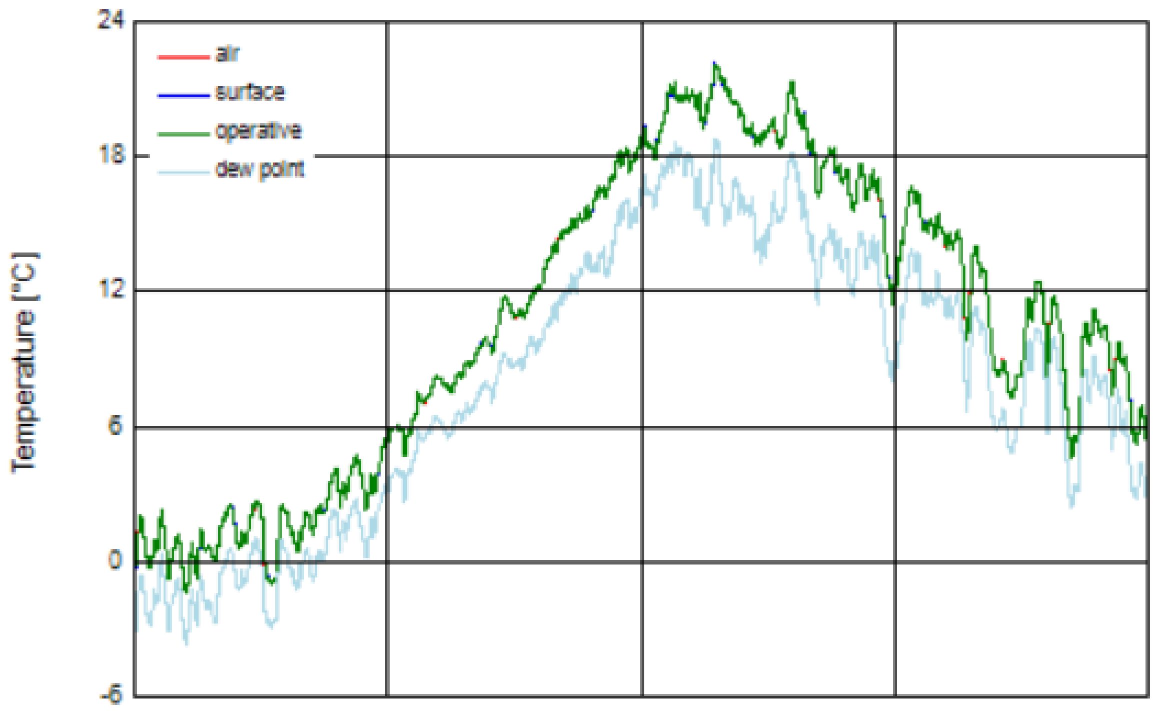


Figure 60. Air Temperature in zone 2.

HEIERSTAD LOFT

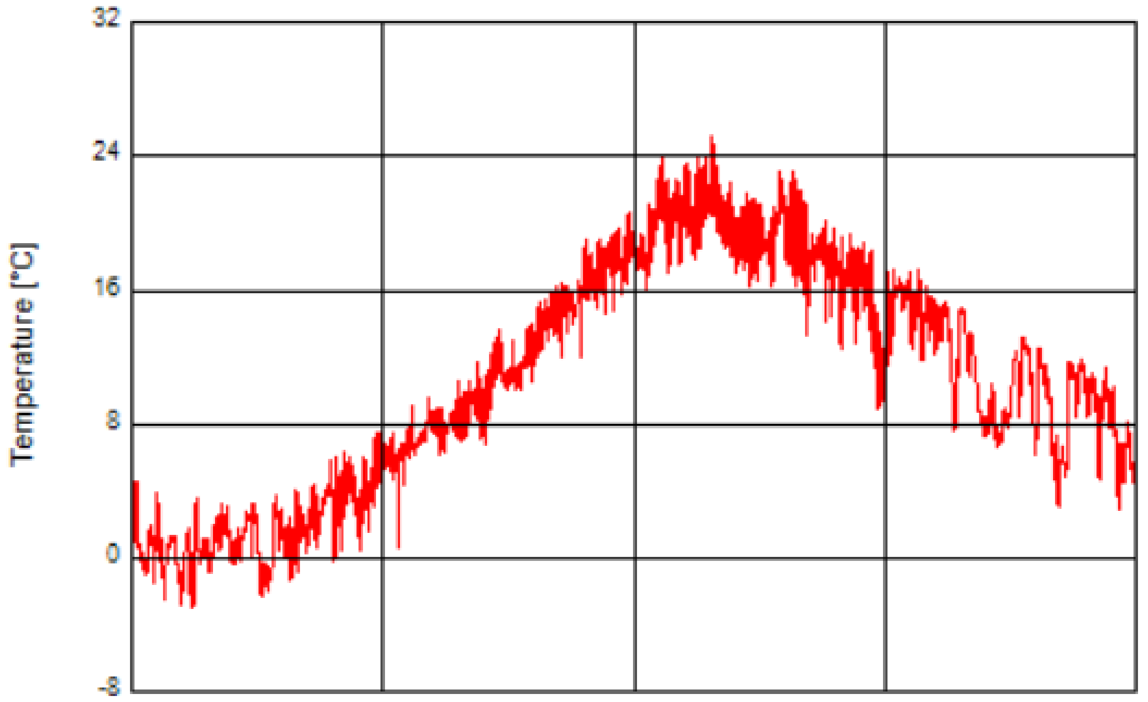


Figure 57. Ambient Air Temperature.

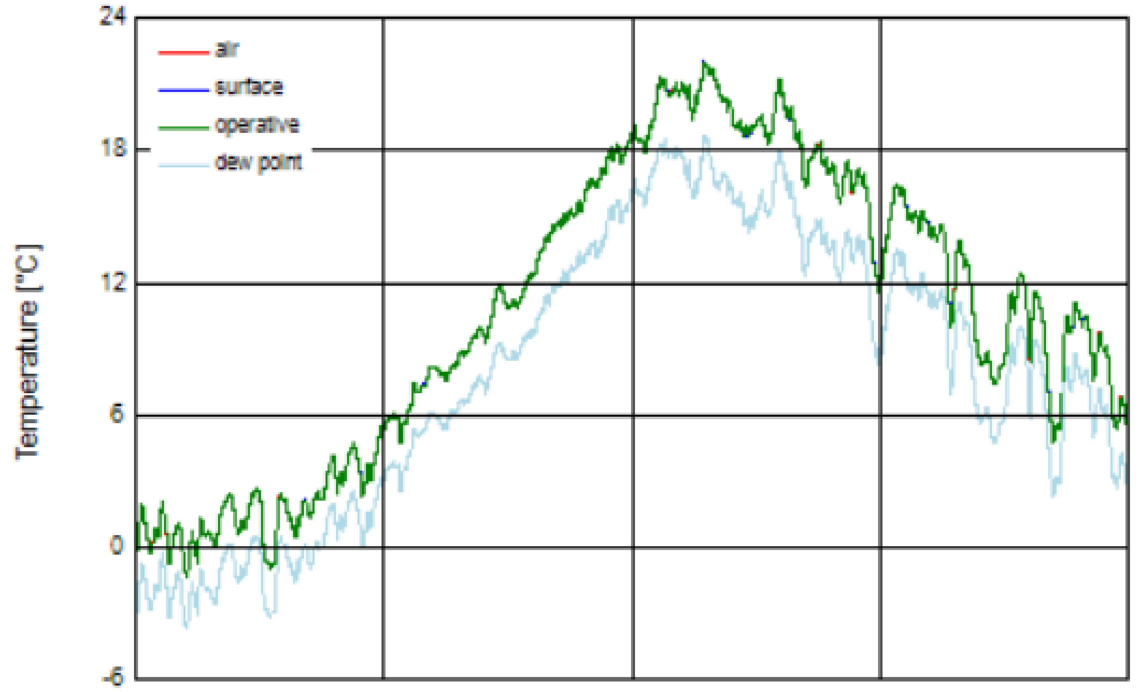


Figure 59. Air Temperature in zone 1.

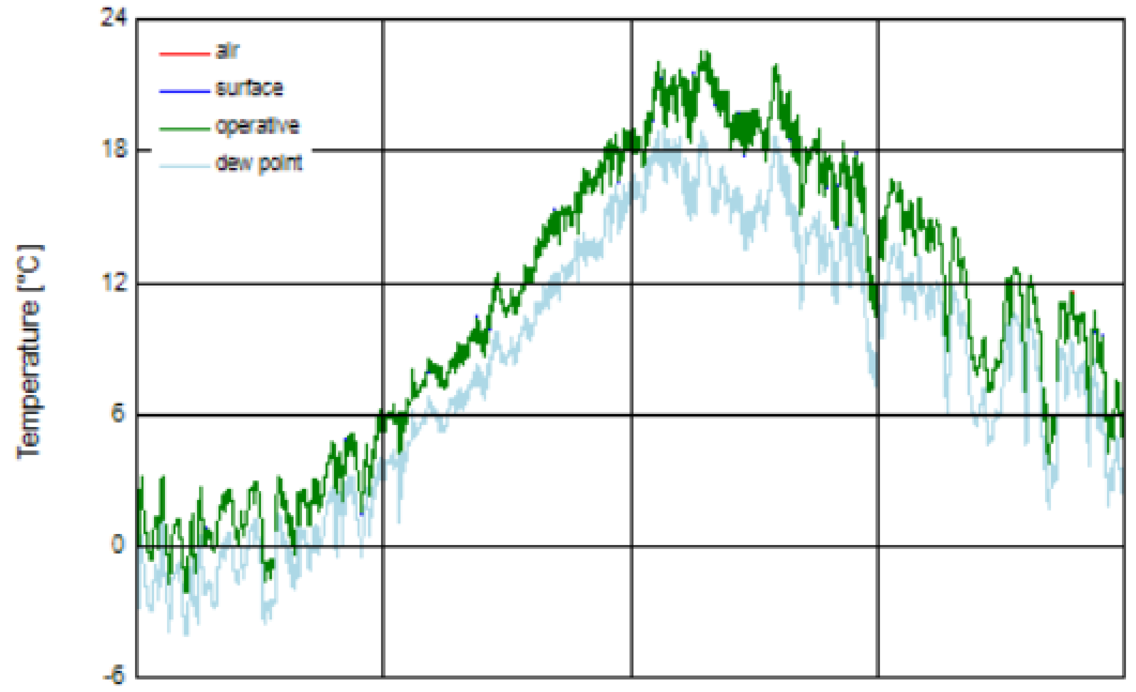


Figure 61. Air Temperature in zone 2.

4.3.2. AIR TEMPERATURE RCP8.5 CLIMATE FILE

HEIERSTAD LOFT

The resemblance between all the inner climate graphs is significant. The peak of air temperature is presented in all graphs in June and July, while the relative humidity decreases notably at the same time. As It is remarkable in the A2 climate file (Fig.43., Fig.45., Fig.47., and Fig.49.), the air temperature in 2100 has a wider peak, reflecting the expected increase due to the GHG emissions. Moreover, the values are considerably unstable comparing the current climate data (Fig.42., Fig.44., Fig.46., and Fig.48.), which might affect the deterioration of the building materials in a more severe way. Furthermore, the graphs of the outer conditions (Fig.56. and Fig.57.) appear as inconsistant as the two other climate files. The temperature differences between the outer and the inner zones are slightly small, which means the building is badly isolated.

FADUM STOREHOUSE

Comparing to the graphs which belong to the current climate data (Fig.50., Fig.52., and Fig.54.), the increase of air temperature both outside and inside the building can be affirmed. Moreover, there is not a significant difference between inside and outside, which leads to confirm the bad isolation of the Fadum Storehouse. Furthermore, the air temperature in zone 2 is higher than in zone 1, due to the higher exposer of solar radiation. The zone 1, which corresponds to the main room, is protected by the slanted roofs and it is less affected by the sun (Fig.58. and Fig.59.)

CURRENT
(TYPICAL YEAR)

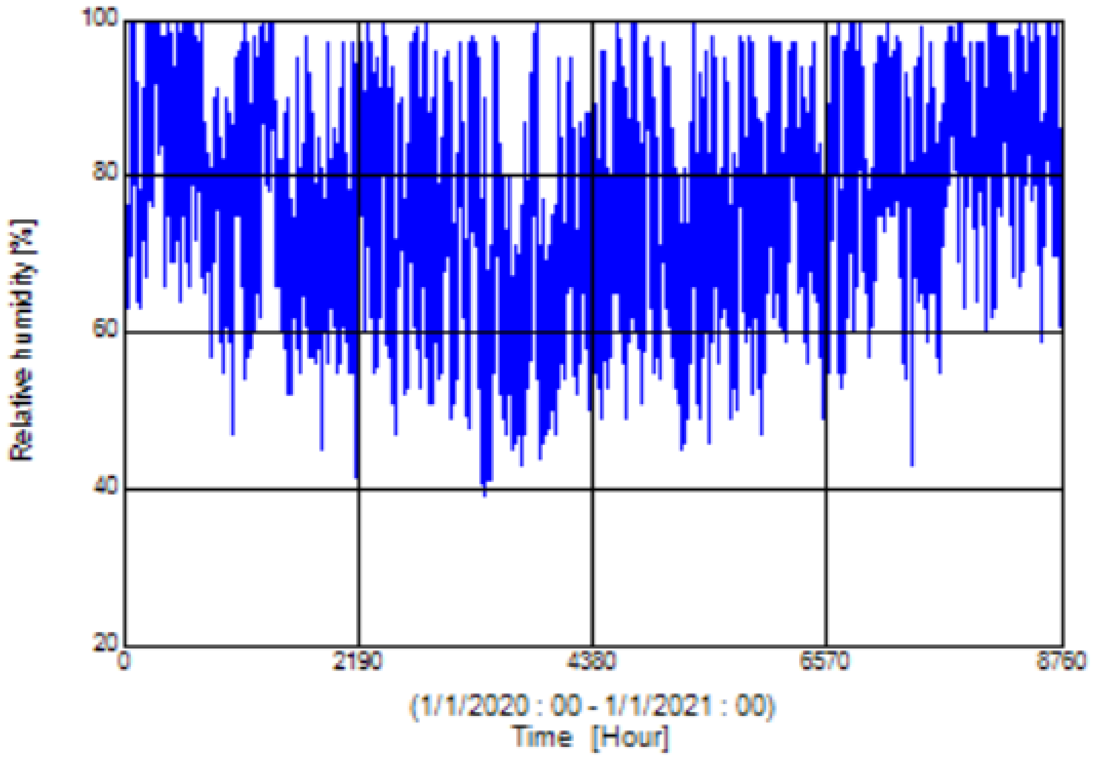


Figure 62. Ambient Relative Humidity

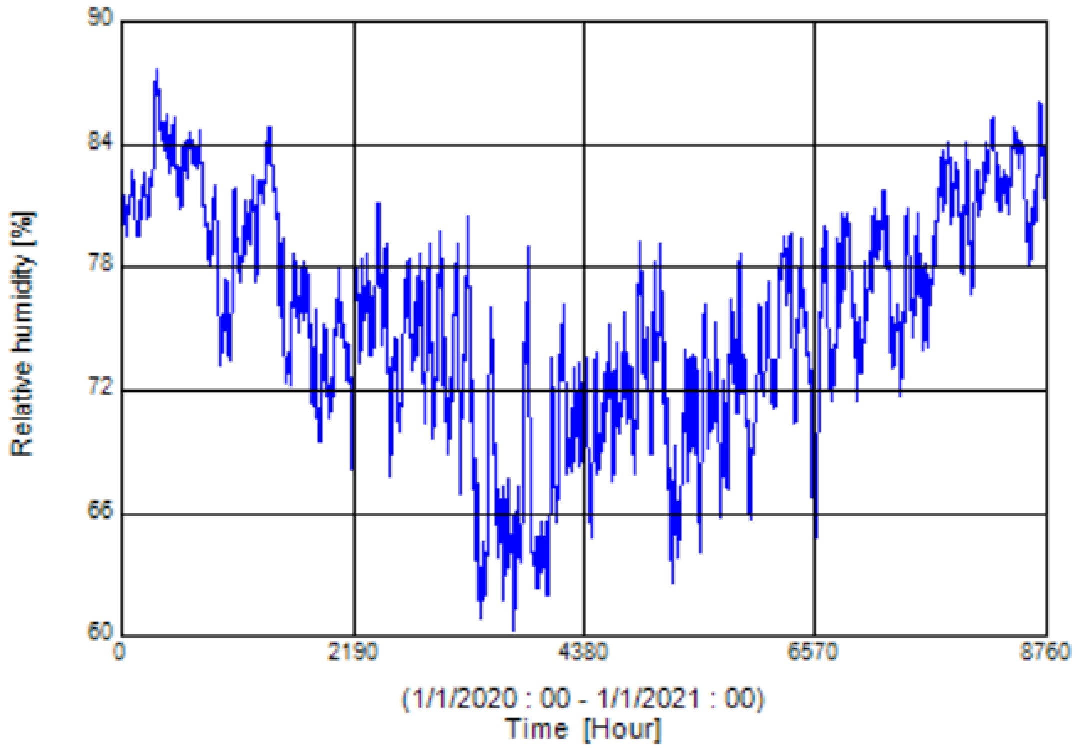


Figure 64. Relative Humidity in zone 1

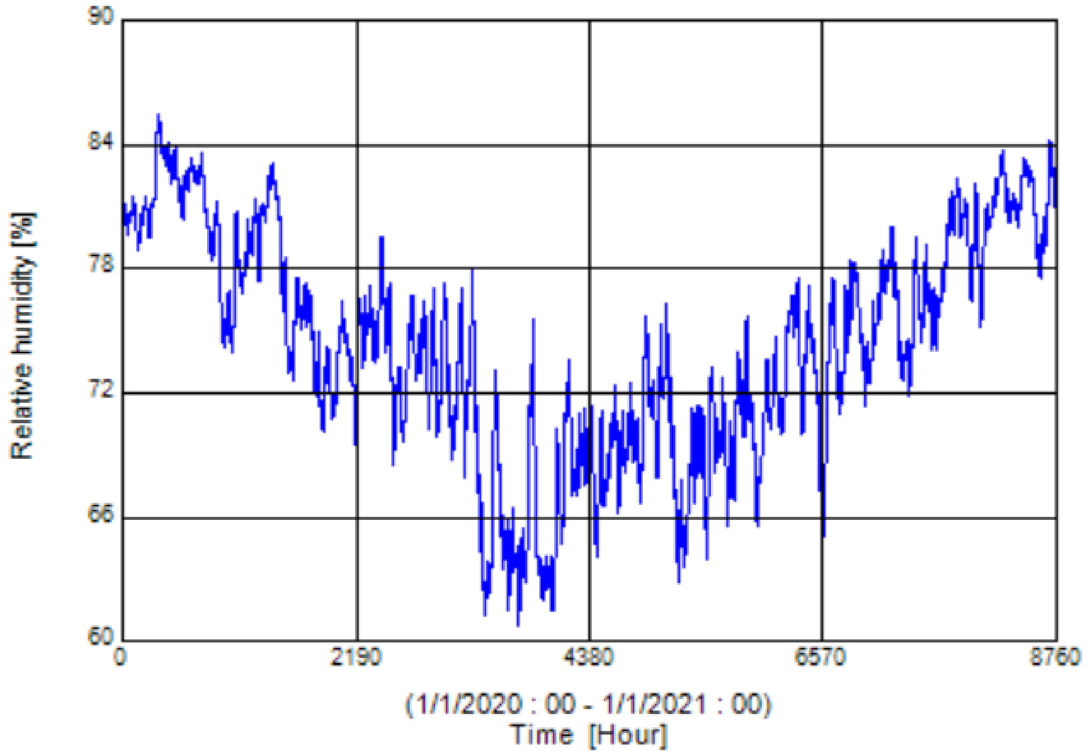


Figure 66. Relative Humidity in zone 2

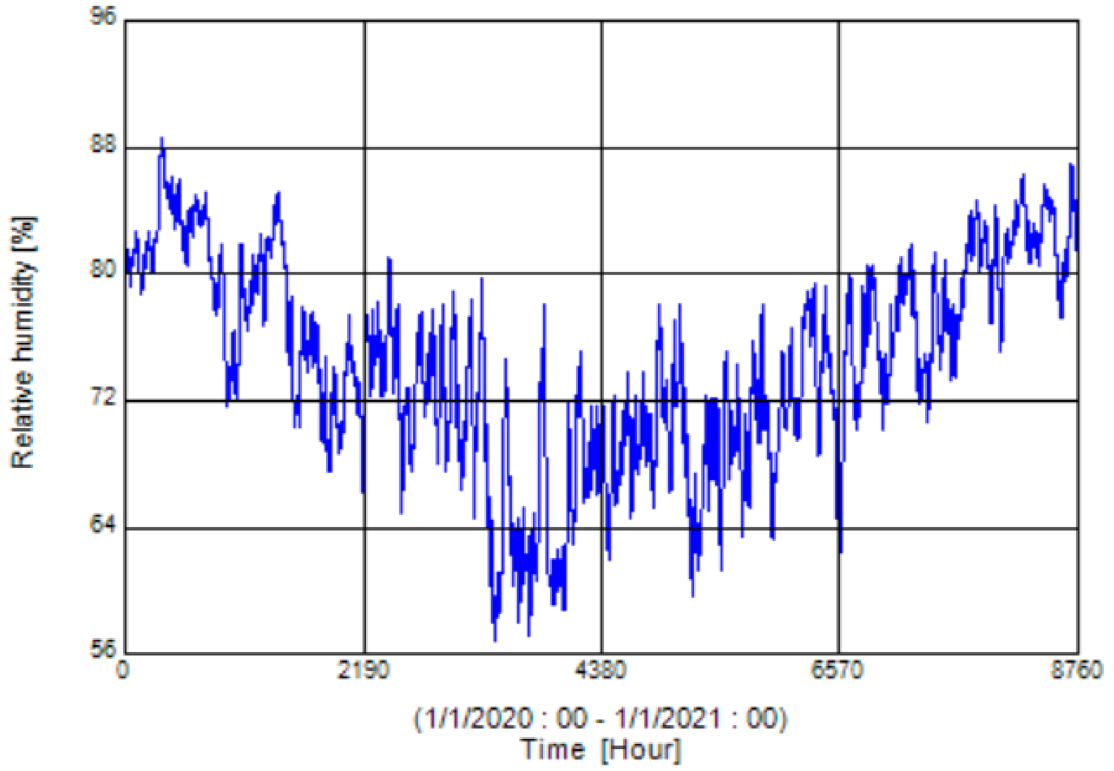


Figure 68. Relative Humidity in zone 3

A2 SCENARIO
(2100)

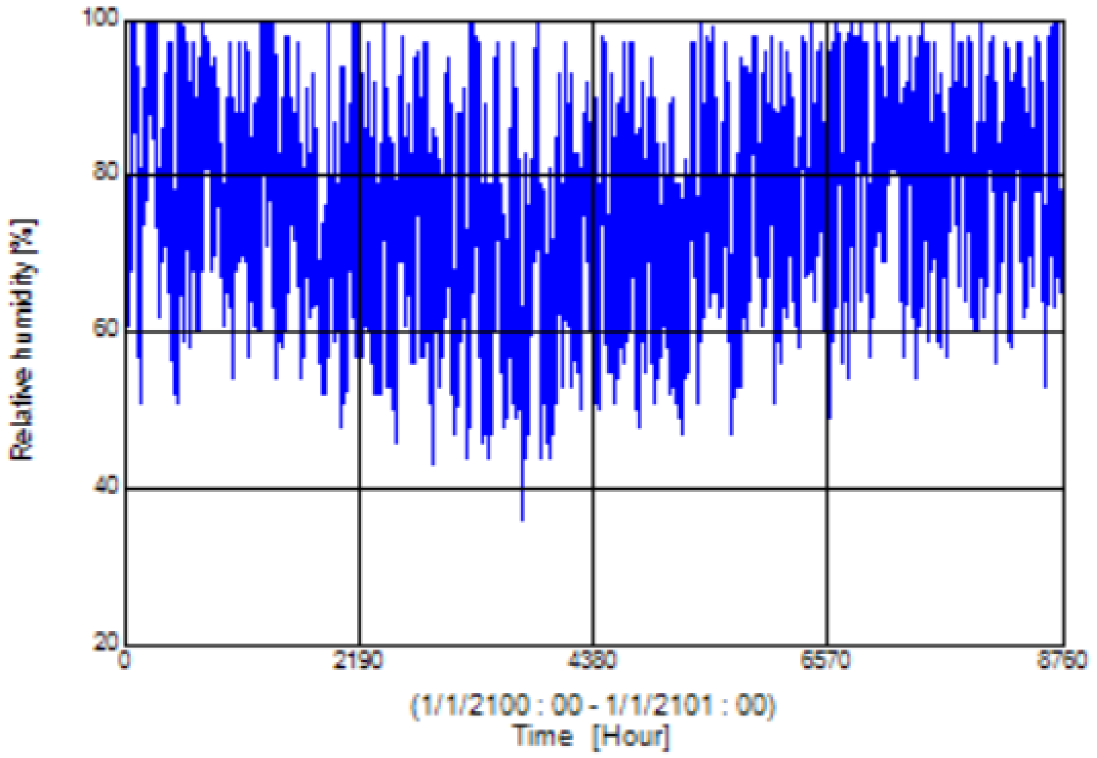


Figure 63. Ambient Relative Humidity

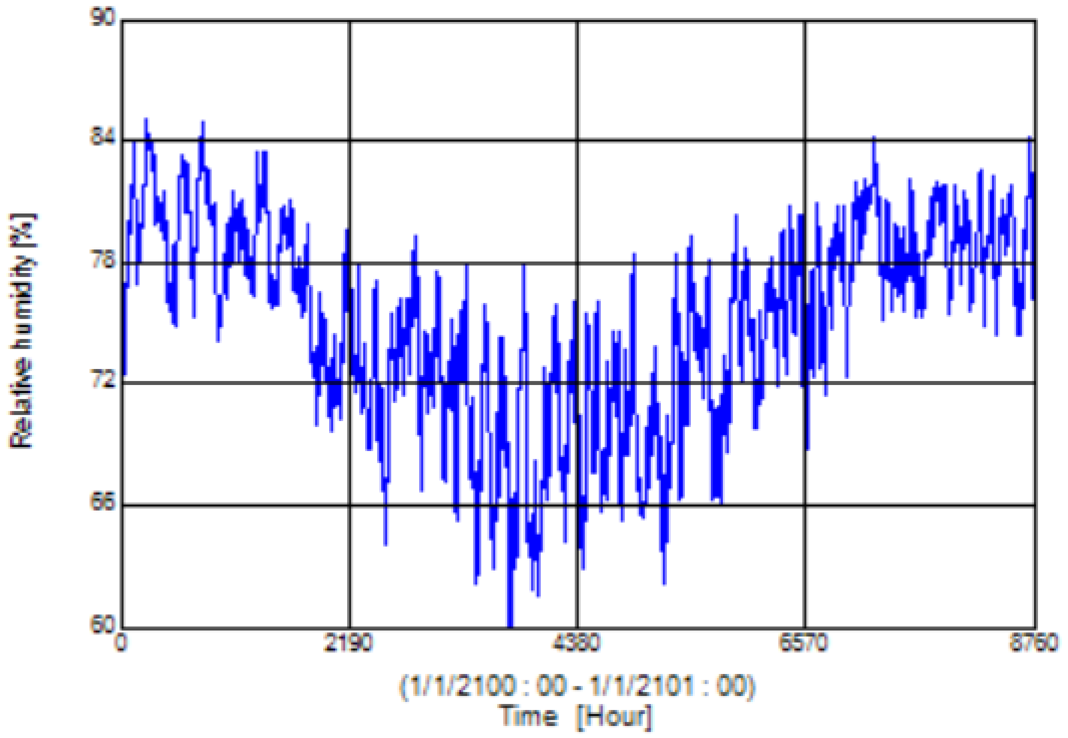


Figure 65. Relative Humidity in zone 1

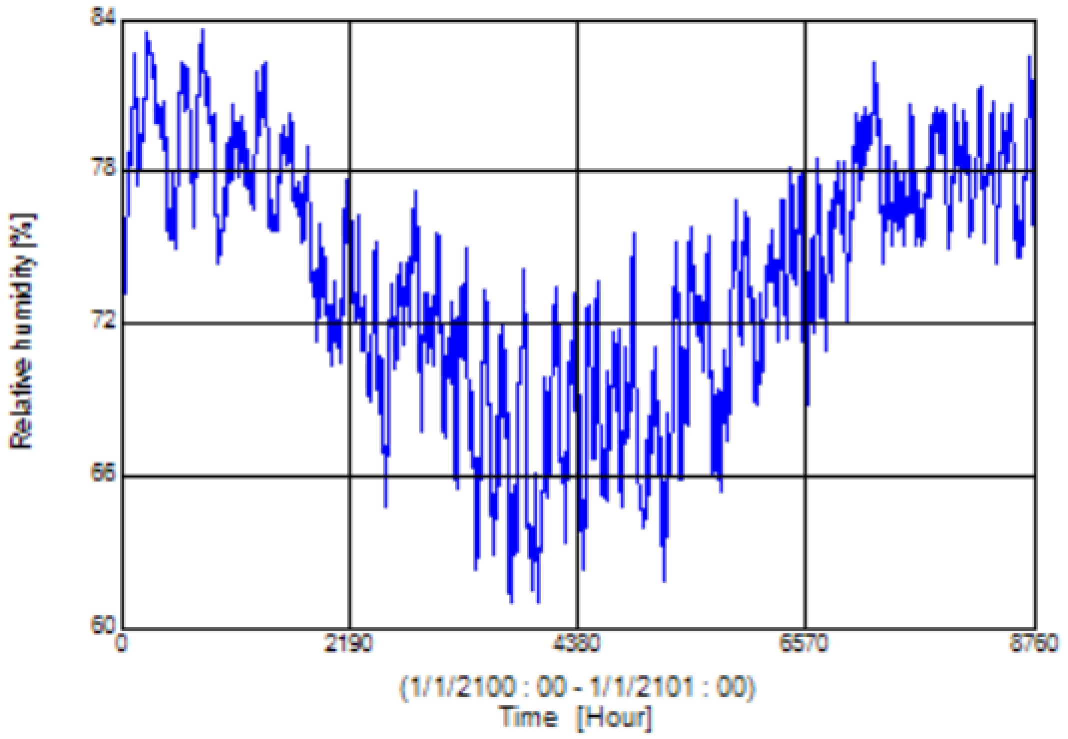


Figure 67. Relative Humidity in zone 2

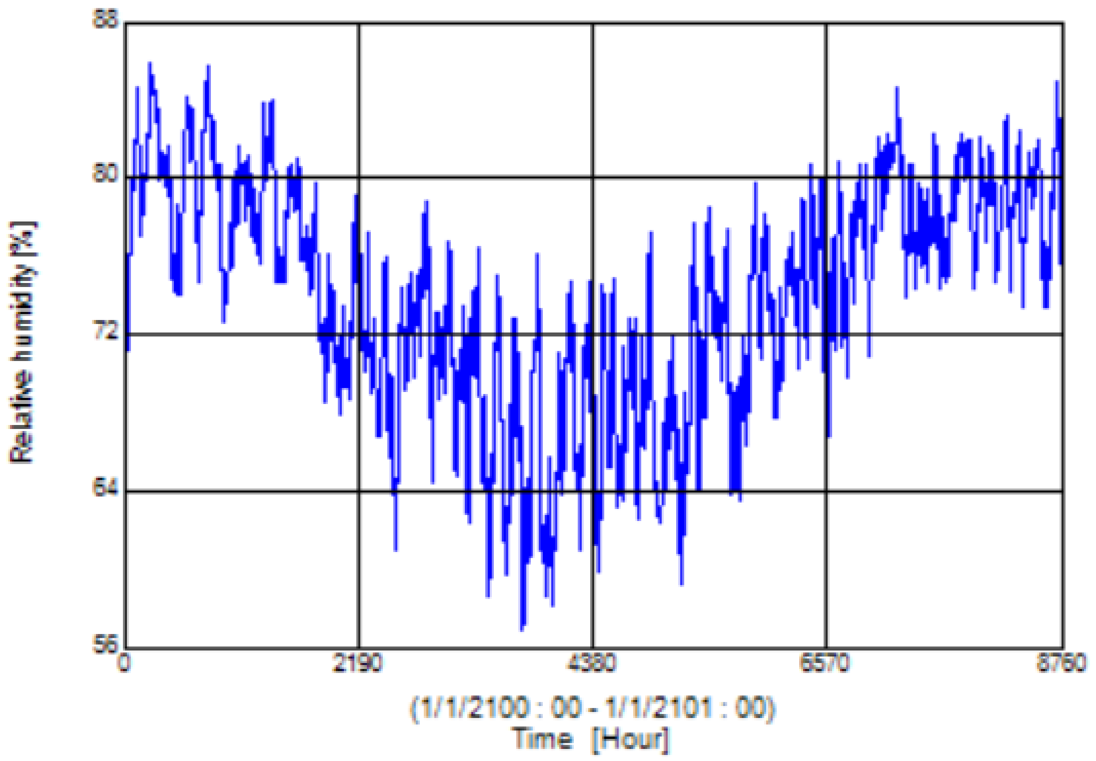


Figure 69. Relative Humidity in zone 3

4.3.3. RELATIVE HUMIDITY

HEIERSTAD LOFT

By comparing the outer relative humidity (RH) with the relative humidity of the different zones it becomes obvious that the ambient relative humidity is more unstable. This is noticeable by the amount of fluctuations, which are much more in Fig.62. and Fig.63. Another difference between outside and inside is the range of RH; the ambient RH varies from 40% to 100%. Zone 1, ground floor, goes from 60% to 88% (Fig.64. and Fig.65.). Zone 2, corridor, has a slightly smaller range from 62% to around 86% (Fig.66. and Fig.67.), while zone 3, rooms, varies from 57% to 89% (Fig.68. and Fig.69.). By analyzing the numbers above, it can be concluded that the building offers some protection, that’s why the range is in general smaller inside than outside, which buffers the maxima and minima of RH. All the graphs of the zones of the current climate follow similar fluctuations, these fluctuations are partially changed in the future climate . Another difference between the current and the future climate in the zones is that the relative humidity decreases with an average of around 3%.

CURRENT (TYPICAL YEAR)

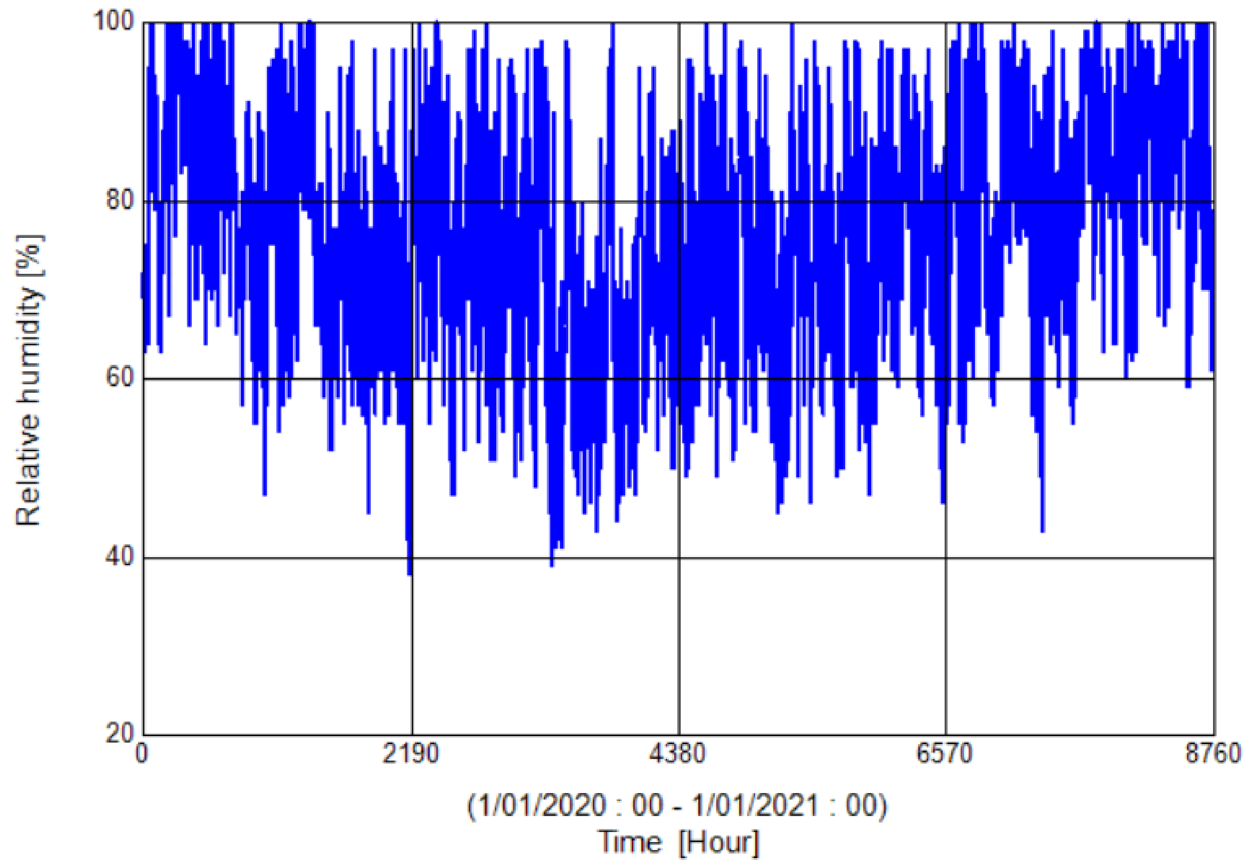


Figure 70. Ambient Relative Humidity

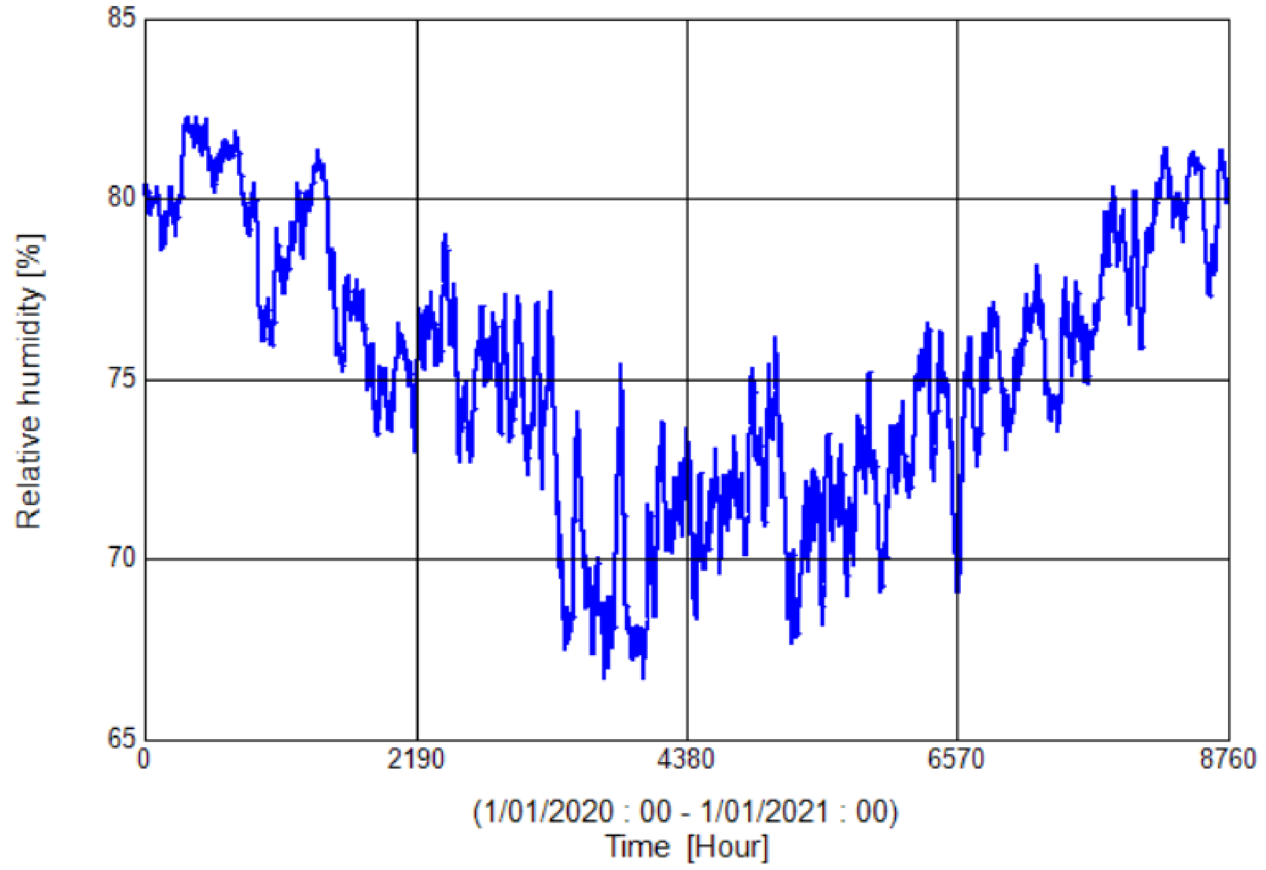


Figure 72. Relative Humidity in zone 1

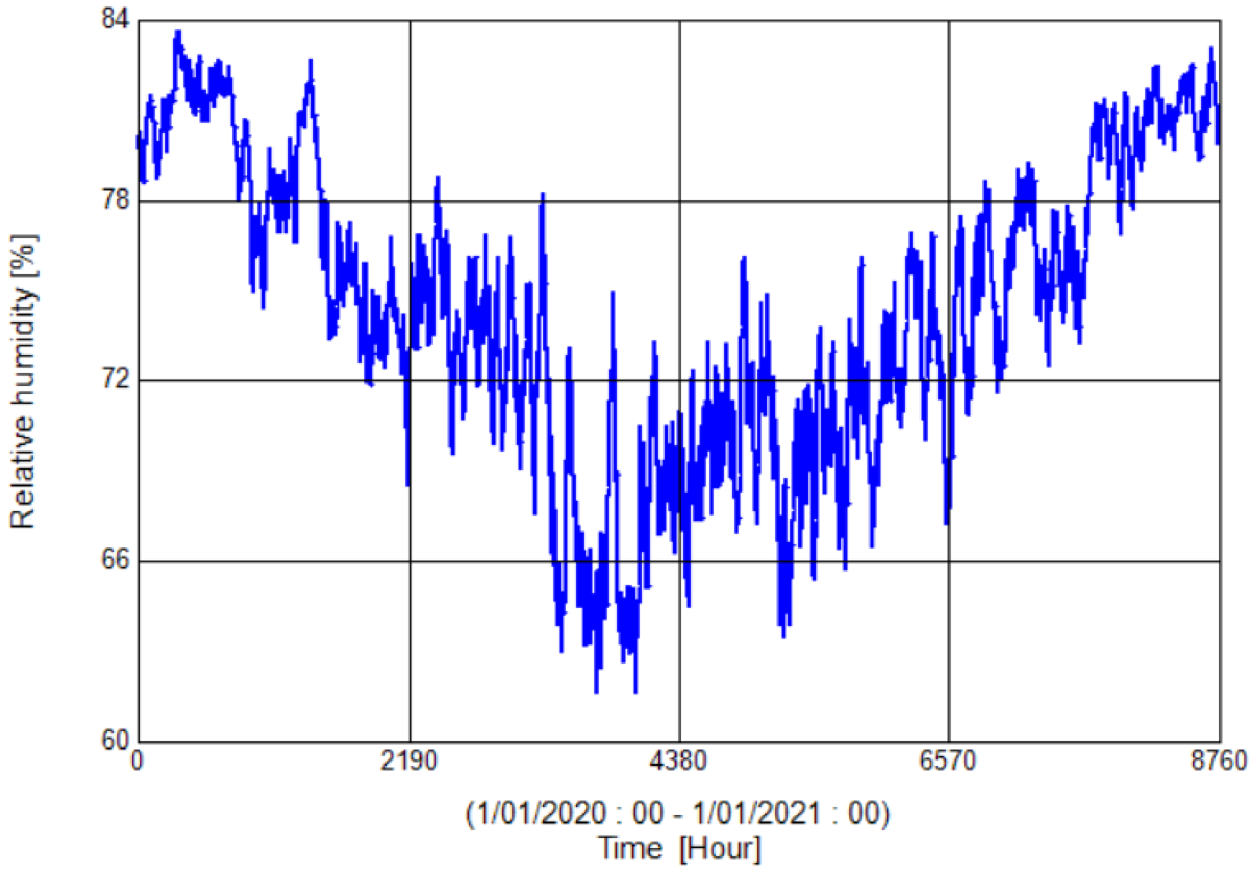


Figure 74. Relative Humidity in zone 2

A2 SCENARIO (2100)

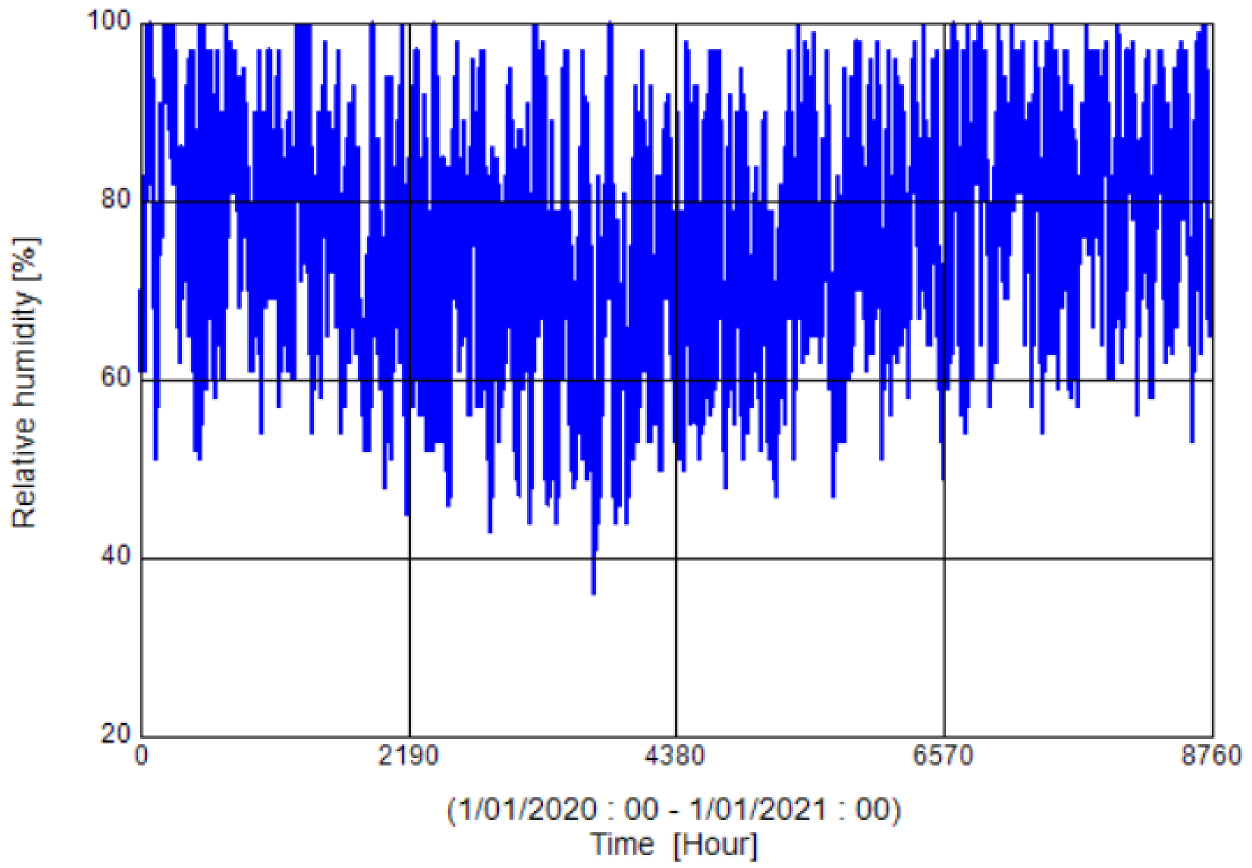


Figure 71. Ambient Relative Humidity

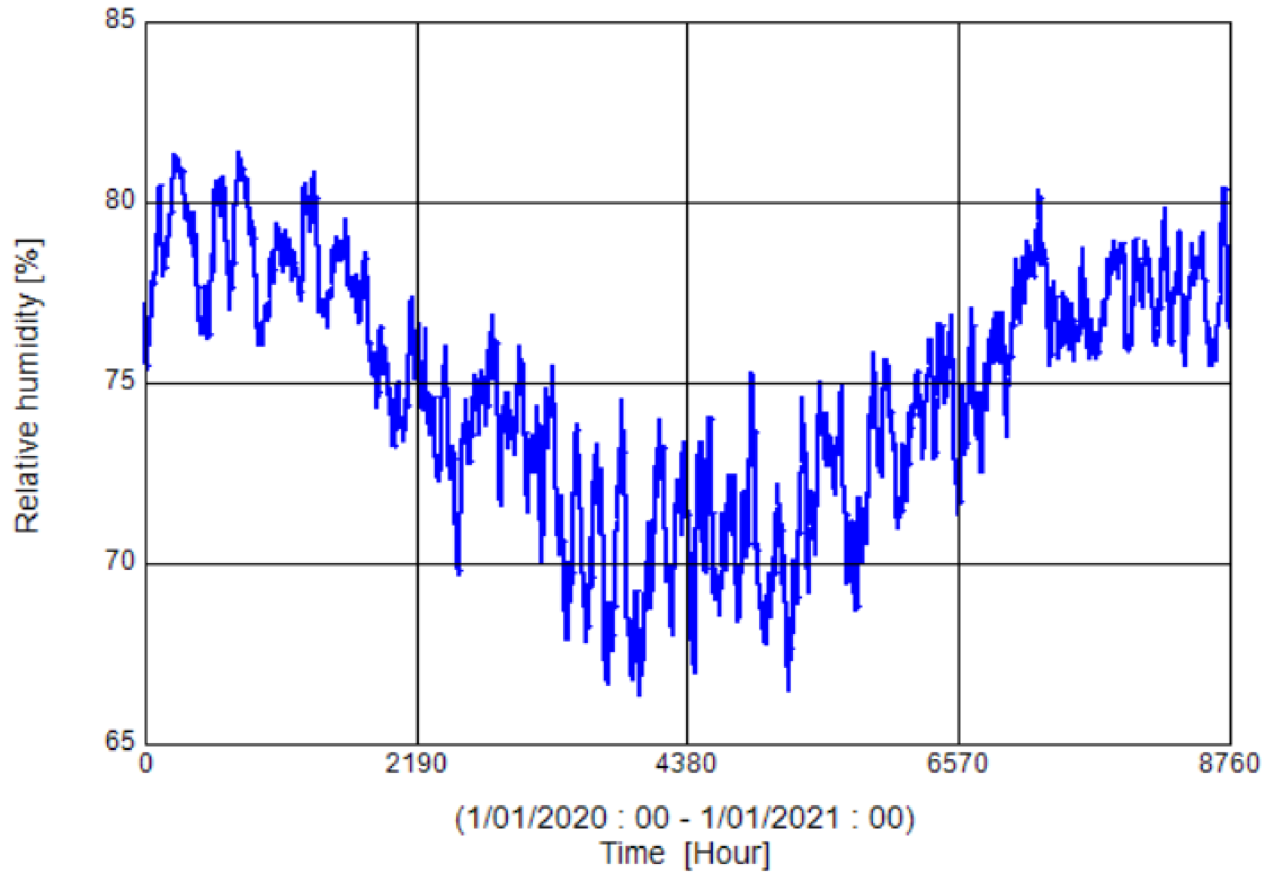


Figure 73. Relative Humidity in zone 1

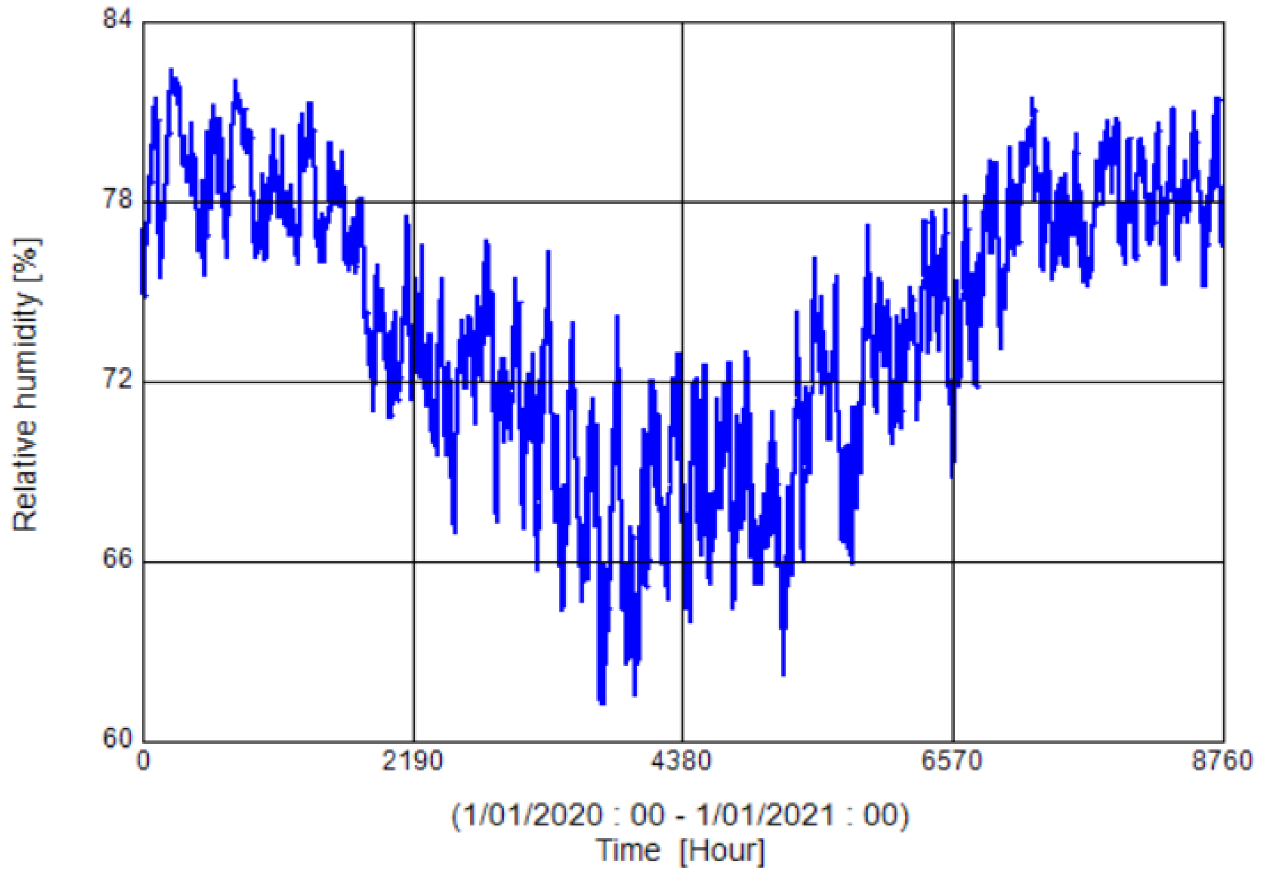


Figure 75. Relative Humidity in zone 2

FADUM STOREHOSE

In graph Fig.70. and Fig.71., the ambient relative humidity is unstable. Fig.70. and Fig.71. are very unclear because the outer relative humidity changes quickly. Another conclusion that can be made, is that zone 2 (Fig.74. and Fig.75.), of the current climate, has a wider range of results. The relative humidity of zone 2, of the current climate, goes from around 62 to 82. While zone 1 (Fig.72. and Fig.73.), of the current climate, goes from around 67 to 81. The ambient relative humidity has a range that variates from around 35 to above 100 (Fig.70. and Fig.71.). It can be concluded in this case that the building gives some protection, that's why the relative humidity inside is more stable than outside. The relative humidity of the graphs on the second row is around 2% lower than the RH of the first row. This means that the relative humidity in 2100 will be slightly lower than today. When the graphs of the current climate are compared with those of the future climate, we can also see a small difference in the fluctuations of the graphs of zone 1 and 2. This is noticeable on the graphs Fig.72., Fig.73., Fig.74., and Fig.75. between the hour 2190 and 4380.

FADUM STOREHOUSE

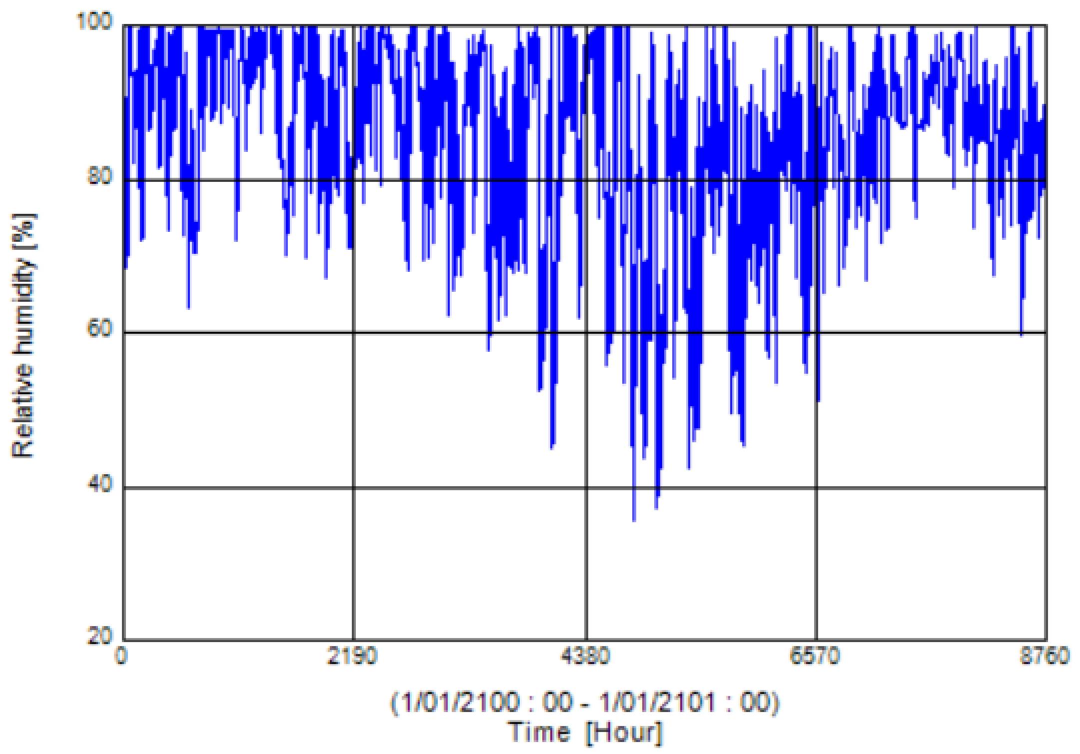


Figure 76. Ambient Relative Humidity

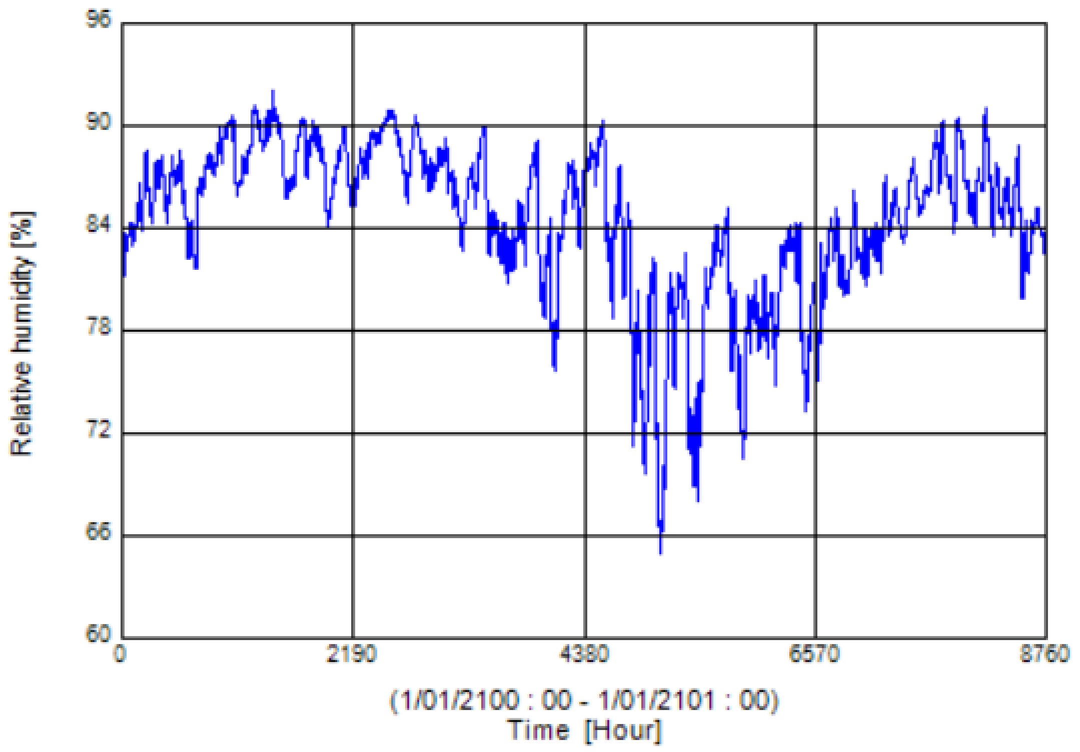


Figure 75. Relative Humidity in zone 1

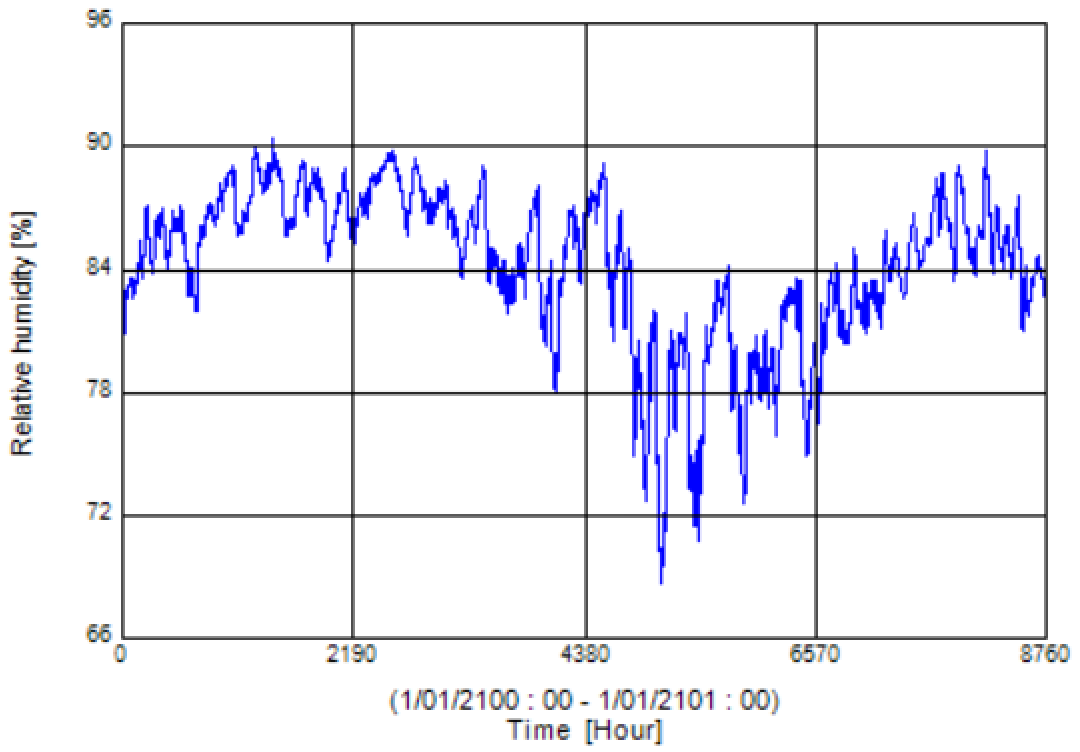


Figure 77. Relative Humidity in zone 2

HEIERSTAD LOFT

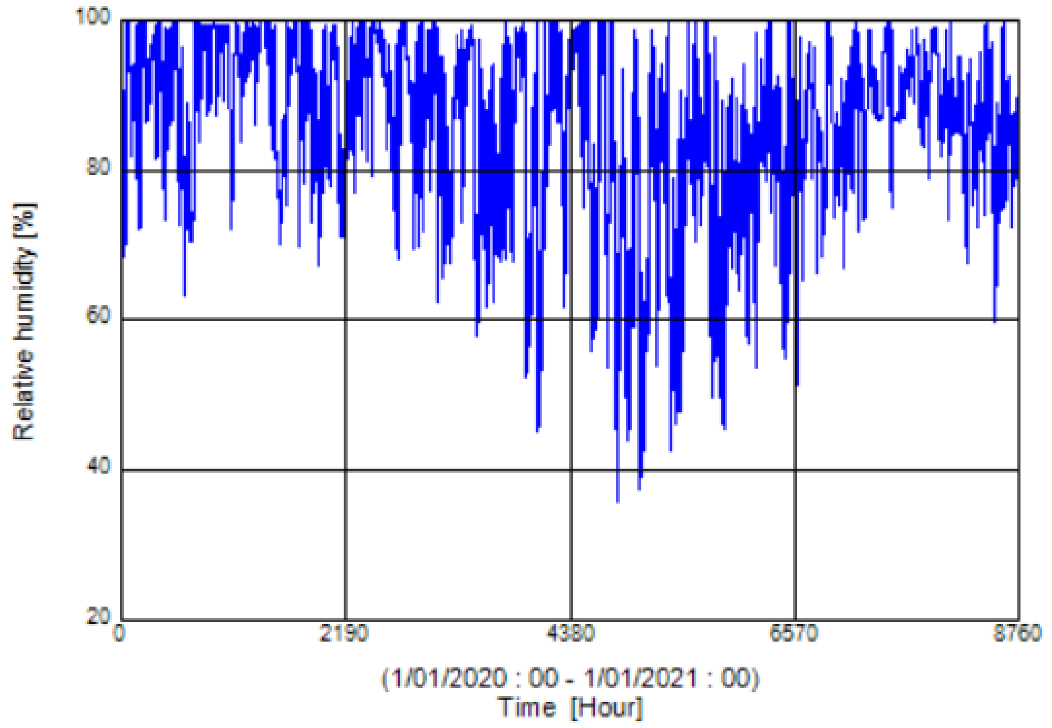


Figure 77. Ambient Relative Humidity

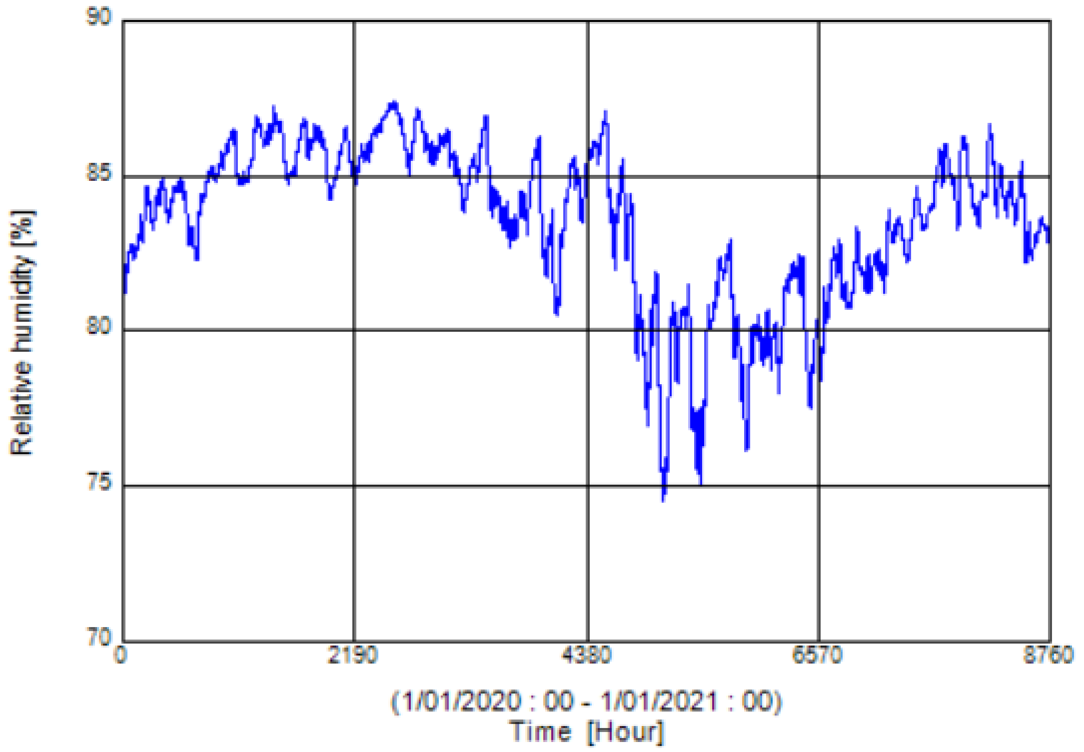


Figure 76. Relative Humidity in zone 1

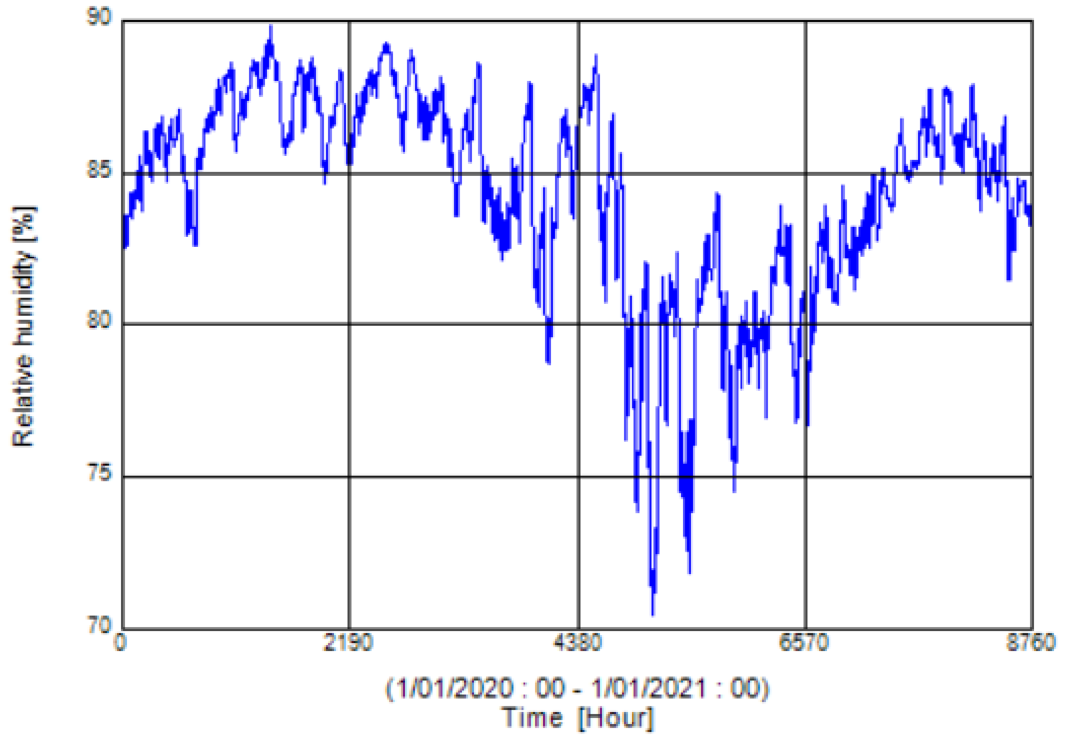


Figure 78. Relative Humidity in zone 2

4.3.4. RELATIVE HUMIDITY RCP8.5 CLIMATE FILE

HEIERSTAD LOFT

Referring to the relative humidity inside the Heierstad Loft, the values are not stable and they make rough fluctuations. The range of relative humidity in the different zones varies from 65% to 92% (Fig.78.) in zone 1, which corresponds to the ground floor; in zone 2, the values go from 68% to 91% (Fig.80.) and coincide with the corridor; and in zone 3, the range goes from 63% to around 94%, the two rooms on the first floor. Those percentages are considered remarkably high and in addition to the high air temperature, it might result in a worse biodeterioration scenario. The increase of the values is appreciable comparing to the current data (Fig.62., Fig.64., Fig.66., and, Fig.68.)

FADUM STOREHOUSE

The Fadum Storehouse has the same problem as Heierstad Loft; both are affected by abrupt variations of relative humidity outside and inside the building. Considering the values of the different two zones, it can be affirmed that the zone 2 is as unstable as zone 1, but the range of values is wider: Zone 1 goes from 74% to 87% (Fig.79.) while Zone 2 varies from 71% to 90% (Fig.81.). These are very high numbers for indoor spaces, and make the building more vulnerable to mold growth. If the graphs of the current climate are compared with the future climate graphs, some slight fluctuations in both zones are visible. However, the difference between both climate data is very little and the impact in the future would be as significant as it is currently.

On the next page, graphs are shown comparing the moisture content in the different components of both buildings. The results indicate values for the minimum amount of water content, the maximum and the mean value. Current data are placed next to future data, thus it facilitates the comparison between both scenarios.

CURRENT (TYPICAL YEAR)	A2 SCENARIO (2100)	CURRENT (TYPICAL YEAR)	A2 SCENARIO (2100)

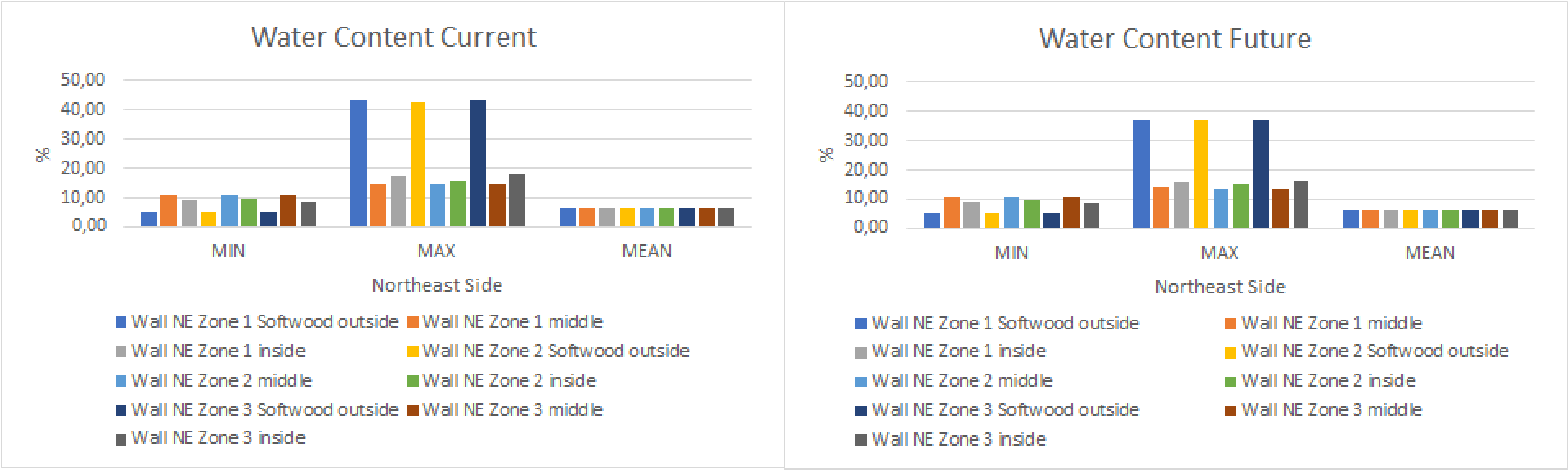


Figure 79. Moisture content in the Northeast wall

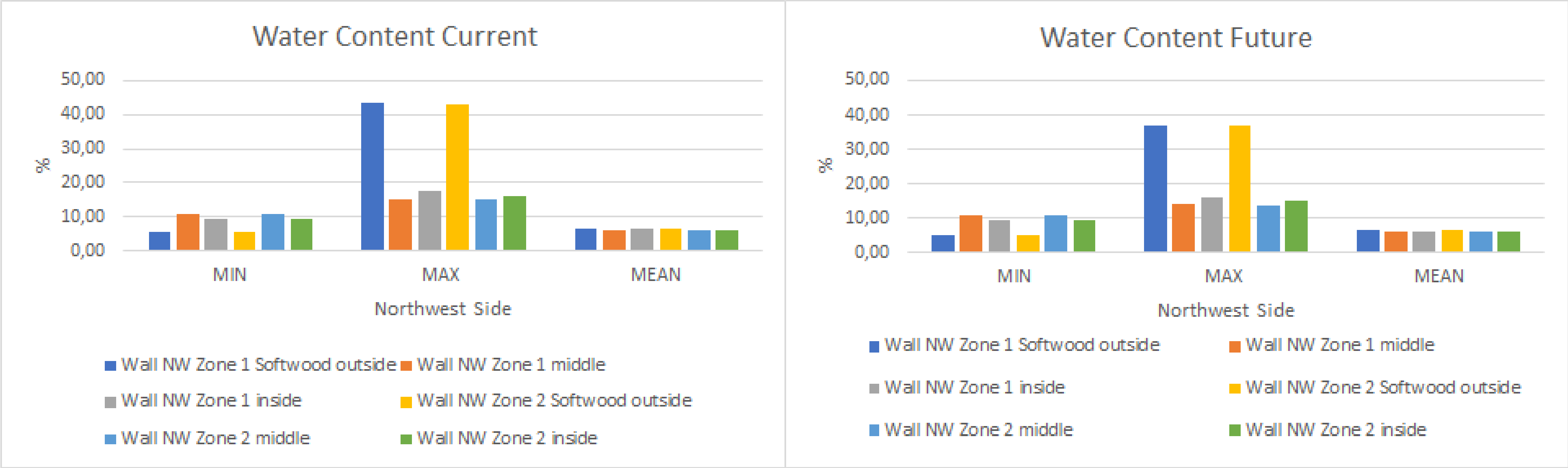


Figure 80. Moisture content in the Northwest wall

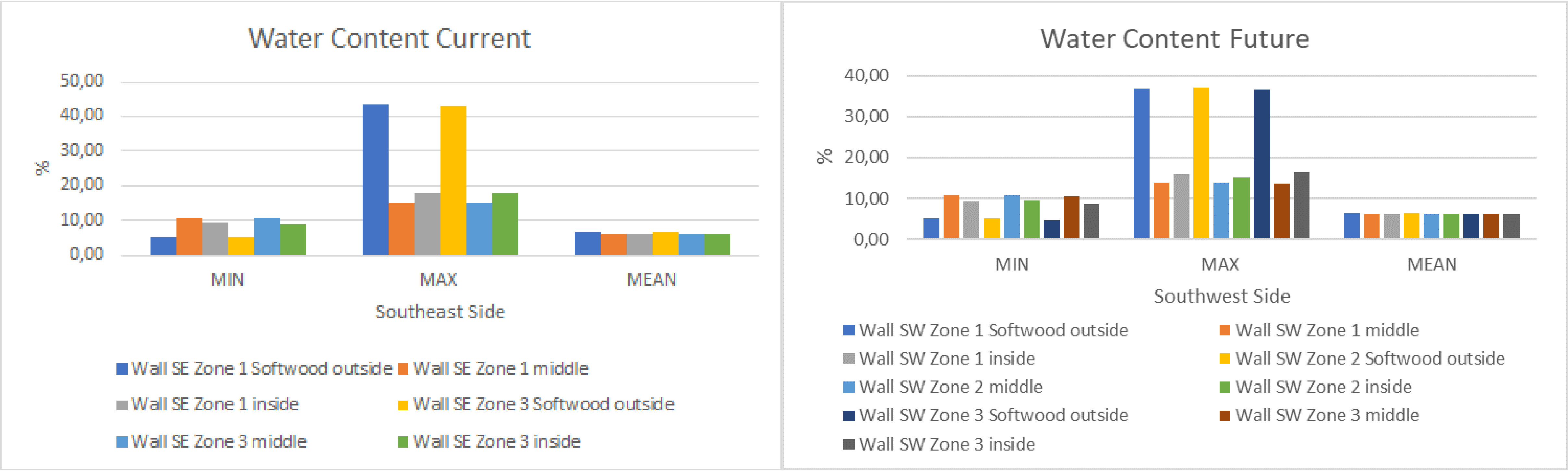


Figure 81. Moisture content in the Southeast wall

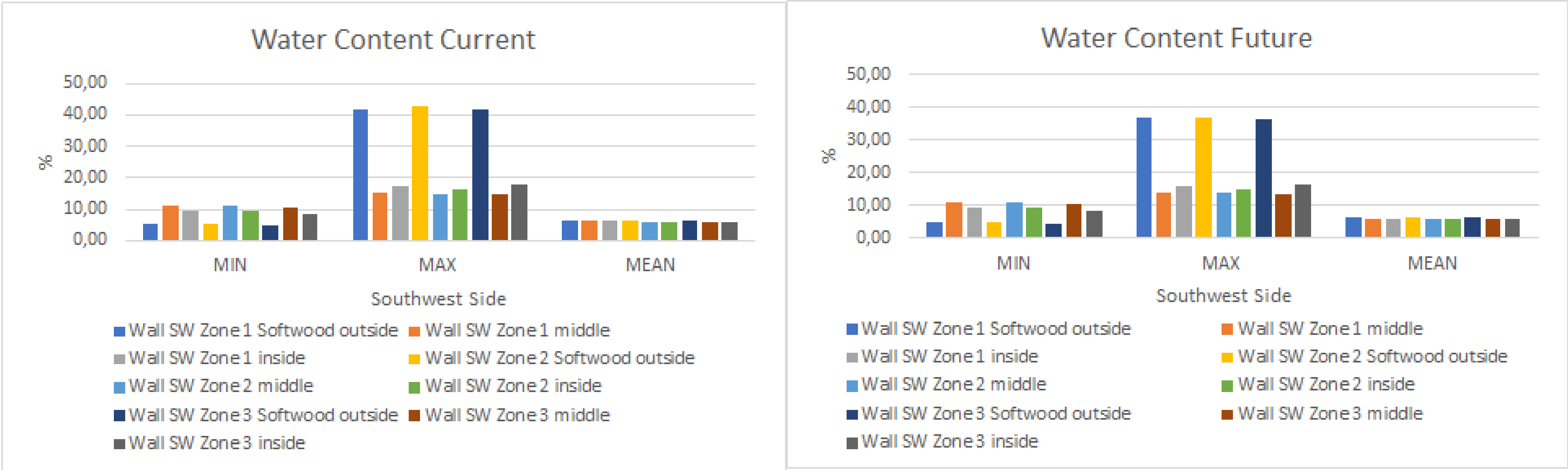


Figure 82. Moisture content in the Southwest wall

4.3.5. MOISTURE CONTENT

HEIERSTAD LOFT

In most graphs is the exterior layer significantly less stable than the other two layers. This is due to the fact that this specific layer is in direct contact with the outdoor climatic conditions, e.g. rain or solar radiation. In the graphs this is visualised with the minimum and maximum values. Also noticeable is that the wind direction of the exterior walls does not make a significant difference in the results. Looking at the graphs Fig.79., Fig.80., Fig.81., and Fig.82., the maximum and minimum values are almost identical. A general conclusion about all of these graphs is the difference in water content between the current climate and the future climate. The decrease of the water content in the future is mostly visible in the maximum value but is present in all the values. An exception to the previous statement are the “Green roofs”, visible in graphs Fig.85., Fig.86., and Fig.87. In these cases there is a reversed result, looking at the graphs, both the minimum and maximum values increase. This due to the difference in assembly between a green roof, which exist in this case out of grass and soil, and for instance a brick roof, which has no vegetation.

CURRENT (TYPICAL YEAR) | A2 SCENARIO (2100)

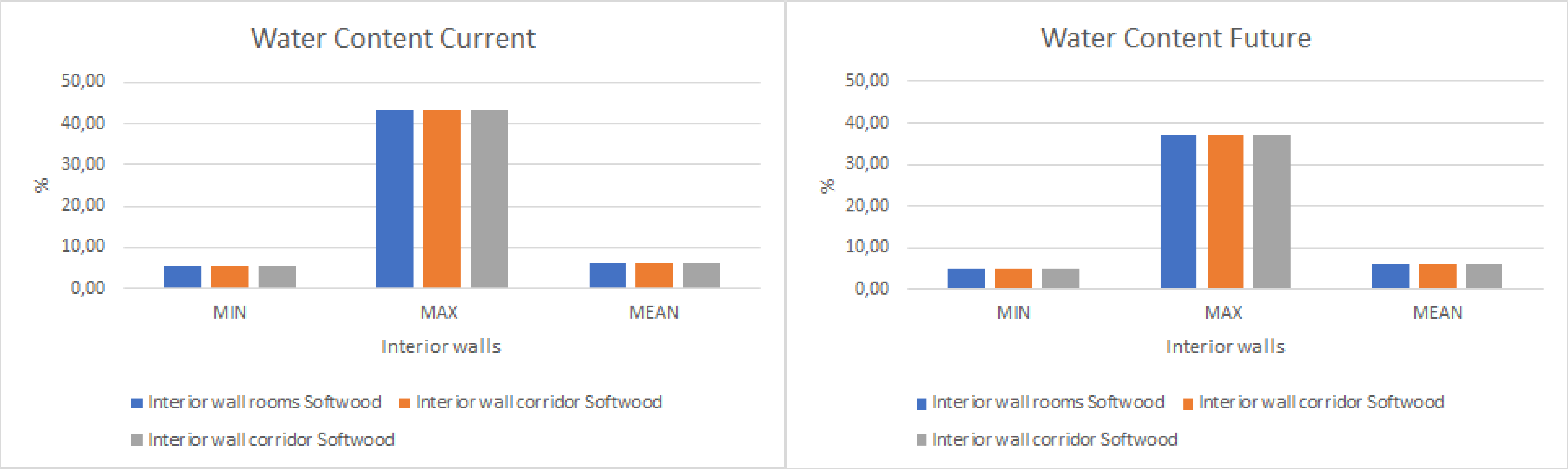


Figure 83. Moisture content in the interior walls

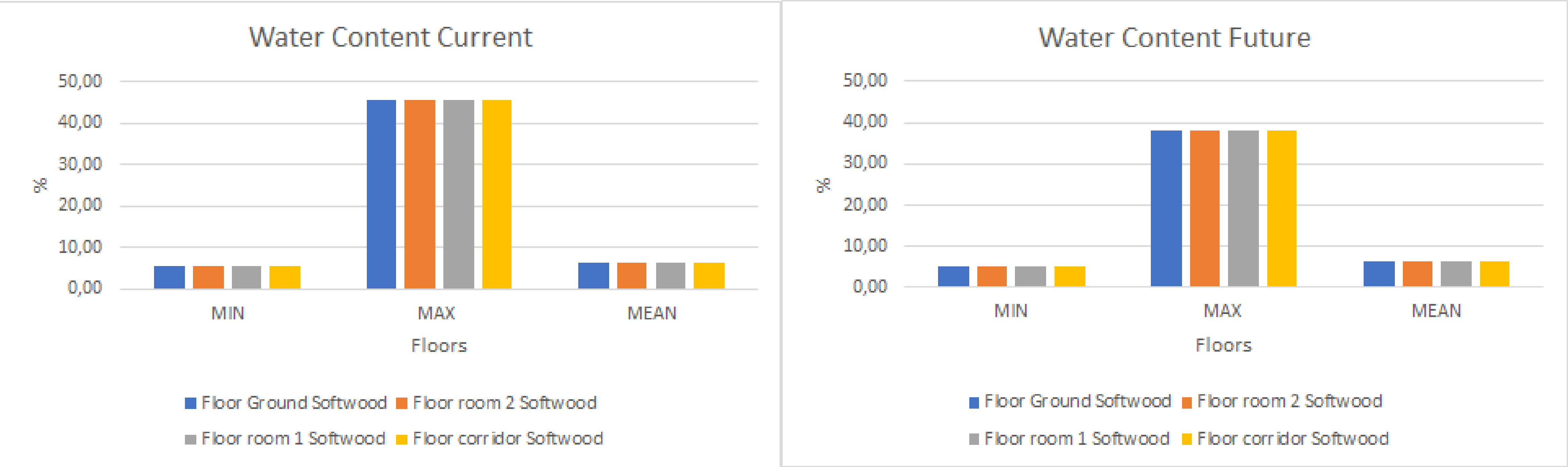


Figure 84. Moisture content in the floors

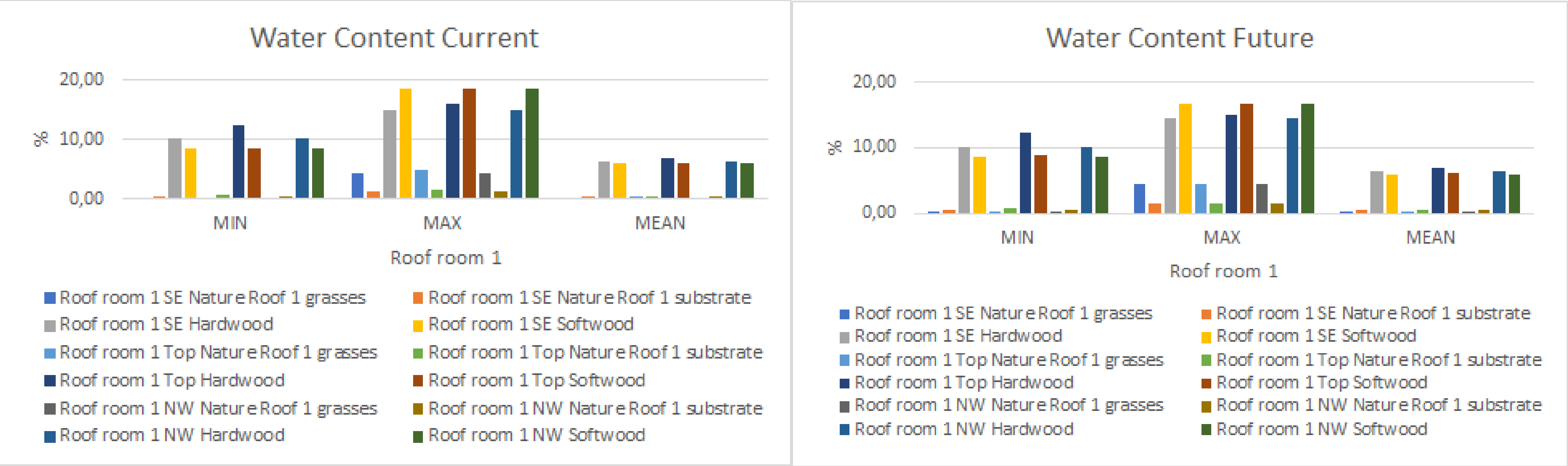


Figure 85. Moisture content in the room 1 of the roof

CURRENT (TYPICAL YEAR) | A2 SCENARIO (2100)

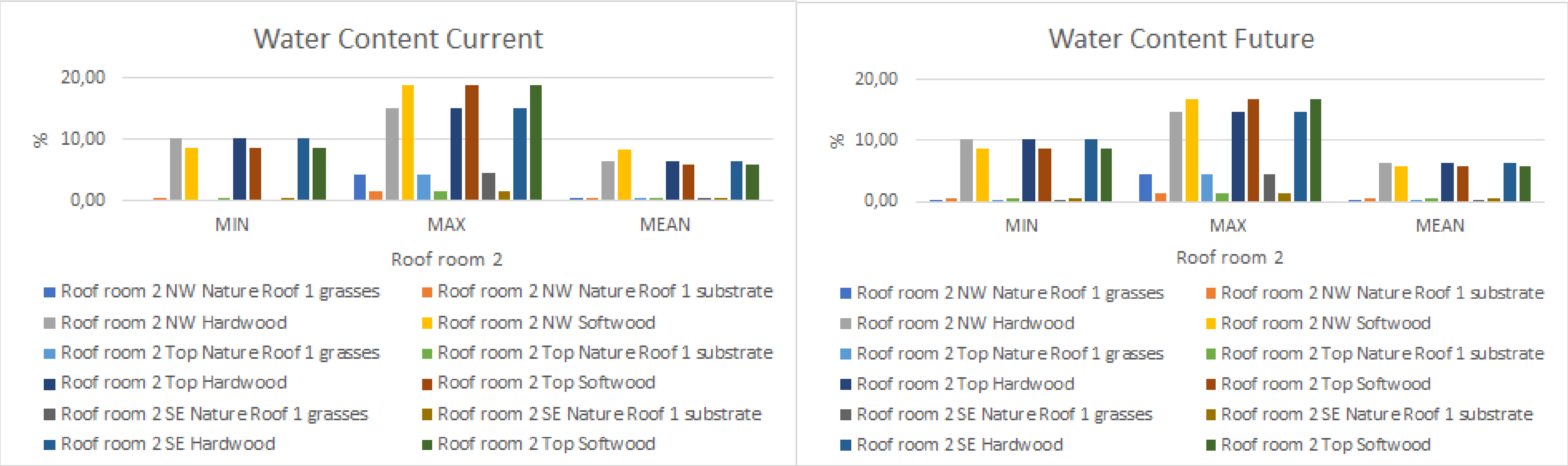


Figure 86. Moisture content in the room 2 of the roof

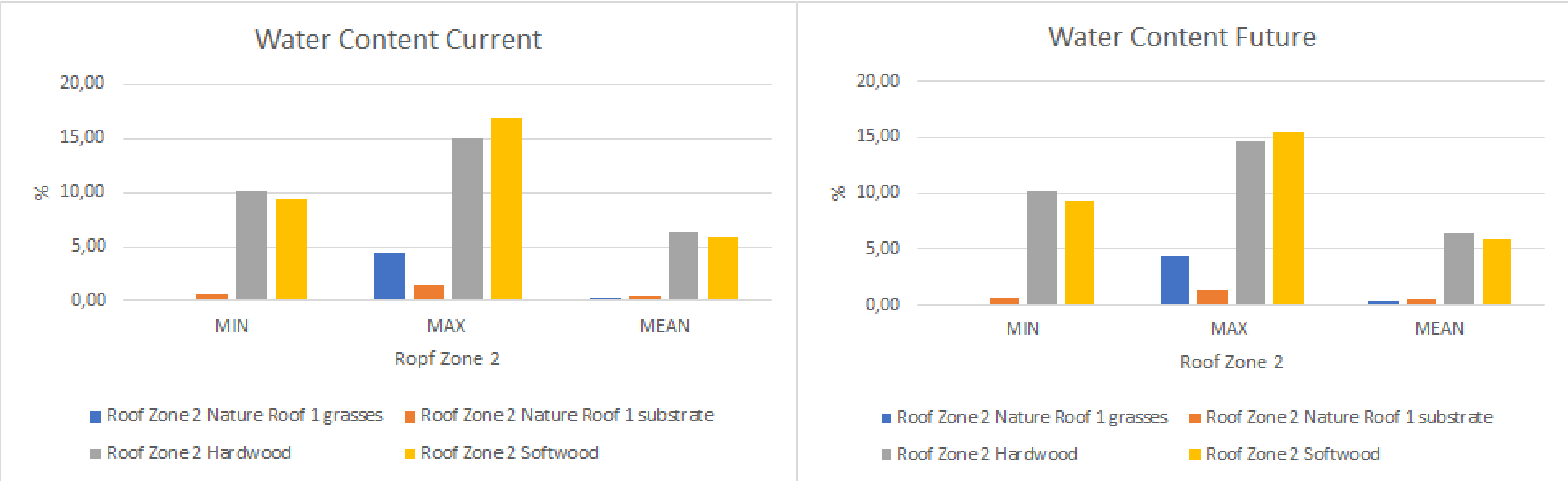


Figure 87. Moisture content in zone 2 of the roof

HEIERSTAD LOFT

CURRENT
(TYPICAL YEAR)

A2 SCENARIO
(2100)

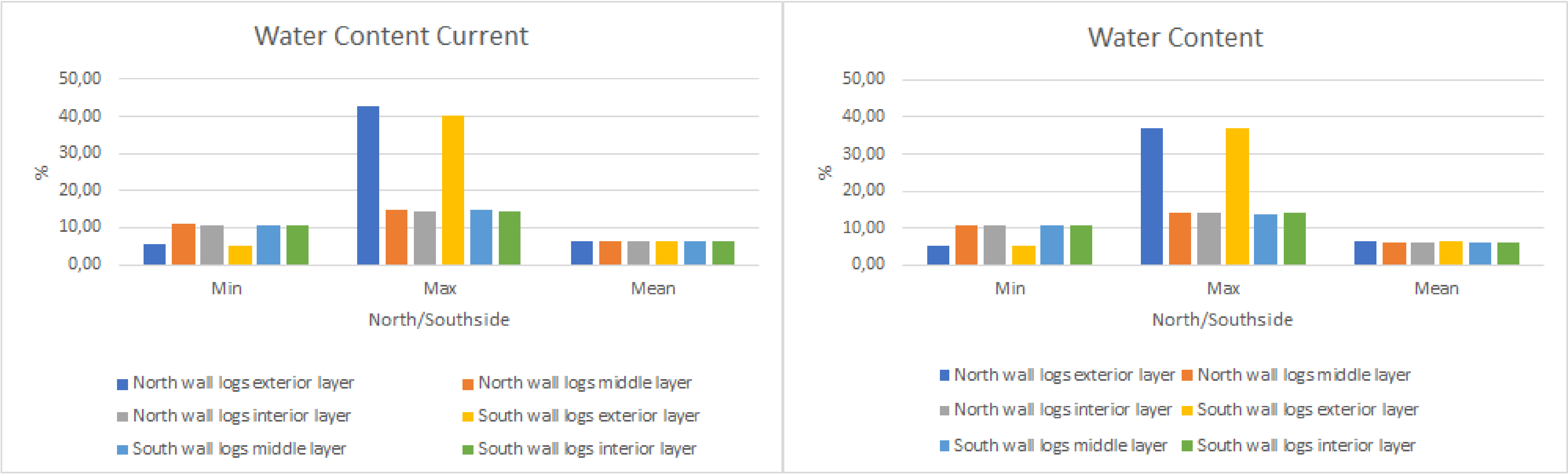


Figure 88. Moisture content in the North and South walls

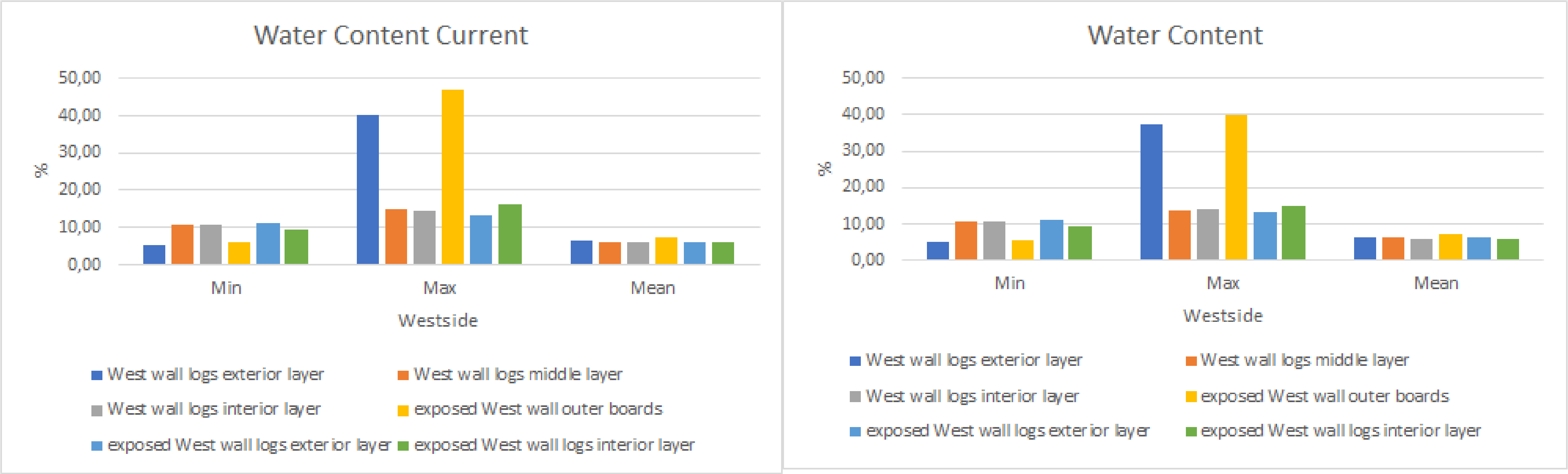


Figure 89. Moisture content in the West walls

FADUM STOREHOUSE

The Northern and Eastern wall have a slightly higher maximum value of water content than the Southern and Western wall (Fig.88., Fig.89., Fig.90.). Additionally consist the exposed vertical walls (Fig.89. and Fig.90.) of more water content than the exterior walls of zone 1. This can be explained by the fact that the walls of zone 1 are covered by the slanted roofs, which gives the exterior walls protection from solar radiation and rain. The same situation, where the exterior layers are less stable, as in Heierstad Loft, occurs also in the Fadum Storehouse. In addition, the maxima and minima of moisture content in the exterior layer is higher and lower respectively compared to the other two layers. The phenomenon that the water content decreases significantly in the future appears also in all the graphs of the Fadum Storehouse.

CURRENT
(TYPICAL YEAR)

A2 SCENARIO
(2100)

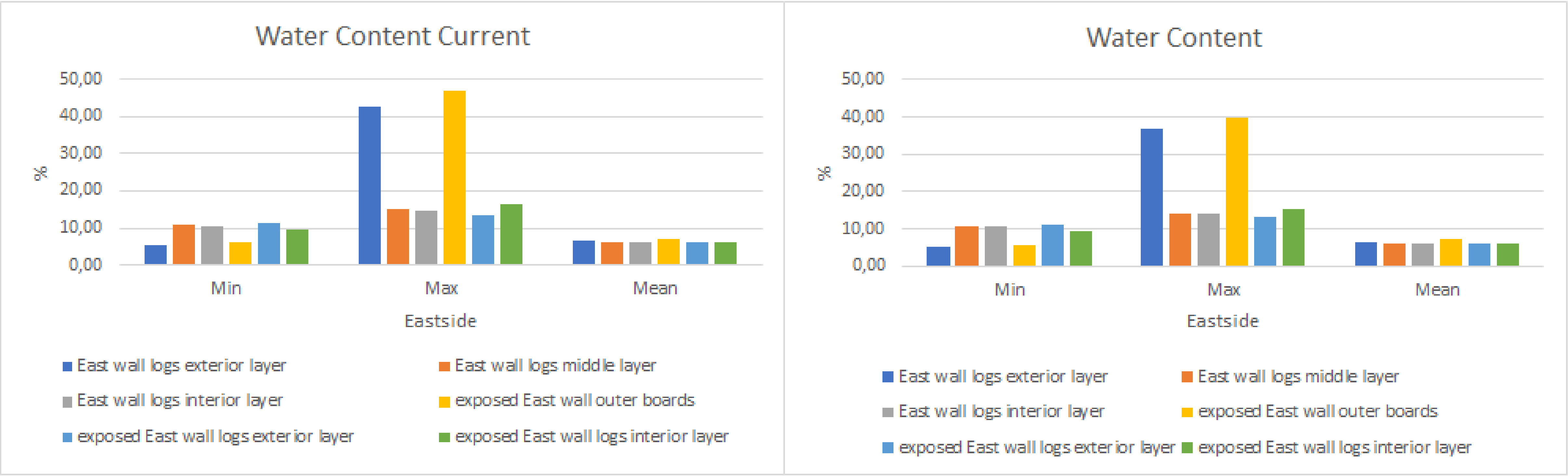


Figure 90. Moisture content in the east walls

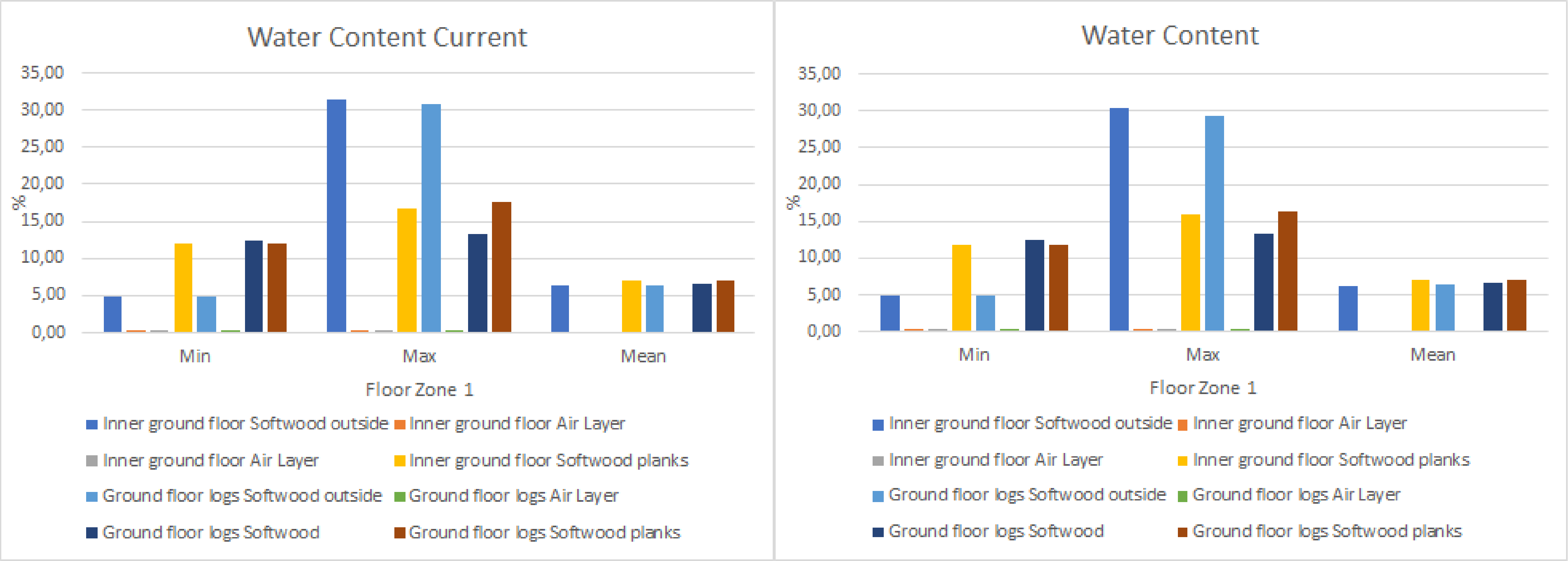


Figure 91. Moisture content in zone 1 of the floor

CURRENT
(TYPICAL YEAR)

A2 SCENARIO
(2100)

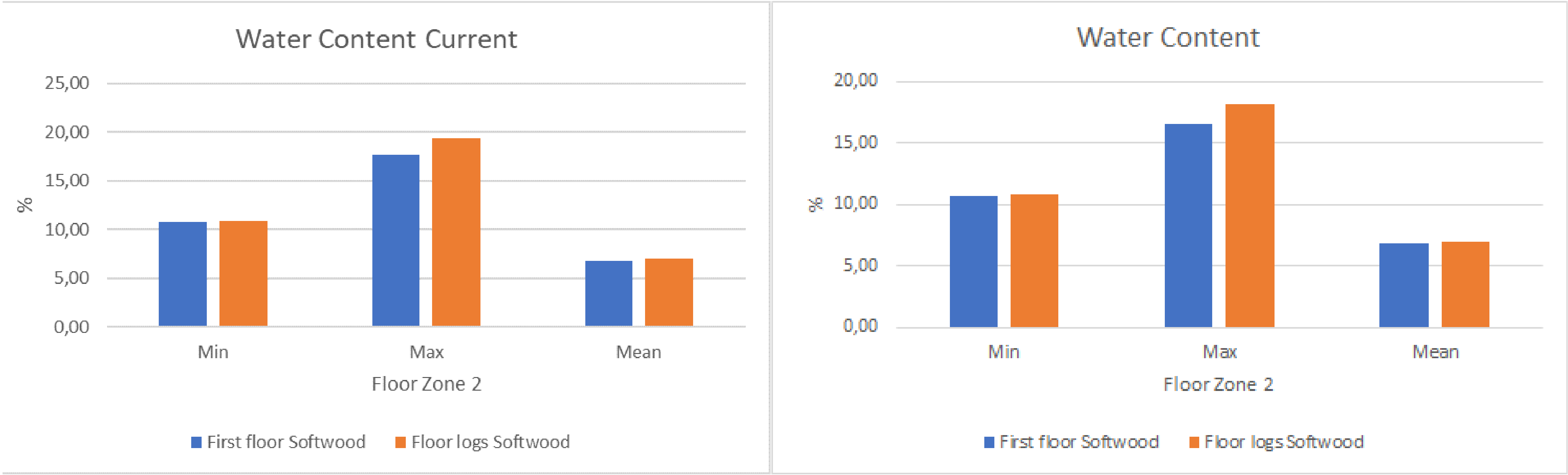


Figure 92. Moisture content in zone 2 of the floor

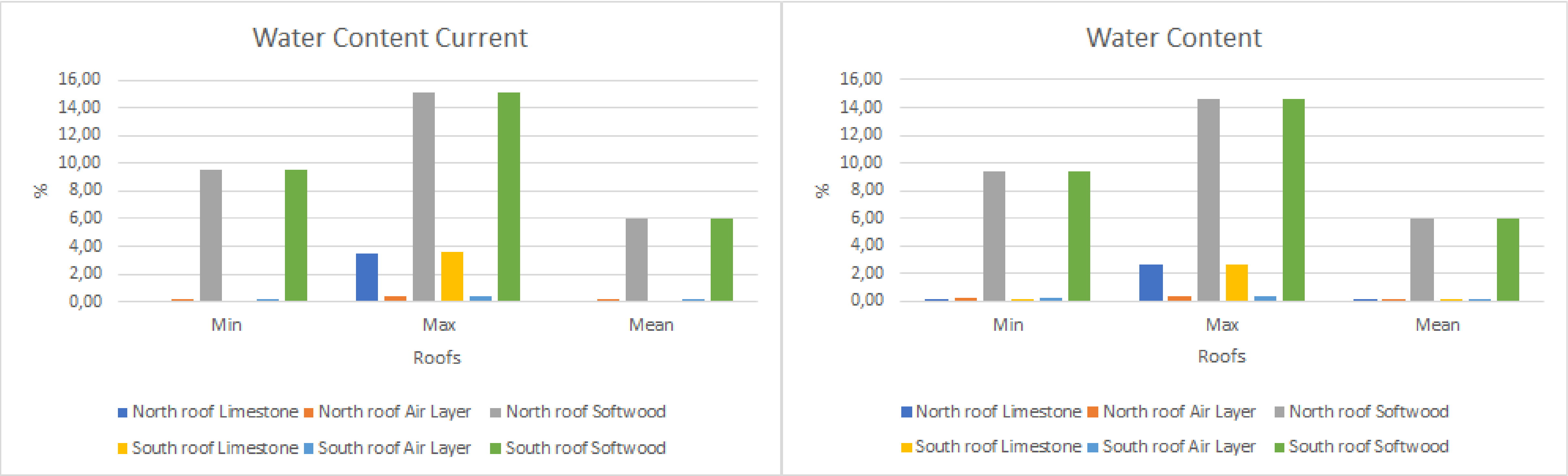


Figure 93. Moisture content in the roofs

FADUM STOREHOUSE

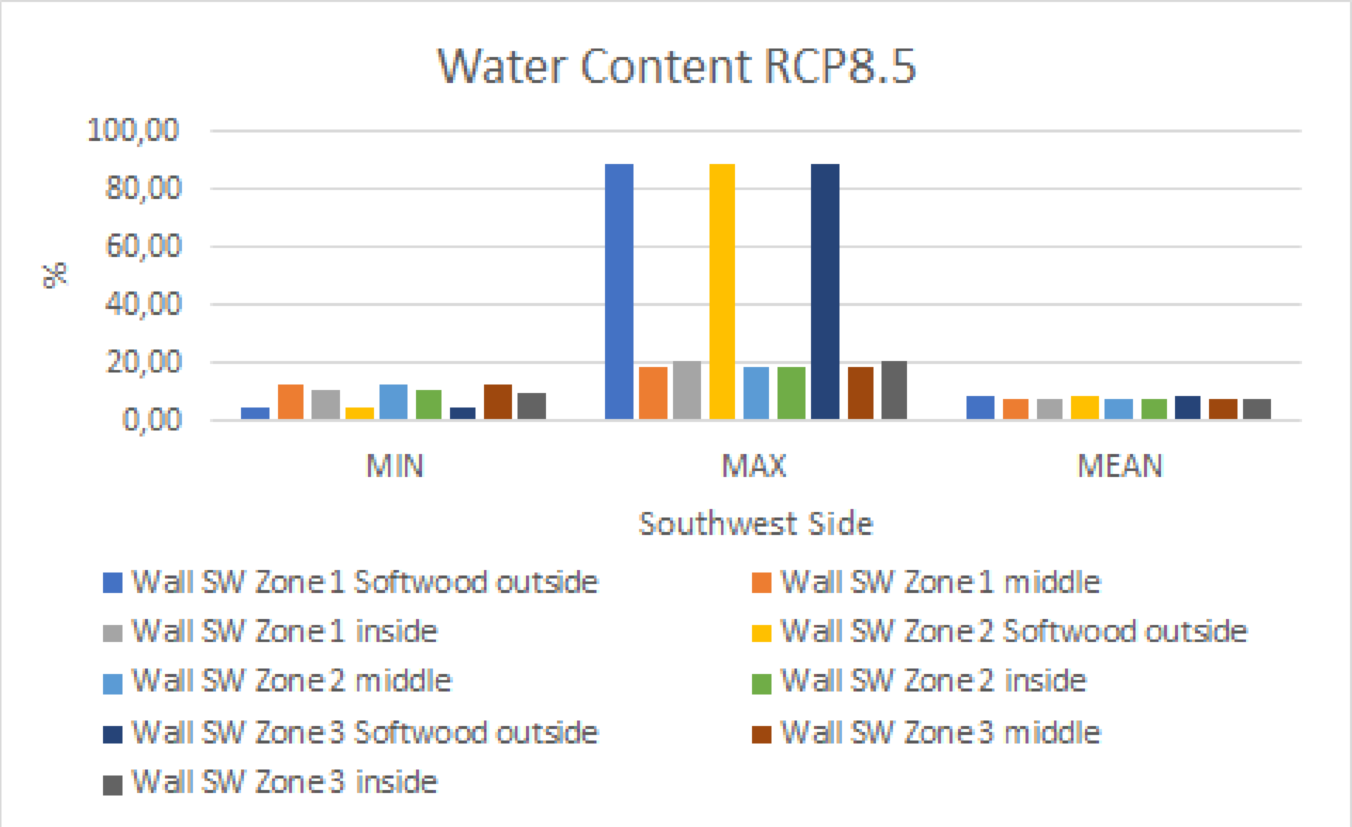


Figure 94. Moisture content in the SouthWest wall

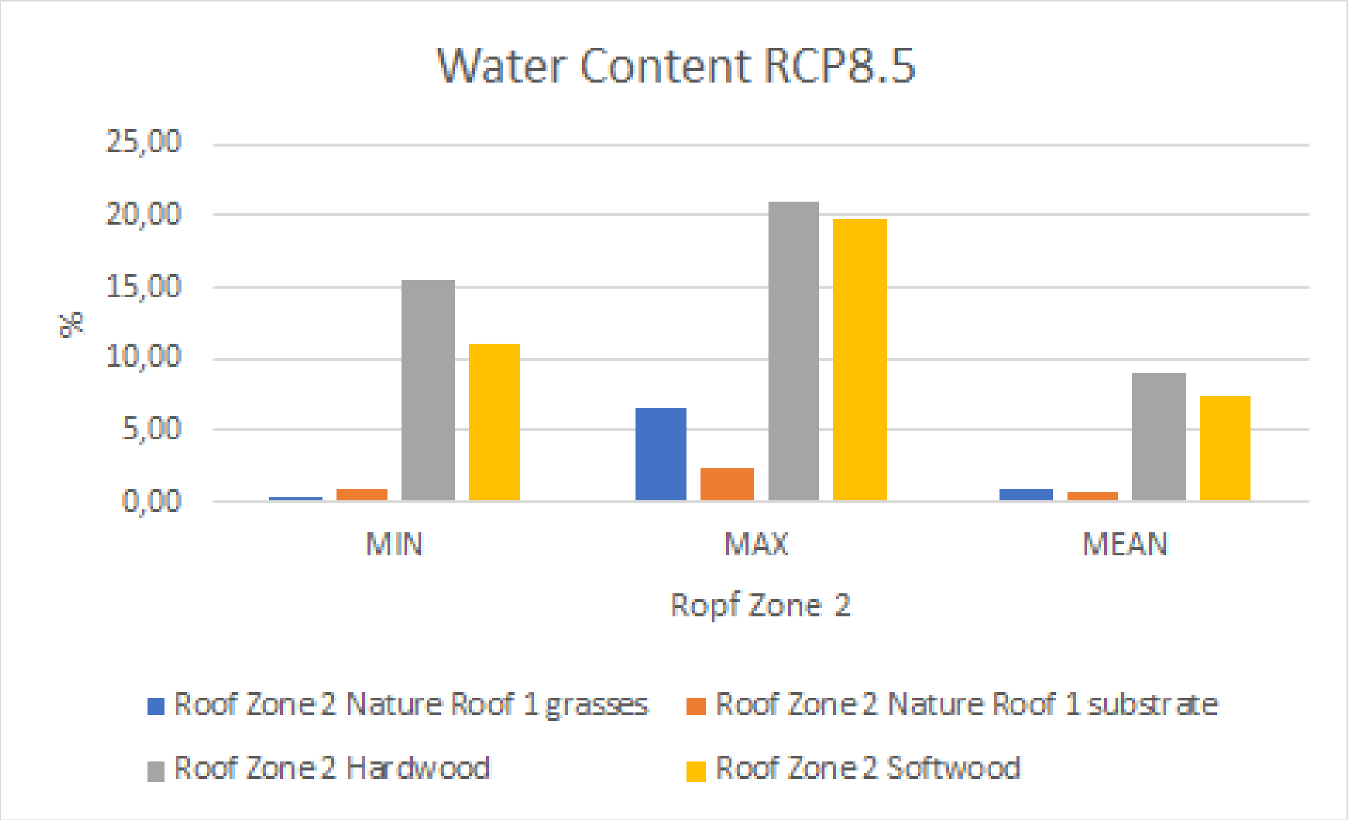


Figure 96. Moisture content in zone 2 of the roof

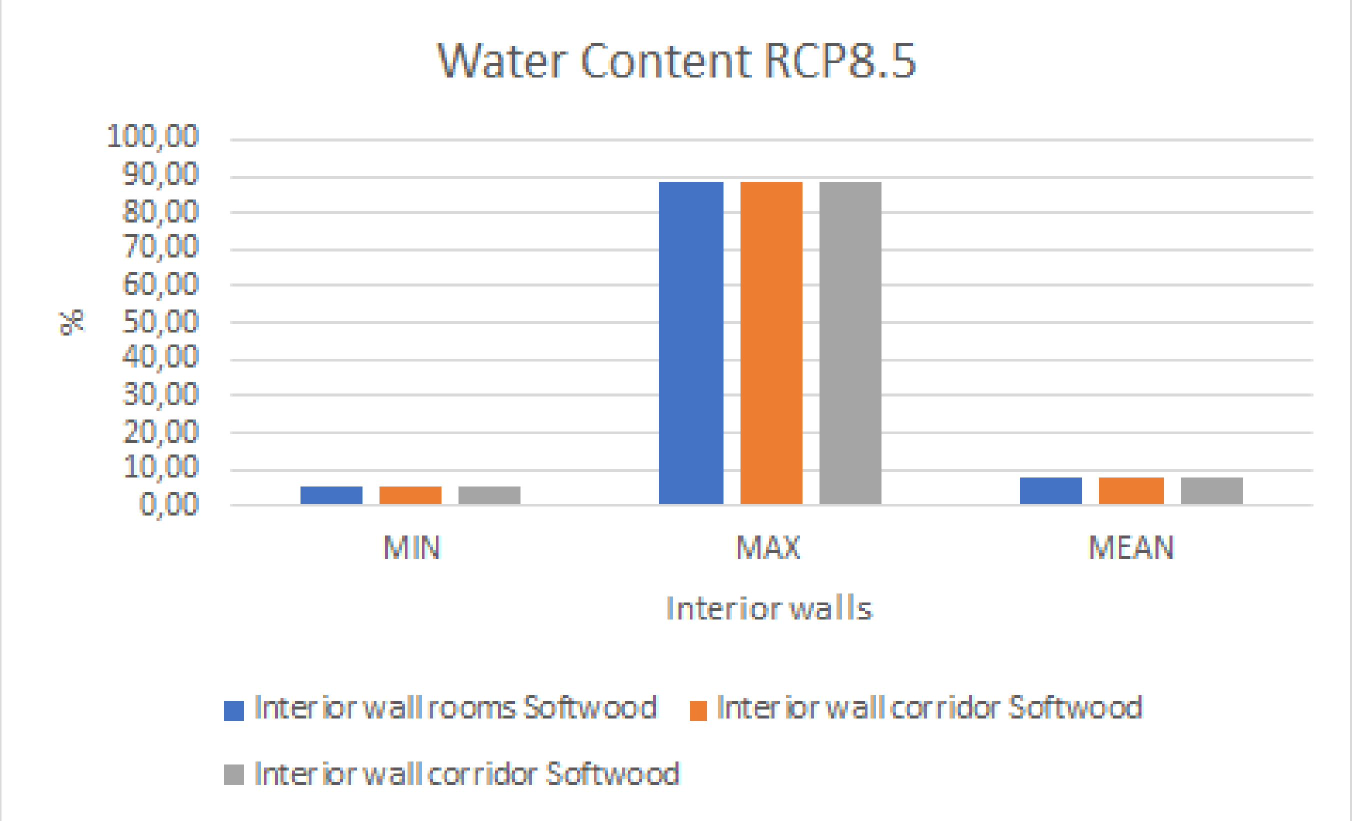


Figure 95. Moisture content in the internal walls

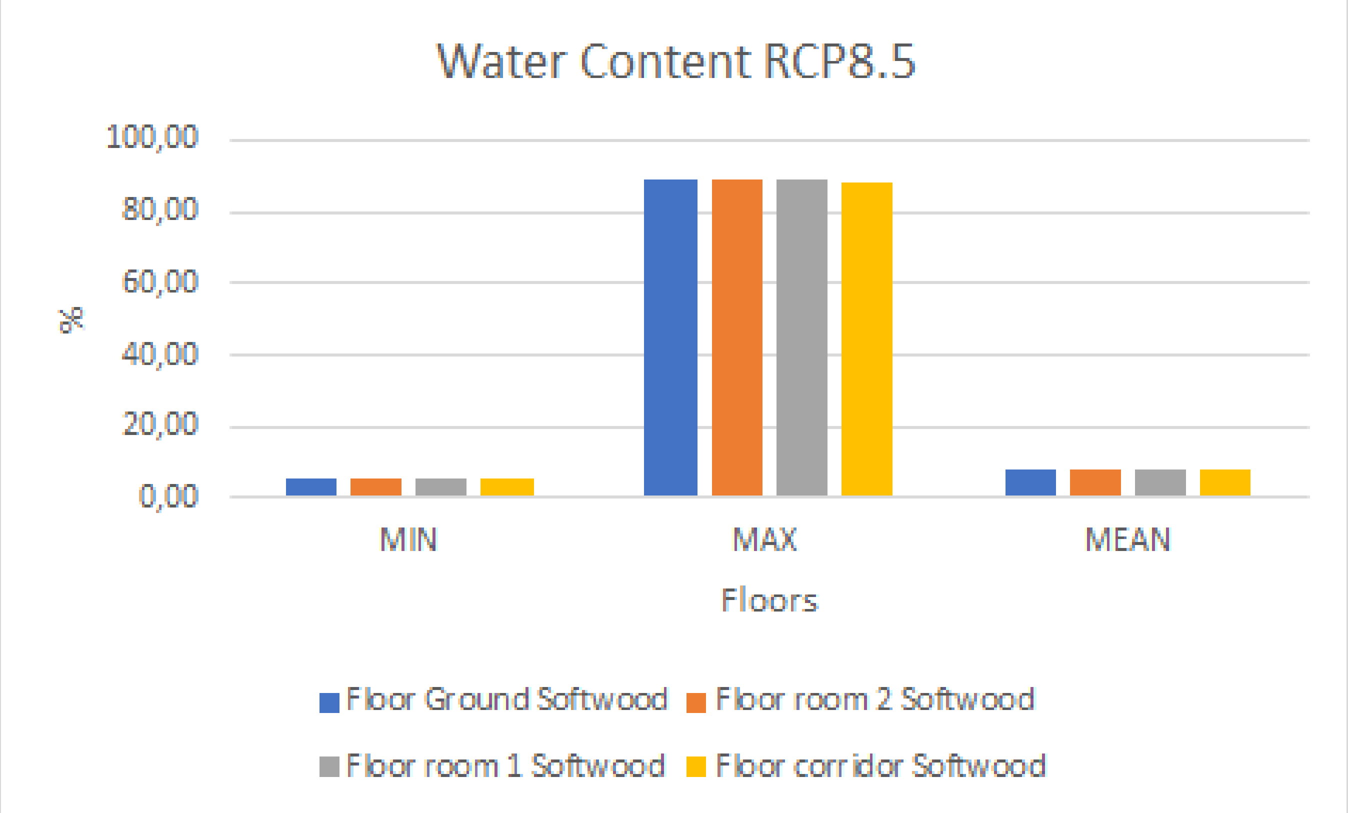


Figure 97. Moisture content in the floors

4.3.6. MOISTURE CONTENT RCP8.5 SCENARIO

HEIERSTAD LOFT

The wind direction has no major impact on the results. Figure. 94. shows the results for one side of the outer walls of the Heierstad Loft. Results for the outer walls are mostly the same. It is noticeable that the exterior layer is less stable than the inner layers. This is due to the fact that the exterior layer is directly affected by the outer conditions. Remarkable is the maximum value of the exterior layer. It goes towards 90%. Compared to the results of the A2 scenario, this is of double the size. The minimum and mean value however, are similar for all three simulations. Surprisingly is the maximum value of the interior walls. They do not stand under the influence of the outer conditions and yet they also have very high water content up to 90%.

The same counts for the floors of the building as shown in Figure 97. When it comes to the roofs, the Figure. 96. is representative as the results for the roofs are very similar, it is to mention that the results for the roofs are just slightly higher than from the results of the current situation and the A2 scenario. More graphs for the other components can be found in appendices.

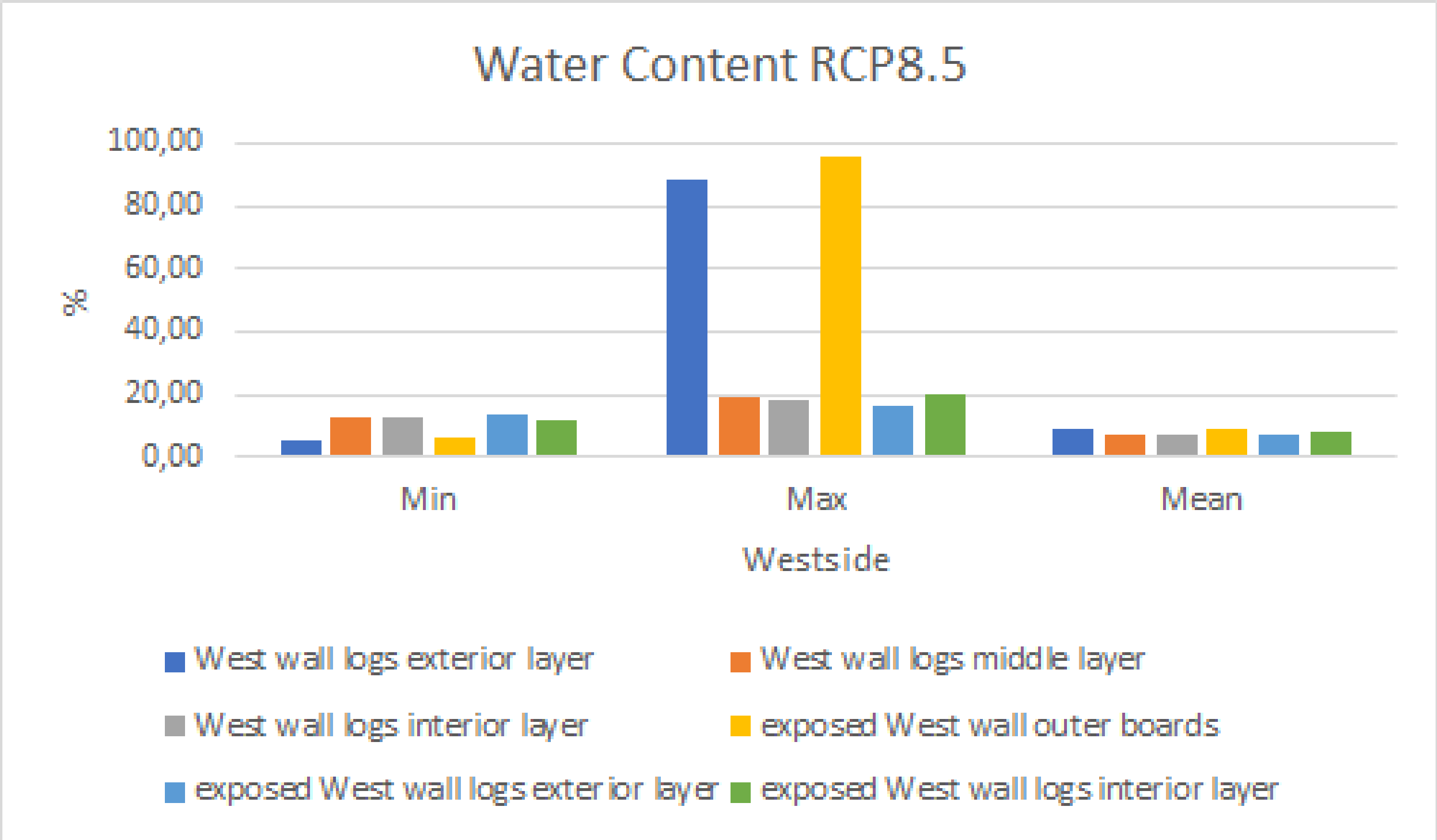


Figure 98. Moisture content in the West wall

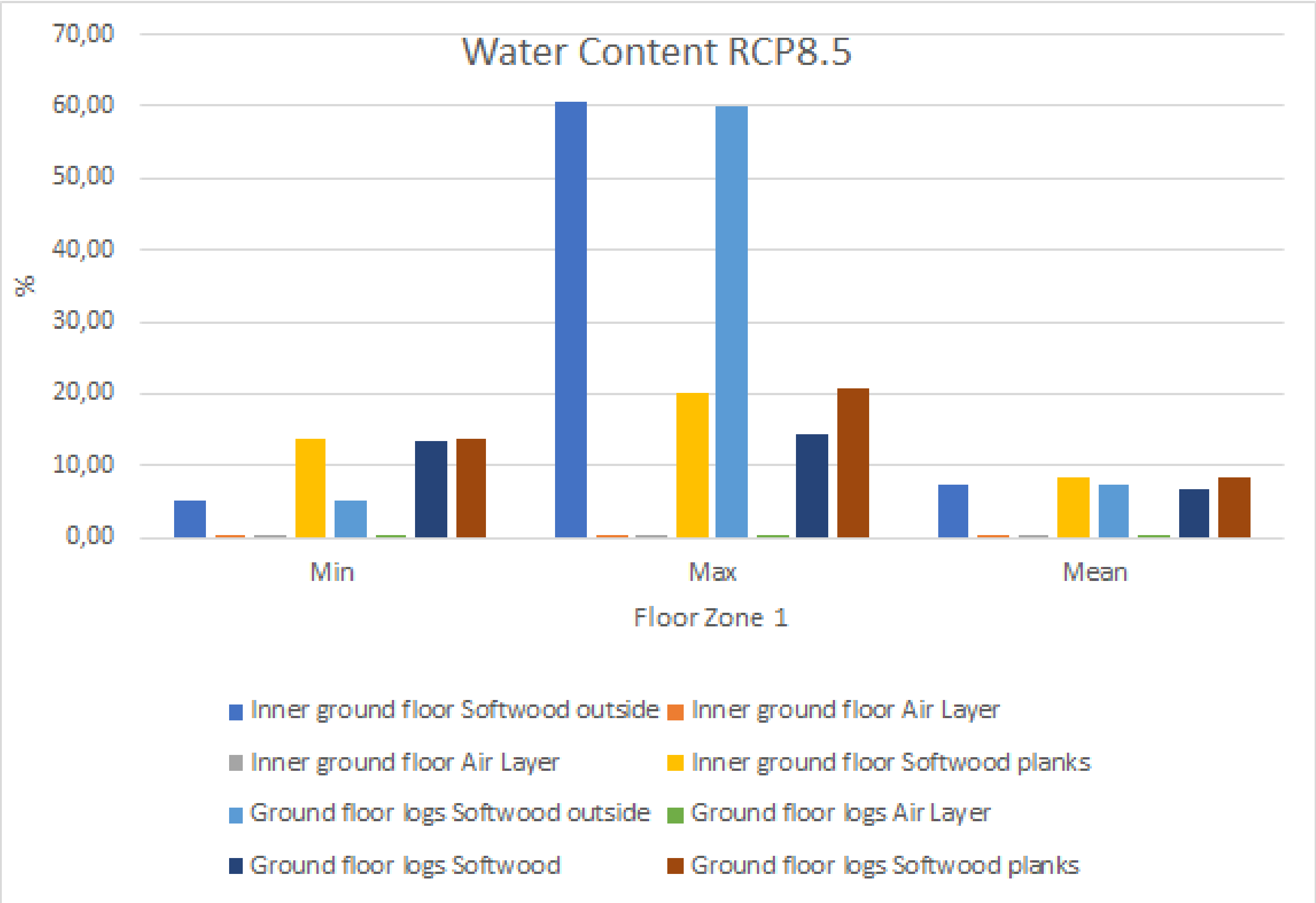


Figure 100. Moisture content in zone 1 of the floors

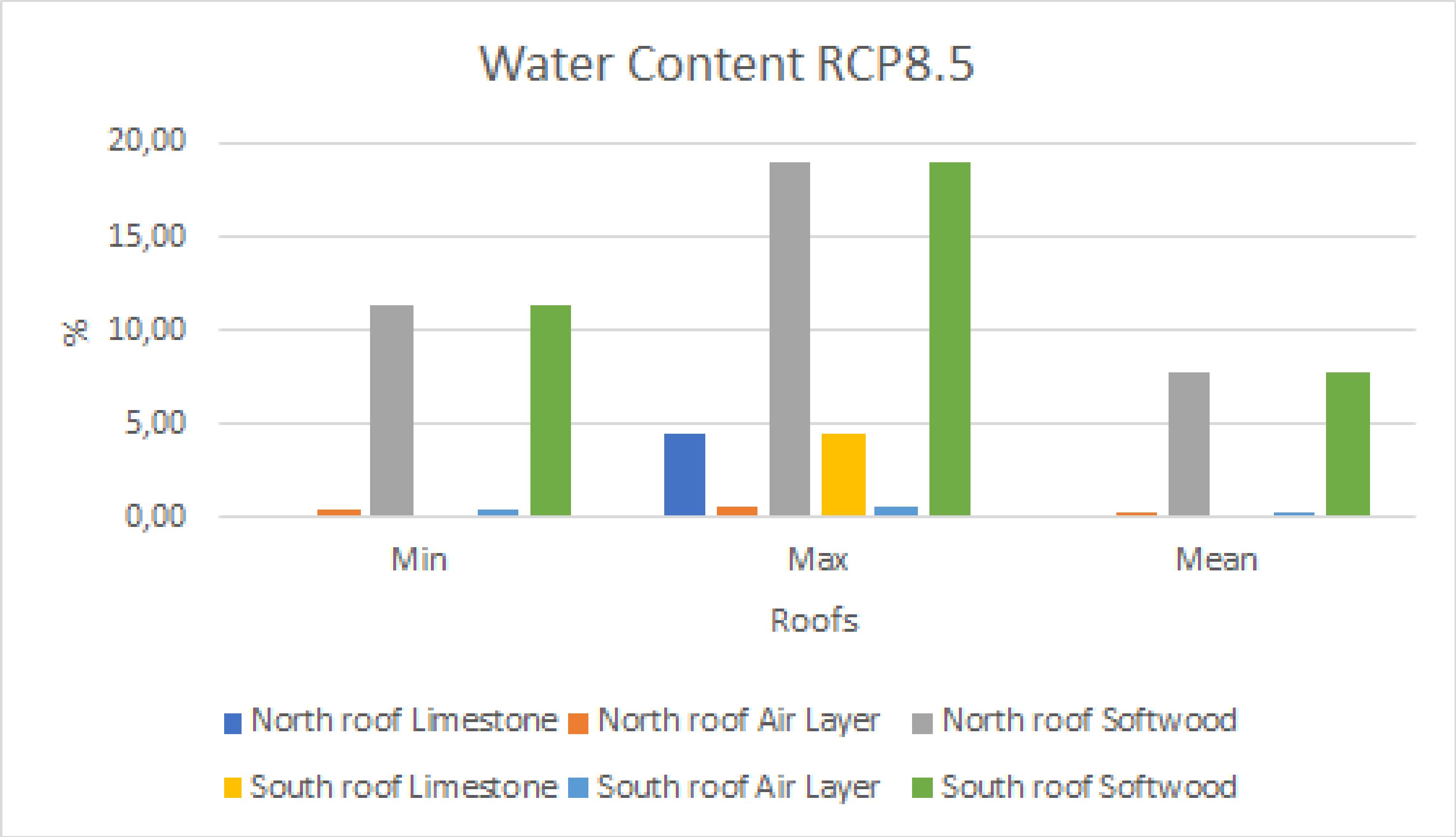


Figure 99. Moisture content in the roofs

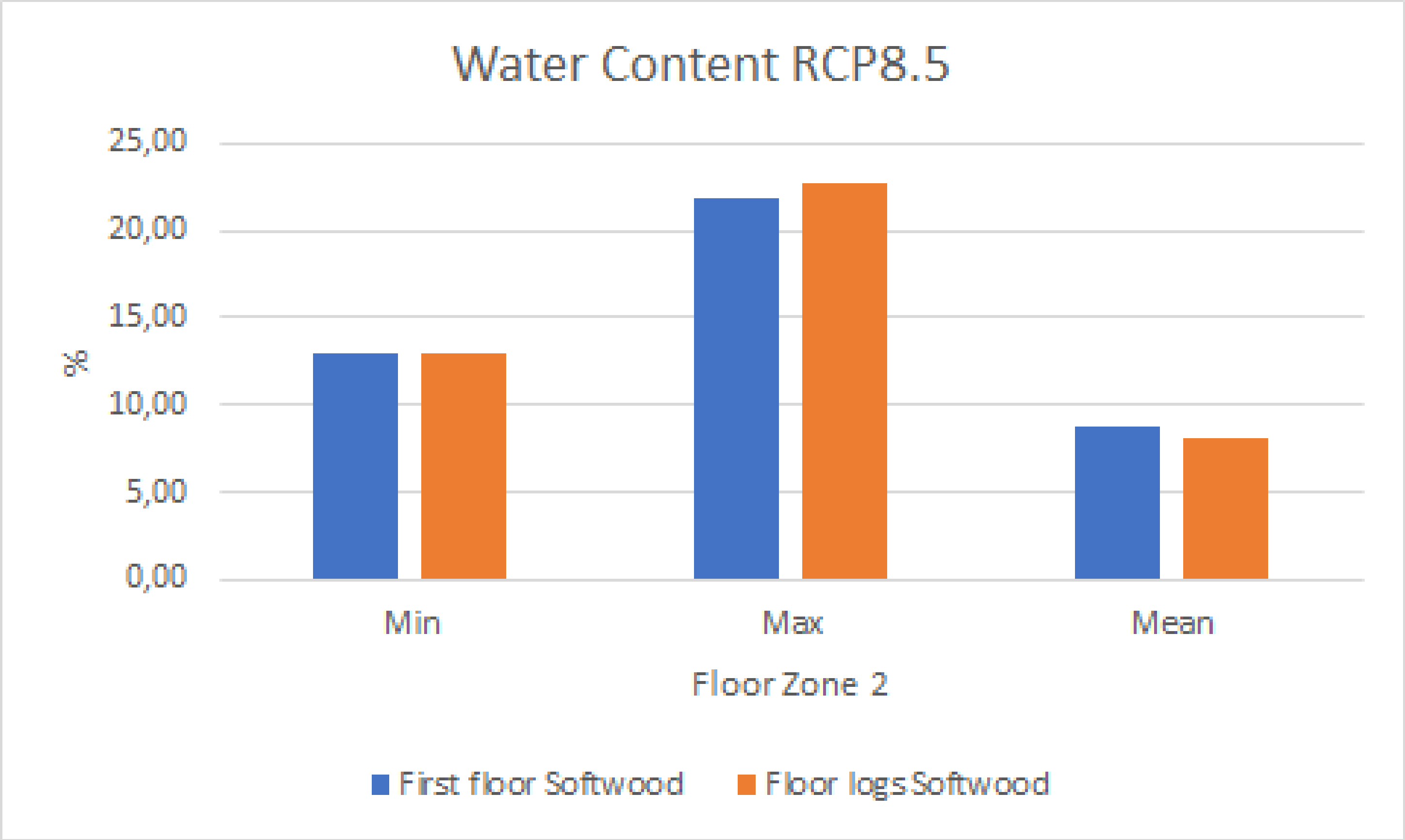


Figure 101. Moisture content in zone 2 of the floor

FADUM STOREHOUSE

As in the Heierstad Loft, the exterior layer of the outer walls in the Fadum Storehouse is less stable than the inner layers. The maximum water content goes up to 90% for all sides of the building. Exceptions are the exposed parts of the westside and eastside walls which are not protected by the slanted roof. Their values even go up to 95%. As for the Heierstad Loft, the results for the roofs are just slightly higher than the previous results.

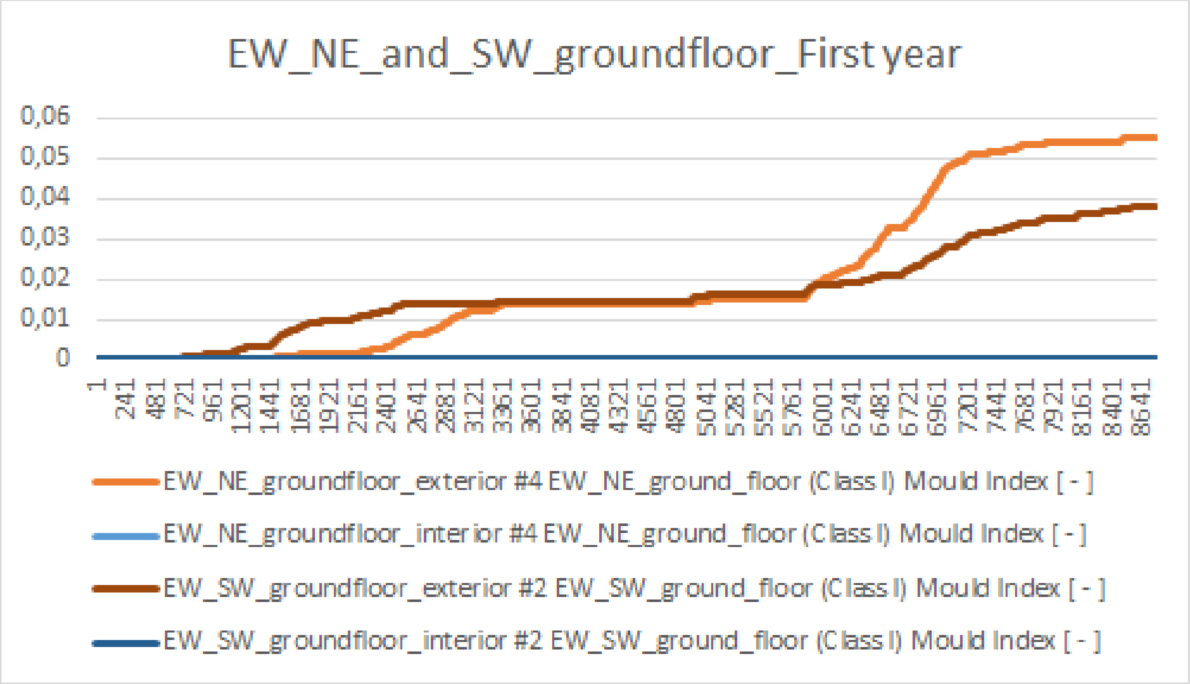
Except the outer parts of the ground floor, both ground and first floor have same maximum values of moisture content around 20%. However, the maximum values of the outer parts are 60%. That is double the amount than it is in the results for the current situation and the A2 scenario. More graphs are in appendices.

4.4. WUFI BIO RESULTS

In the following graphs, it is shown the mould index values extracted in WUFI bio, the software that helps to analyze mould risk. As shown previously in other graphs, it is compared to the current climate situation with the future scenario. The maximum number possible for mould index is 6 and the minimum is 0, so the values will be always between 0 and 6. The factors that affect the capacity of the components to have a higher or a lower mould index values are temperature, time, relative humidity and the typology of the assembly considered.

CURRENT (TYPICAL YEAR)

RCP8.5 SCENARIO (2100)



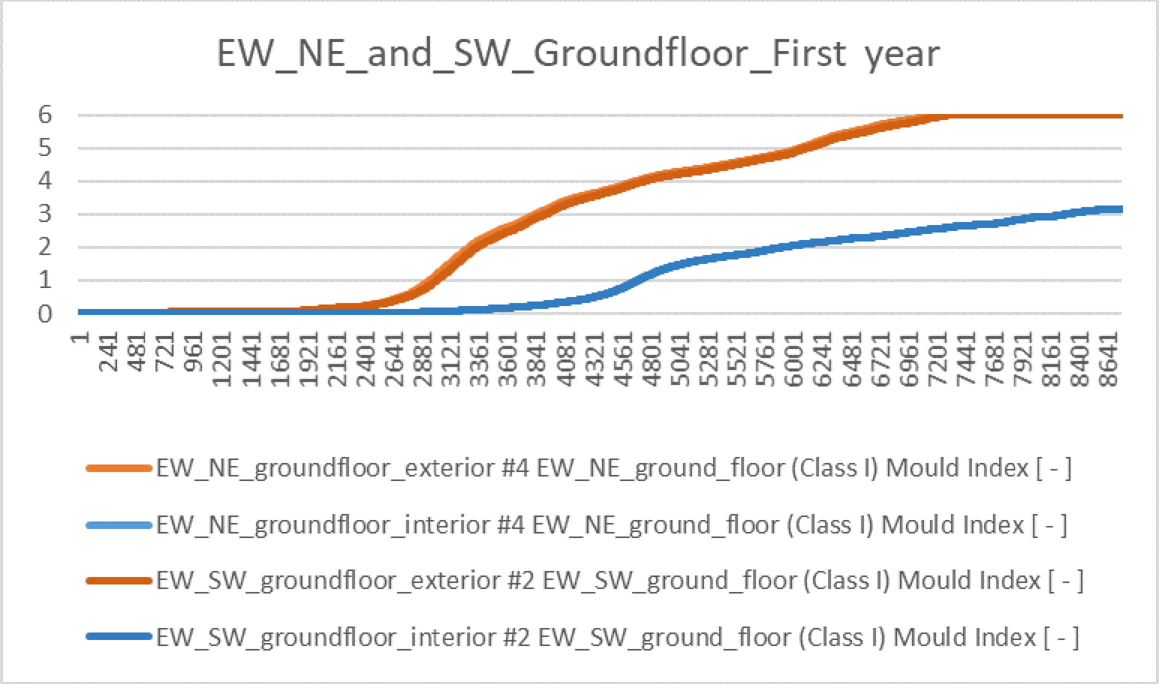
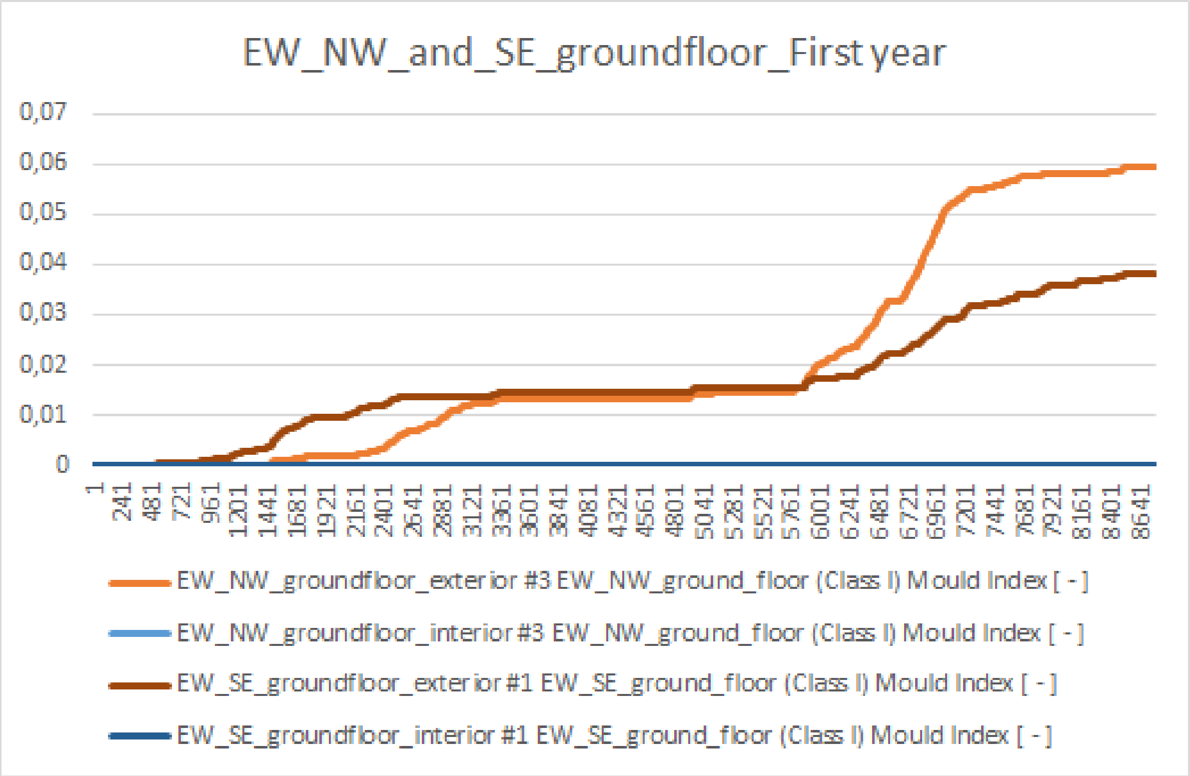


Figure 102. Mold index of the Northeastern and Southwestern wall on the groundfloor.



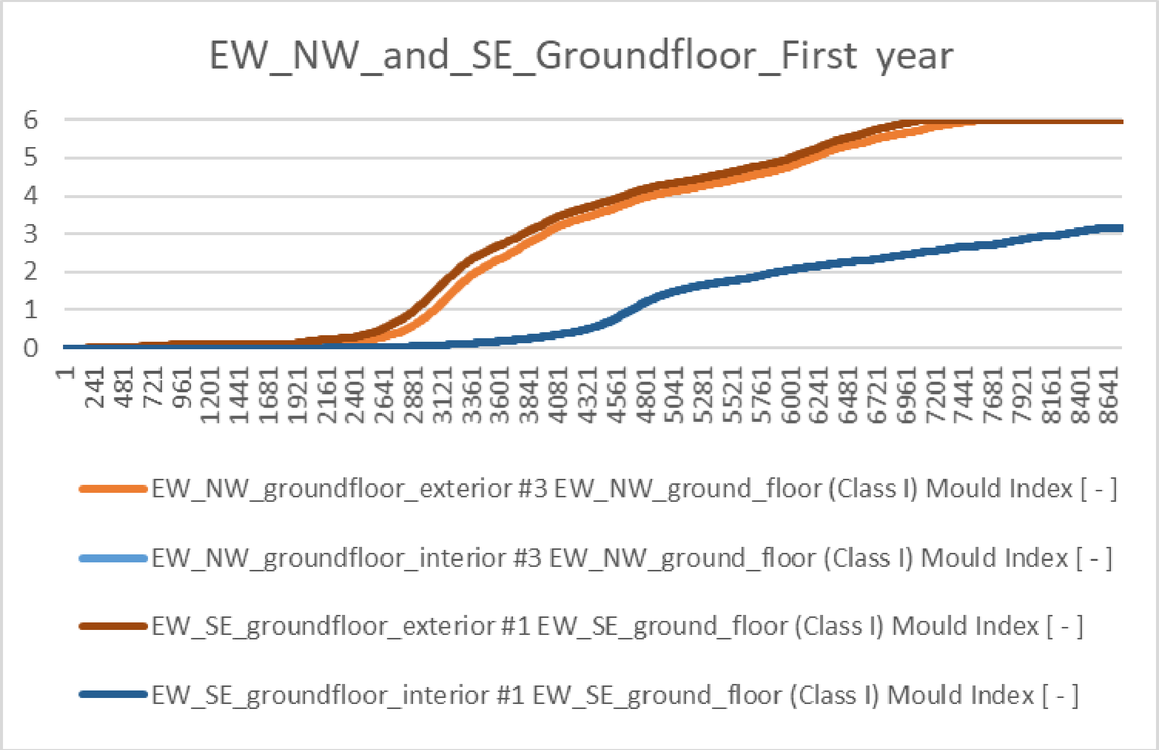
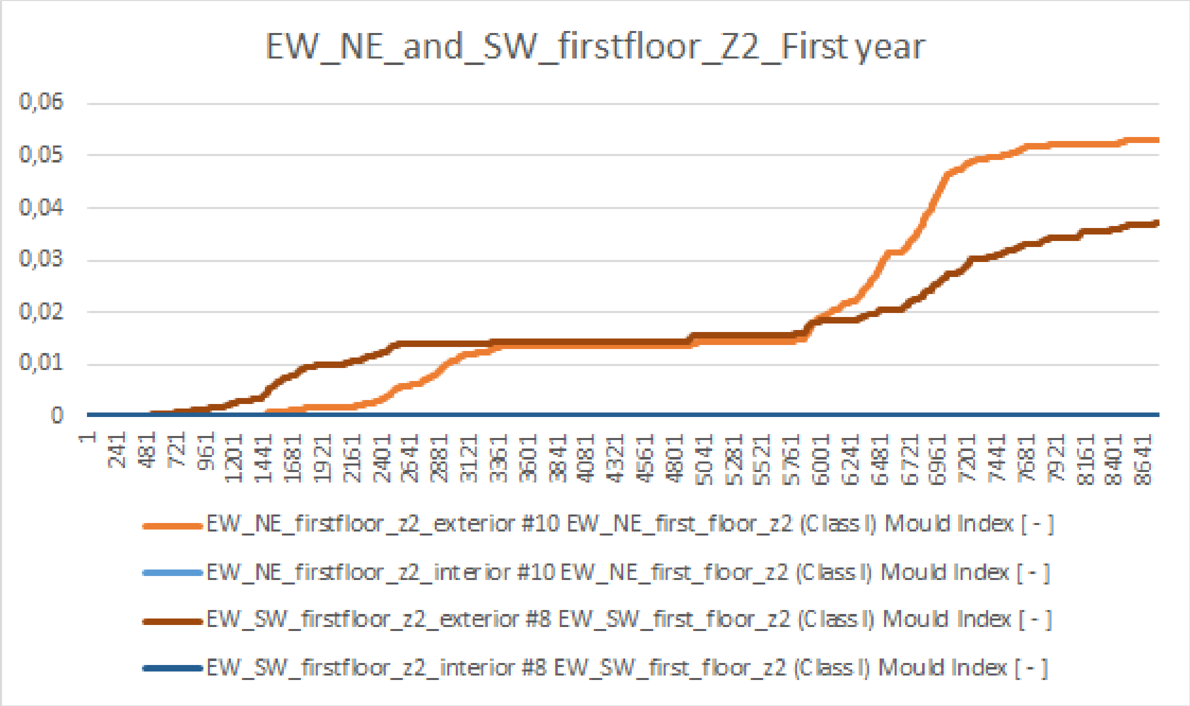


Figure 103. Mold index of the Northwestern and Southeastern wall on the groundfloor.



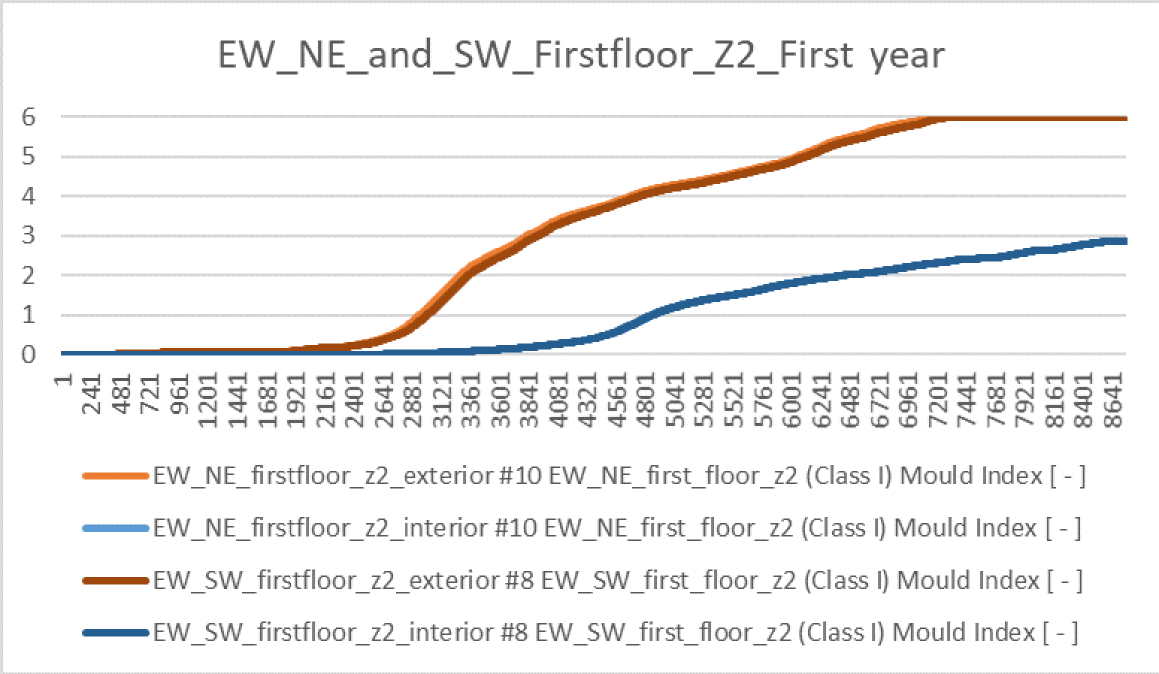


Figure 104. Mold index of the Northeastern and Southwestern wall in zone 2.

HEIERSTAD LOFT

The majority of the graphs do not show significant mold growth, the exceptions are the roofs and the ground floor (Fig. 108. and Fig.109). In all graphs an equilibrium will be reached after approximately the first typical year of simulation. The external walls (Fig.102-106) of the Heierstad Loft are fully exposed to the outdoor climate. The mould index in these walls is very low because the mold can dry out due to the solar radiation and wind. Previous research mentioned that temperature and relative humidity are significant variables, while rain is not. The internal walls (Fig.107) have zero mold index, this can be explained by the fact that these walls are protected from the outside. The maximum mold index of the ground floor (Fig.108.) is 2,8 , which is due to the fact that the exterior side of the ground floor is not affected by solar radiation and wind, which could contribute to the drying of the construction. The highest values of mould index can be found in the green roofs (Fig.109.), which can be explained by the presence of the grass and earth. After the implementation of the new future climate file, a significant rise in the mold index is noticeable. The mold index is critical in all the results of the future file. This increase is due to the the change in climate, which consits of more relative humidity and a higher temperature for Norway.

CURRENT (TYPICAL YEAR) | RCP8.5 SCENARIO (2100) | CURRENT (TYPICAL YEAR) | RCP8.5 SCENARIO (2100)

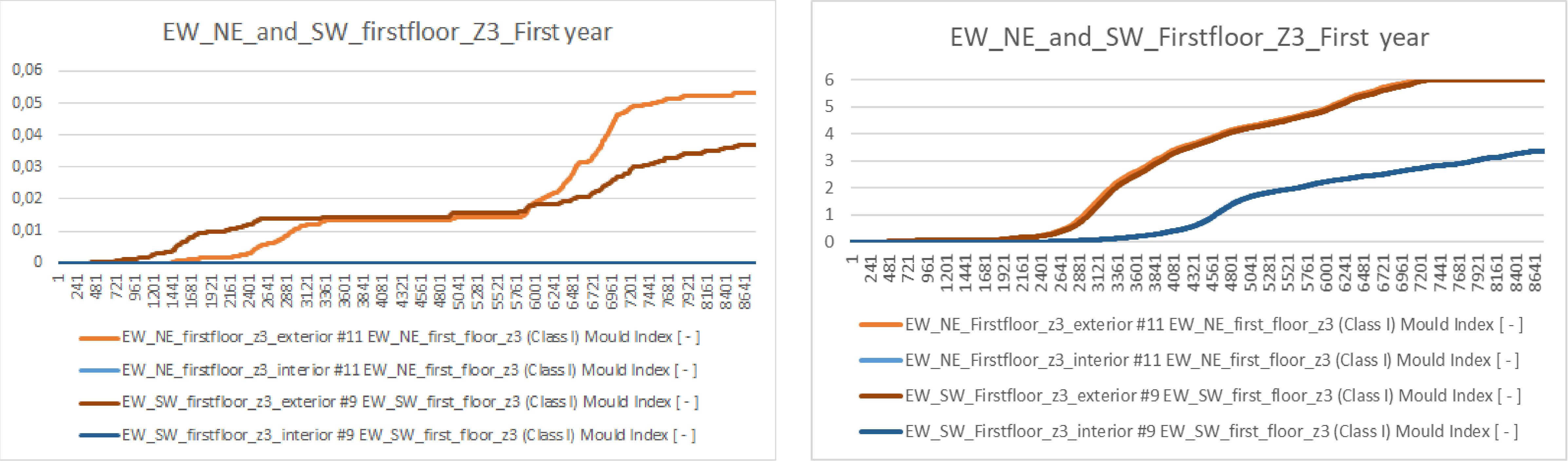


Figure 105. Mold index of the Northeastern and Southwestern wall in zone 3.

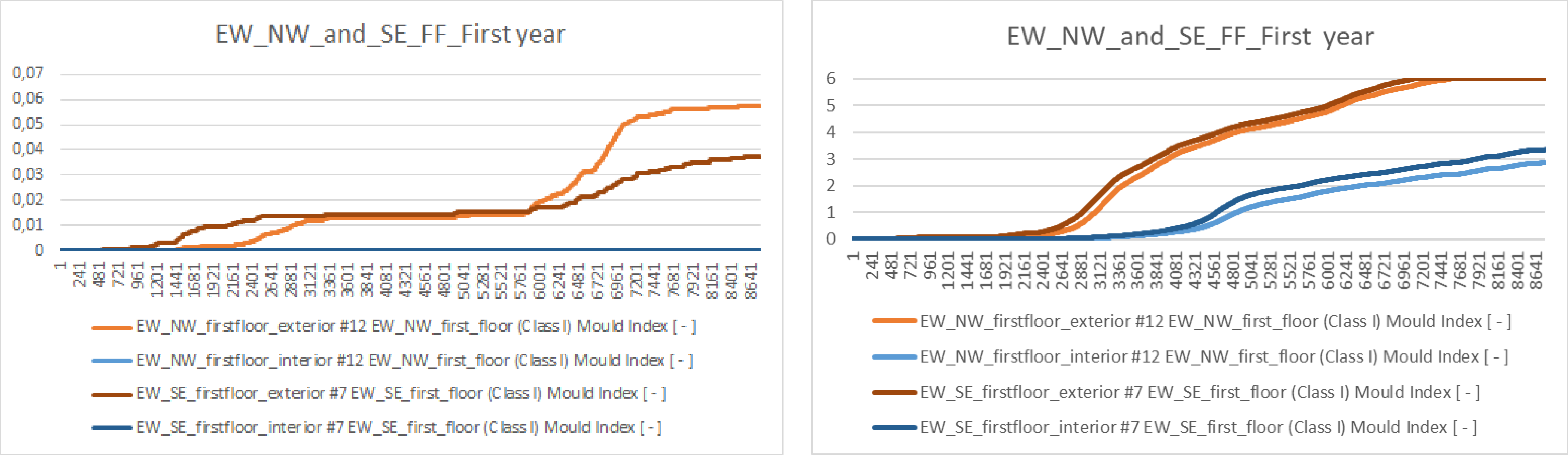


Figure 106. Mold index of the Northwestern and Southeastern wall of the firstfloor.

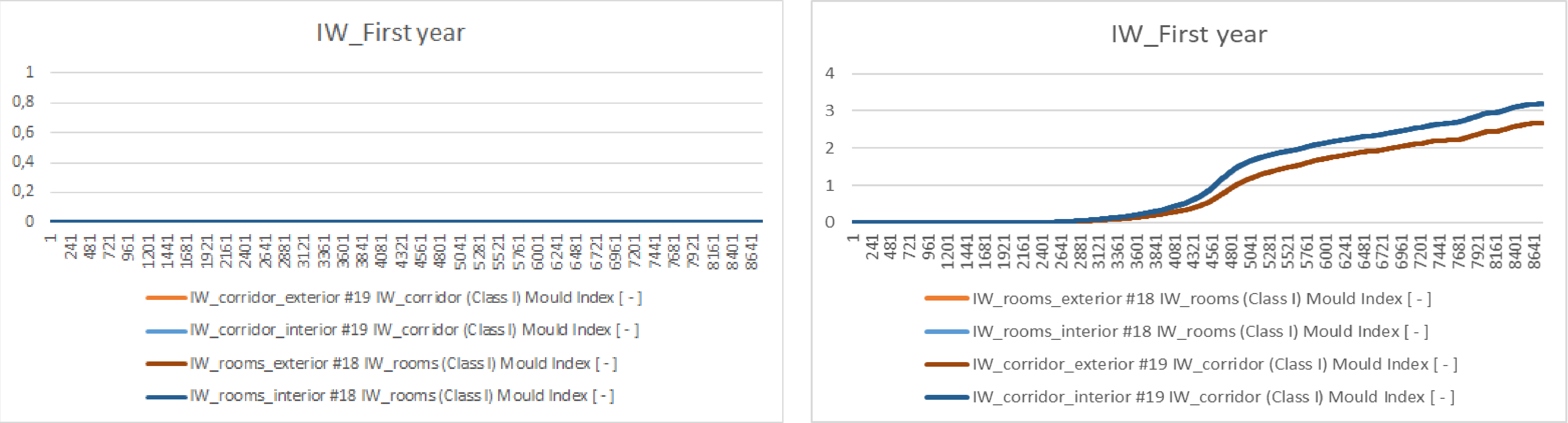


Figure 107. Mold index of the internal walls.

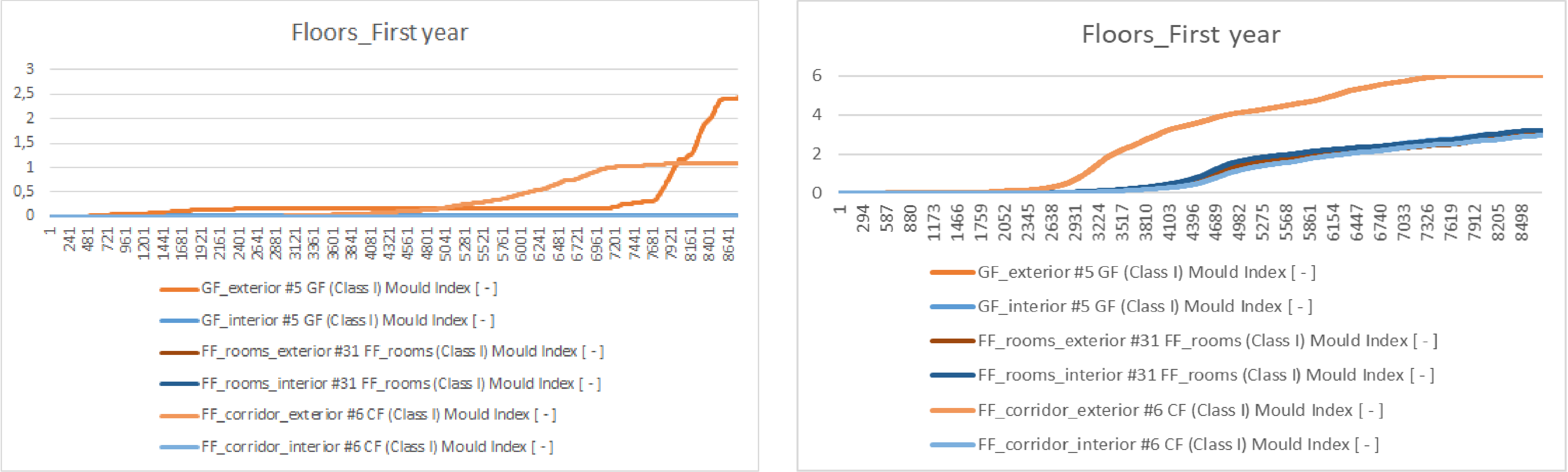


Figure 108. Mold index in the floors.

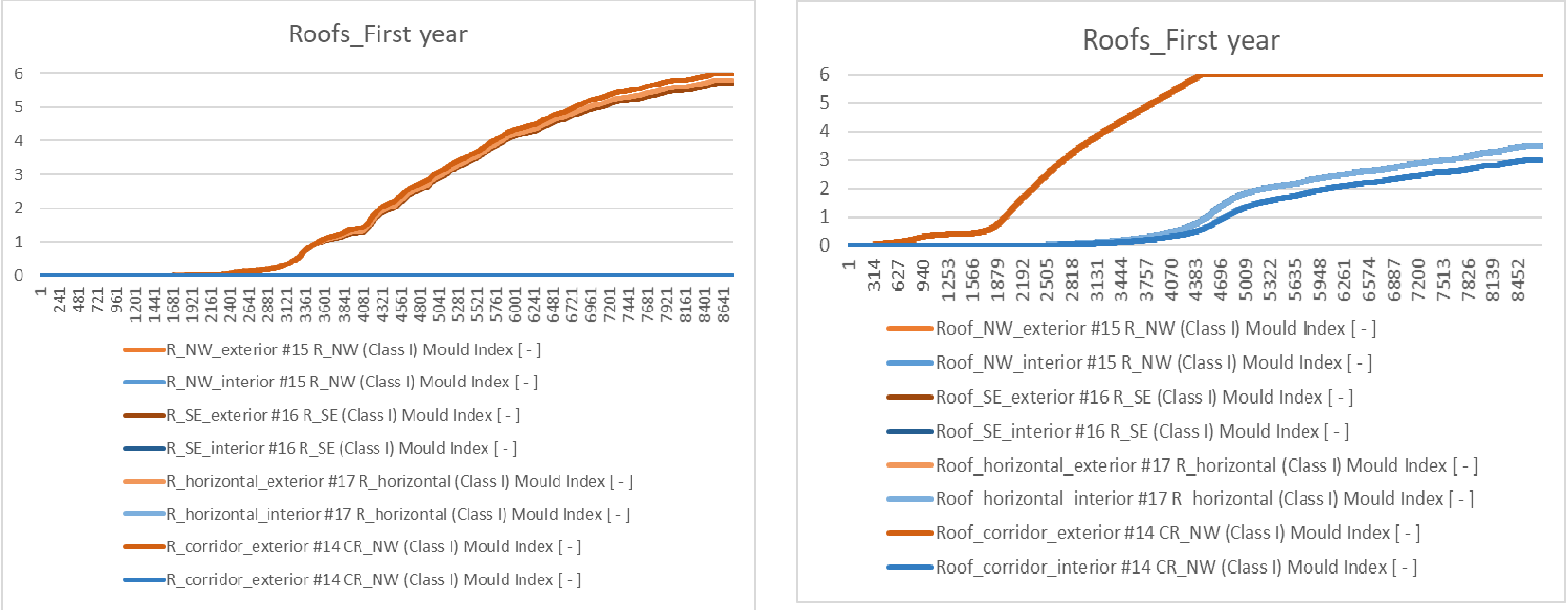


Figure 109. Mold index in the roofs.

HEIERSTAD LOFT

CURRENT
(TYPICAL YEAR)

RCP8.5 SCENARIO
(2100)

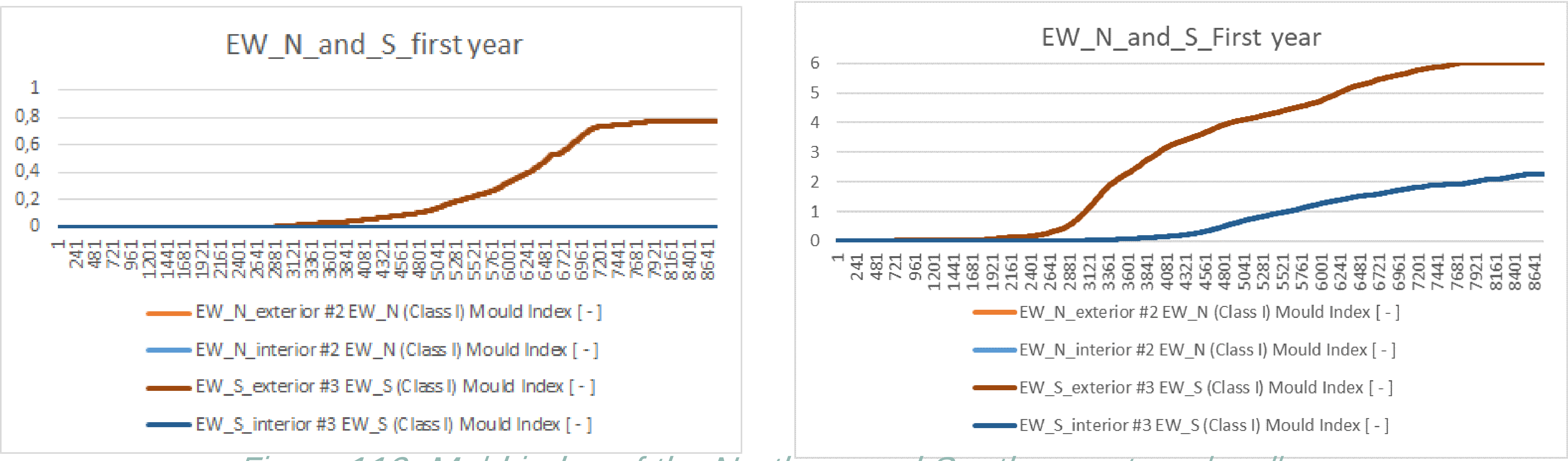


Figure 110. Mold index of the Northern and Southern external wall.

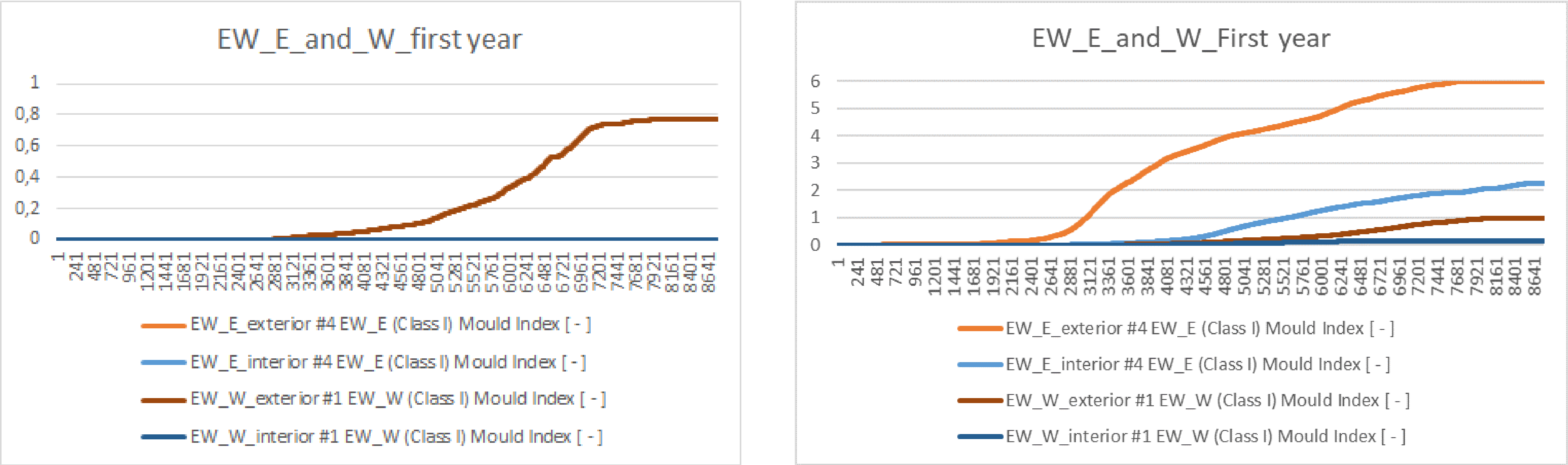


Figure 111. Mold index of the Eastern and Western external wall.

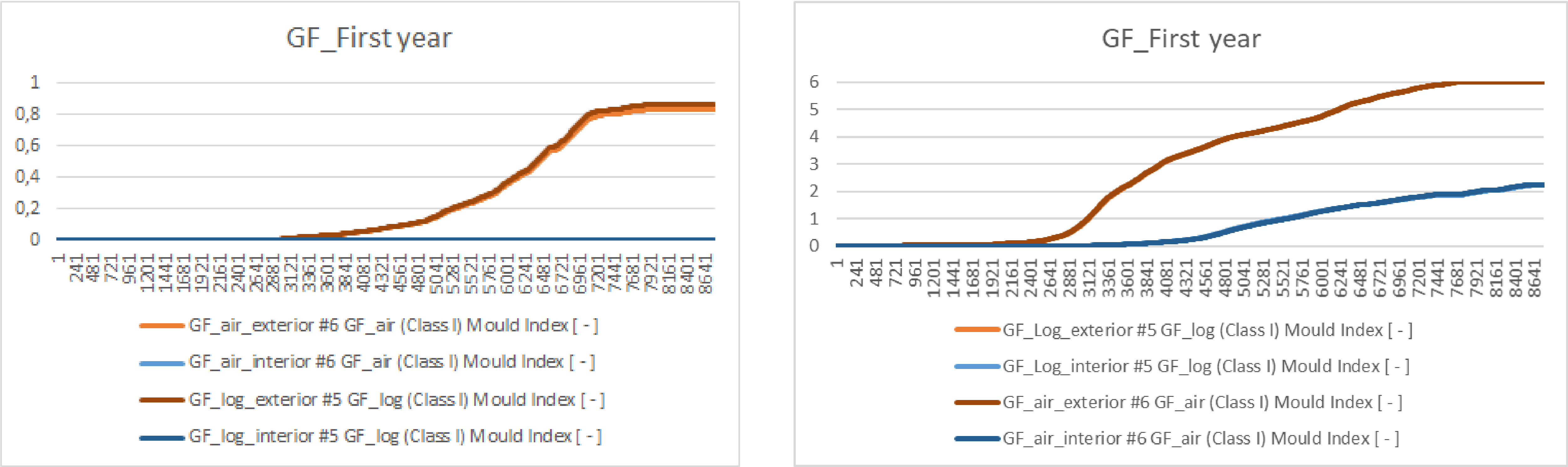


Figure 112. Mold index of the groundfloor.

FADUM STOREHOUSE

The mold index in most cases is not significant. There is one questionable case, the North Side of the roof (Fig.116.), where the mold index reaches 1.457. The external walls (Fig.110. and Fig.111.) have a noticeable higher amount of mold index than the slanted roofs (Fig.114. and Fig.115.) that cover these walls. This can be explained by the positive effect the solar radiation has on the building components, reducing the moisture content and thus the risk for mould growth. The external walls are covered from the rain and the solar radiation, however, this means that the mold that forms on the components can not dry by the sun, while the slanted roof are completely exposed to all outdoor conditions. These roofs absorb more rain but they also have the ability to dry more quickly because of the direct solar radiation. The first floor (Fig.113.) is only affected by the indoor air temperature and relative humidity, the protection from the outdoor climate makes the mold growth minimal. In the graphs of the roofs (FIg.116it becomes clear that the North side is slightly more touched by mold growth than the other wind directions. All of the graphs show that an equilibrium will be reached after the first circle of a typical year of the building. If the climatic conditions won't change in order to bias this equilibrium, the mould index will remain the same. The future results show a remarkable difference in mold index. The maxima in of the RCP8.5 sceanrio negatively effect both the building as the human health.

CURRENT (TYPICAL YEAR) | RCP8.5 SCENARIO (2100) | CURRENT (TYPICAL YEAR) | RCP8.5 SCENARIO (2100)

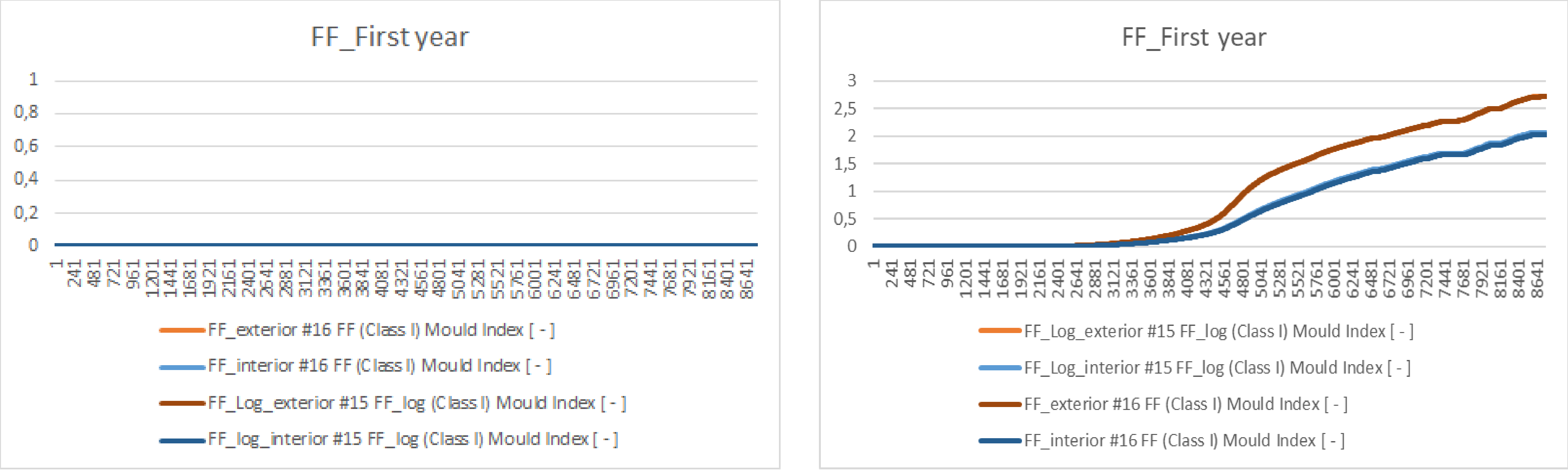


Figure 113. Mold index of the firstfloor.

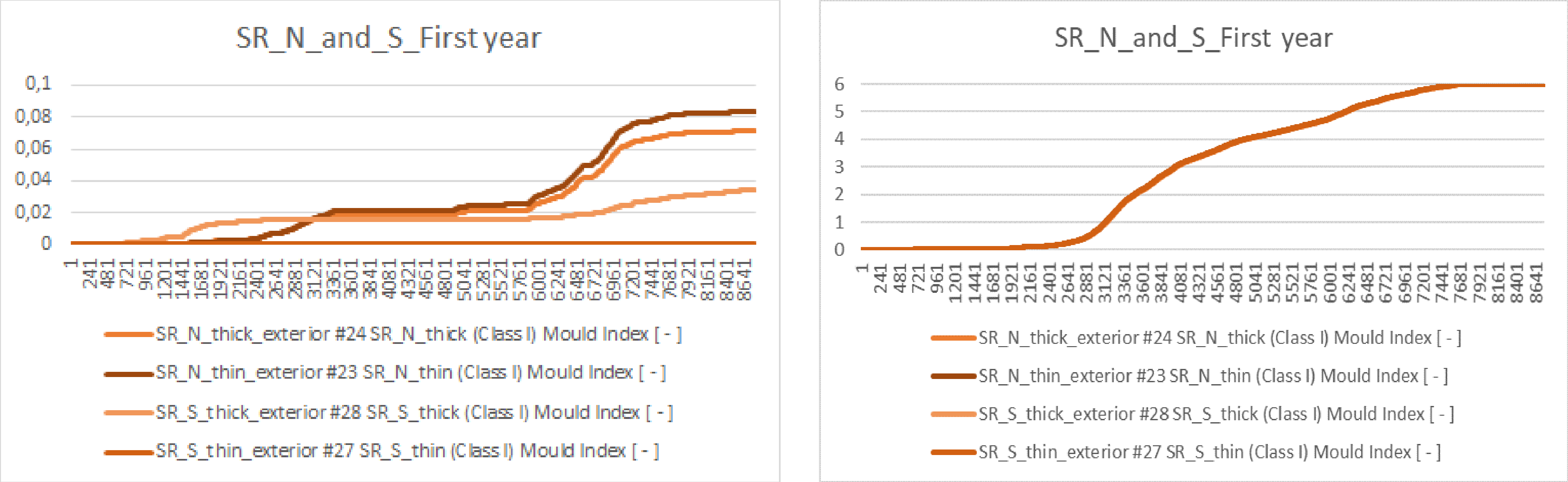


Figure 114. Mold index of the Northern and Southern slanted roofs.

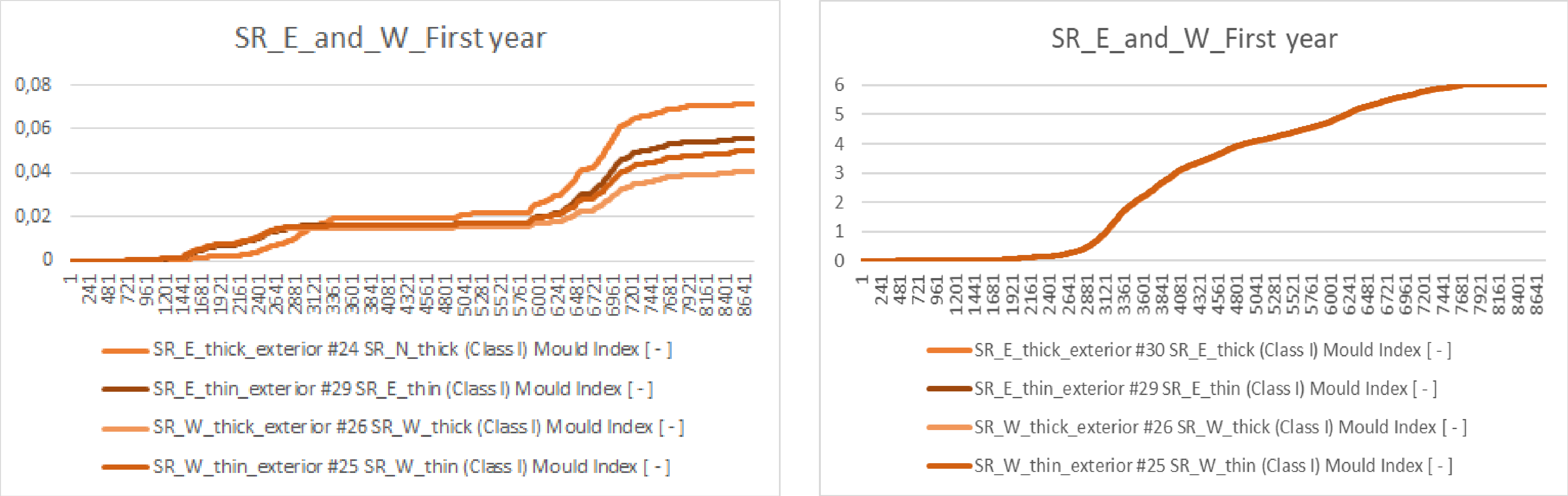


Figure 115. Mold index of the Eastern and Western slanted roofs.

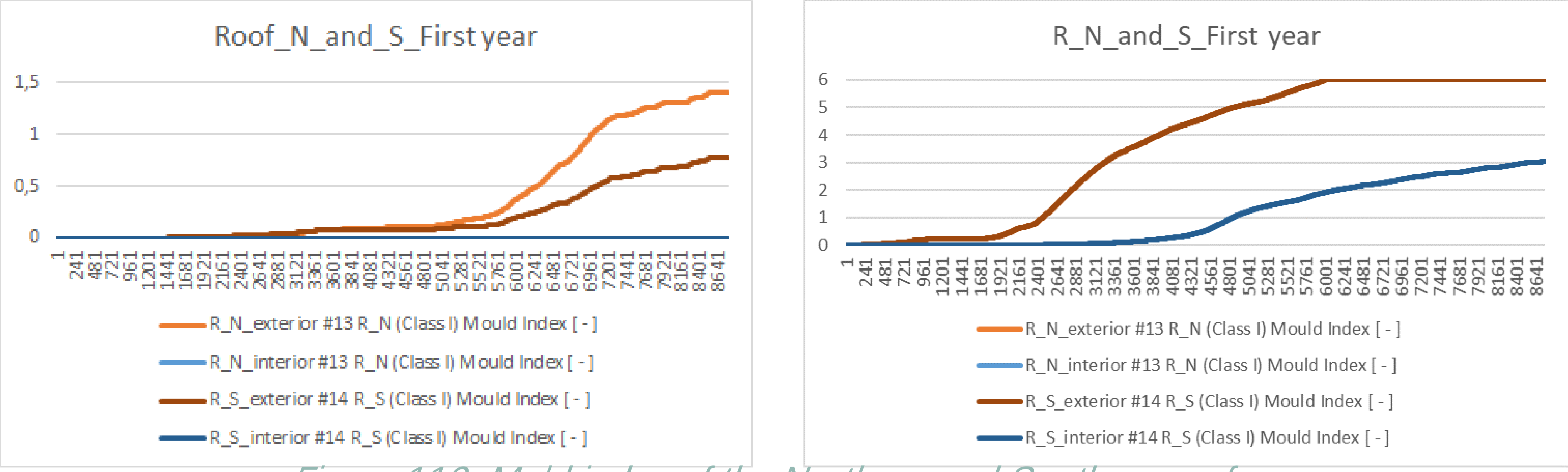


Figure 116. Mold index of the Northern and Southern roofs.

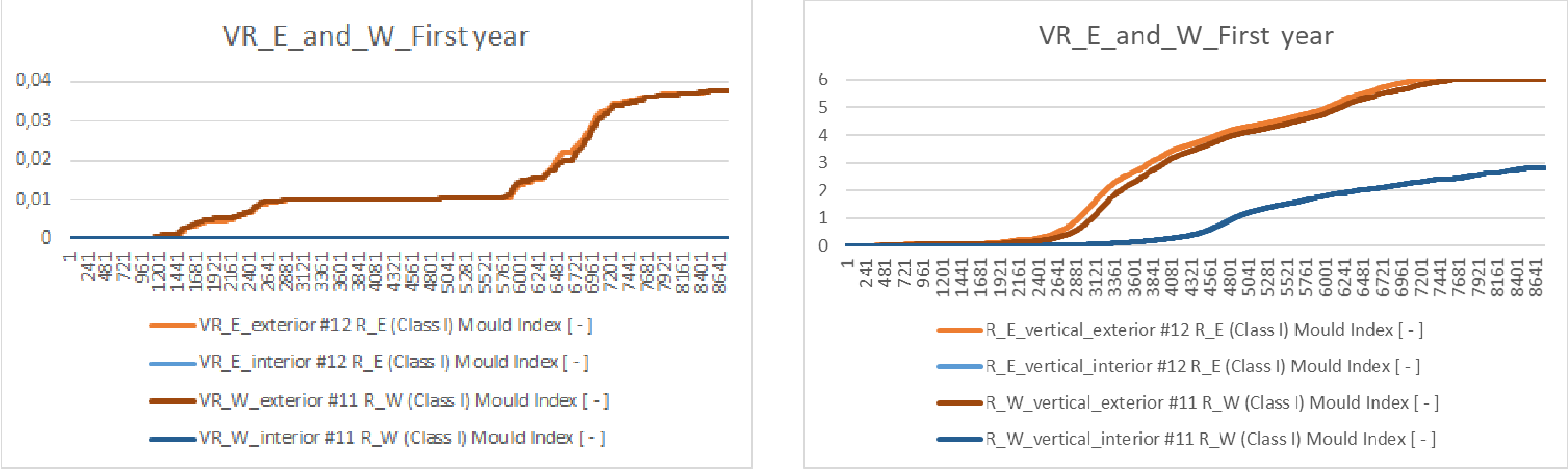


Figure 117. Mold index of the Eastern and Western roofs.

FADUM STOREHOUSE

Fadum: Table Mold Index Current Climate	Exterior	Interior
EW_North	0,791	0,000
EW_South	0,791	0,000
EW_East	0,791	0,000
EW_west	0,791	0,000
EW_transition_North	0,731	0,000
EW_transition_South	0,731	0,000
EW_transition_East	0,731	0,000
EW_transition_West	0,731	0,000
GF_air	0,853	0,000
GF_log	0,888	0,000
FF	0,000	0,000
FF_log	0,000	0,000
R_North	1,457	0,000
R_south	0,861	0,000
VR_East	0,044	0,000
VR_west	0,044	0,000
SR_North_thick	0,080	/
SR_North_thin	0,093	/
SR_South_thick	0,044	/
SR_South_thin	0,000	/
SR_East_thick	0,080	/
SR_East_thin	0,064	/
SR_West_thick	0,048	/
SR_West_thin	0,058	/

Figure 118. Mold Index of the current climate in Fadum Storehouse.

Fadum: Table Mold Index RCP8.5	Exterior	Interior
EW_North	6,000	2,367
EW_South	6,000	2,367
EW_East	6,000	2,367
EW_west	6,000	2,367
EW_transition_North	6,000	2,530
EW_transition_South	6,000	2,530
EW_transition_East	6,000	2,530
EW_transition_West	6,000	2,530
GF_air	6,000	2,332
GF_log	6,000	2,268
FF	2,743	2,043
FF_log	2,756	2,089
R_North	6,000	3,080
R_south	6,000	3,080
VR_East	6,000	2,869
VR_west	6,000	2,869
SR_North_thick	6,000	/
SR_North_thin	6,000	/
SR_South_thick	6,000	/
SR_South_thin	6,000	/
SR_East_thick	6,000	/
SR_East_thin	6,000	/
SR_West_thick	6,000	/
SR_West_thin	6,000	/

Figure 119. Mold Index of the RCP8.5 scenario in Fadum Storehouse.

MOLD INDEX TABLE FADUM STOREHOUSE

After the simulation of the Fadum Storehouse in WUFI Pro and Bio with both the current climate file and the future RCP8.5 climate file, it is possible to compare the mold index. The mold index shows the amount of mold spores. If the values are higher than approximately 1.5 then the result can be considered significant. The tables show the maximum values for both the exterior side as the interior side of the specific cases. The mold index is always higher in the exterior side, since the mold start growing on the outer and humid layer of the wood. The main difference between Fig.118. and Fig. 119. is the large increase of the mold index. While none of the cases in the current climate scenario have a significant mold index, all cases of the RCP8.5 have a dangerous amount of mold. This can be explained by the increase of air temperature, rainfall, and relative humidity. A significant mold index is negative for the the preservation of the wood and for the human health.

Mold Index Table Current Climate	exterior	interior
EW_NE_GF	0,061	0,000
EW_NW_GF	0,065	0,000
EW_SE_GF	0,047	0,000
EW_SW_GF	0,046	0,000
EW_NE_FF_Z2	0,060	0,000
EW_NE_FF_Z3	0,060	0,000
EW_NW_FF	0,064	0,000
EW_SE_FF	0,046	0,000
EW_SW_FF_Z2	0,046	0,000
EW_SW_FF_Z3	0,046	0,000
EW_NE_GF_TRANS	0,069	0,000
EW_NW_GF_TRANS	0,074	0,000
EW_SE_GF_TRANS	0,052	0,000
EW_SW_GF_TRANS	0,054	0,000
EW_NE_FF_Z2_TRANS	0,066	0,000
EW_NE_FF_Z3_TRANS	0,066	0,000
EW_NW_FF_TRANS	0,071	0,000
EW_SE_FF_TRANS	0,052	0,000
EW_SW_FF_Z2_TRANS	0,052	0,000
EW_SW_FF_Z3_TRANS	0,052	0,000
IW_ROOMS	0,000	0,000
IW_CORRIDOR	0,000	0,000
GF	2,800	0,063
FF_ROOMS	0,000	0,000
FF_CORRIDOR	1,112	0,000
R_NW	6,000	0,000
R_SE	5,825	0,000
R_HORIZONTAL	5,934	0,000
R_CORRIDOR	6,000	0,000
SH	1,106	0,000

Figure 120. Mold Index of the current climate in Heierstad Loft.

Mold Index Table RCP8.5	exterior	interior
EW_NE_GF	6,000	3,200
EW_NW_GF	6,000	3,200
EW_SE_GF	6,000	3,201
EW_SW_GF	6,000	3,200
EW_NE_FF_Z2	6,000	2,911
EW_NE_FF_Z3	6,000	3,391
EW_NW_FF	6,000	2,911
EW_SE_FF	6,000	3,392
EW_SW_FF_Z2	6,000	2,912
EW_SW_FF_Z3	6,000	3,391
EW_NE_GF_TRANS	6,000	3,298
EW_NW_GF_TRANS	6,000	3,298
EW_SE_GF_TRANS	6,000	3,300
EW_SW_GF_TRANS	6,000	3,299
EW_NE_FF_Z2_TRANS	6,000	3,022
EW_NE_FF_Z3_TRANS	6,000	3,479
EW_NW_FF_TRANS	3,022	6,000
EW_SE_FF_TRANS	6,000	3,481
EW_SW_FF_Z2_TRANS	6,000	3,023
EW_SW_FF_Z3_TRANS	6,000	3,481
IW_ROOMS	3,219	3,219
IW_CORRIDOR	2,701	3,228
GF	6,000	3,272
FF_ROOMS	3,022	3,251
FF_CORRIDOR	6,000	2,994
R_NW	6,000	3,544
R_SE	6,000	3,544
R_HORIZONTAL	6,000	3,544
R_CORRIDOR	6,000	3,078
SH	6,000	2,959

Figure 121. Mold Index of the RCP8.5 scenario in Heierstad Loft.

MOLD INDEX TABLE HEIERSTAD LOFT

A remarkable increase in mold index is seen in the results of the RCP8.5 climate file. As written in the previous paragraph about the Fadum Storehouse, this is due to the increase of several parameters that make the future climate warmer and wetter. In Fig.120. most cases have a very low mold index. However, there are some exeptions, such as the ground floor and the different roofs. The reason for the higher mold index in these cases can be found in the first paragraph of 4.3..The mold index tables give an overview of the maximum values of all the previous graphs in 4.3..

Mold Index Table RCP8.5	exterior	interior
R_NW	6,000	3,544

Heierstad: Mold Index A2 scenario	Exterior	Interior
R_NW	6	0

Figure 122. Mold Index of the Northwestern roof comparison

Mold Index Table RCP8.5	exterior	interior
EW_SE_GF	6,000	3,201

Heierstad: Mold Index A2 scenario	Exterior
EW_SE_GF	0,0437

Figure 123. Mold Index of the Southeastern wall on the groundfloor comparison

Fadum: Table Mold Index Current Climate	Exterior	Interior
SR_North_thin	6,000	/

Fadum: Mold Index A2 scenario	Exterior
SR_North_thin	0,093152

Figure 123. Mold Index of the Northern slanted roof comparison

MOLD INDEX TABLE: COMPARISON BETWEEN A2 SCENARIO AND RCP8.5
To run the simulations in WUFI Pro and Bio two climate files were used, the current climate file and the RCP8.5 scenario. This decision was made to compare the results and predict the future mold index of the buildings. However, to get a better view between the differences of the two future climate files, the A2 scenario and the RCP8.5 scenario, several seperate cases were run with the A2 scenario. The maximum values can be seen in Fig.122, Fig.123, and Fig.124.. Both future climate files are the worst case scenario but the calculated values are still different. This is due to the fact that the files are based on different models and storylines. If humans will act as predicted in the A2 scenario the maximum mold index will be lower than the results from the RCP8.5 scenario FiG.123. and Fig.124..

WUFI BIO INTERFACE

Fig.124. shows the interface of WUFI Bio. These are the results of one case, the upper graph indicates the water content while the lower graph gives the results of the mold index. In the left upper corner a traffic light signals if the results can be considered significant. A green light means that the mold growth is acceptable when the light turns red the results are too high. The graph of the mold index shows the last year od the simulation.

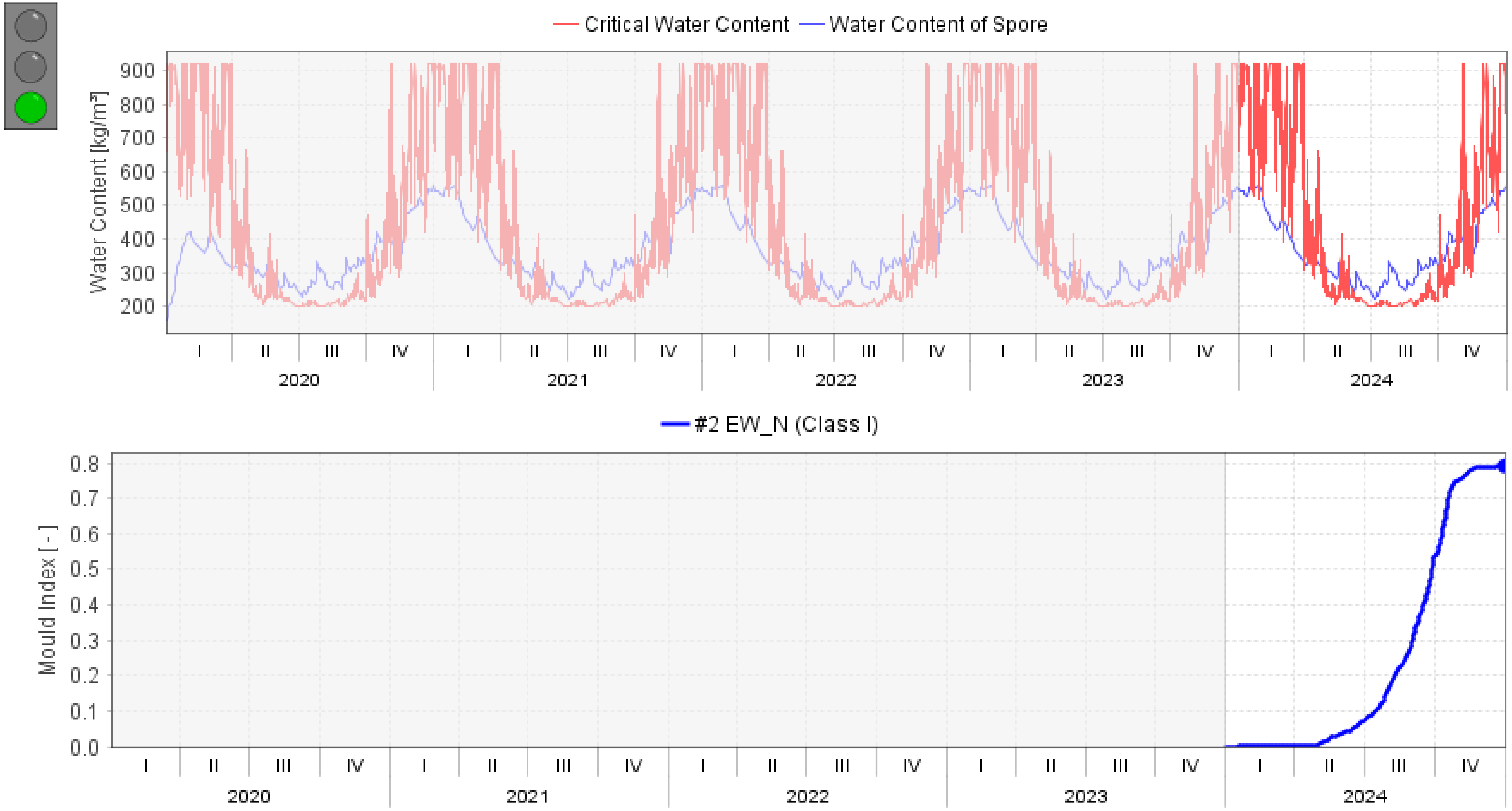


Figure 124. WUFI Bio interface

4.5.DAMAGES

4.5.1. INTRODUCTION

Fungi (brown spots)

Fungi are a group of eukaryotic microorganisms, which have biological characteristics that differentiate them from both the plant and animal kingdoms, forming their own kingdom. They are found in nature, in the stubble of crops, manure, soil, plants, etc.

They reach a good development in cool, humid places and with little sun.

Figure 125. Fungi.

Lichens

Lichen is organisms that arise from the symbiosis between a fungus and algae. Lichens have an important role as immediate-reading bioindicators of environmental pollution, climate change, and soil stabilization.

Figure 126. Lichens.

Green algae

Only 10% of green algae are marine, the rest are freshwater. There are forms, such as Pneumococcus, capable of developing in very humid environments. The gonidia, algae, and lichens are most often green algae.

Figure 127. Green algae.

Crack

A crack is a long, narrow opening that results from the separation of two materials.

The infrared spectrum of sunlight causes drying of the wood, and can generate cracks in it, especially in darker woods. These cracks can trigger consequences of two types:

- Structural damage.
- Allow moisture to enter, creating an environment prone to fungal growth.

Figure 128. Crack.

Discoloring

The advantages of using wood in the home far outweigh the drawbacks, although the material is relatively vulnerable to different climatic agents (sunlight and humidity). Ultraviolet radiation can act on wood cellulose and may be responsible for the loss of the original color. Therefore, the greater the exposure of wood to ultraviolet radiation, the greater its discoloration. This impact can be multiplied if the wood is exposed to rain at the same time as it is exposed to ultraviolet radiation.

Discoloration generally has a brown to black appearance and can be confused with the appearance of fungus, soot, moss, or fallen things from trees.

Figure 129. Discoloring.

Insects attack (holes/material loss)

Holes caused by insects is external signs of are the life cycle of insects, which begins when the females lay their eggs in the wood, from these new eggs small larvae hatch and begin to feed on the wood making galleries. As the end of their larva cycle approaches it approaches the surface of the wood, creates an isolated chamber where it transforms into a pupa and continues its process of metamorphosis until it becomes an adult insect with wings. This breaks the pupation chamber and the thin layer of wood that remains superficially.

Figure 130. Insects attack.

T	HREL	RH>HREL	TL<T	T<TH	TL<T<TH	TEMPERATURE
1,30	0,70	1,00	1,00	0,00	1,00	0,00
0,90	0,70	1,00	1,00	0,00	1,00	0,00
-2,13	0,70	1,00	1,00	0,00	1,00	0,00
-2,44	0,70	1,00	1,00	0,00	1,00	0,00
-3,67	0,70	1,00	1,00	0,00	1,00	0,00

Table 131. Table Insect Attack.

DEGREE-DAYS 2	DEGREE-DAYS 1	TEMPERATURE & HUMIDITY
0,00	0,00	2,00
0,00	0,00	2,00
0,00	0,00	2,00
0,00	0,00	2,00
0,00	0,00	2,00

Table 132. Table Insect Attack.

RH=	0,75
TH=	30,00
TL=	15,00
TRUE=	0,00
FALSE=	1,00
T:	mean daily temperature

Table 133. Table Insect Attack.

T	HREL	RH>HREL	TL<T	T<TH	TL<T<TH	TEMPERATURE
-5,31	0,66	1,00	1,00	0,00	1,00	0,00
-2,93	0,75	1,00	1,00	0,00	1,00	0,00
-4,36	0,92	0,00	1,00	0,00	1,00	0,00
-6,28	0,99	0,00	1,00	0,00	1,00	0,00
0,14	0,81	0,00	1,00	0,00	1,00	0,00

Table 134. Table Insect Attack.

DEGREE-DAYS 2	DEGREE-DAYS 1	TEMPERATURE & HUMIDITY
0,00	0,00	2,00
0,00	0,00	2,00
0,00	0,00	1,00
0,00	0,00	1,00
0,00	0,00	1,00

Table 135. Table Insect Attack.

4.5.2. TOOLS: CLIMATE DATE
CLIMATE DATA IN THE PAST
Insect attack
The first and second columns show the temperature and daily relative humidity in a year (Table. 131.).
The thresholds are compared below (Table. 150. and Table. 132.).

CLIMATE DATA IN THE FUTURE
Insect attack
The first and second columns show the temperature and daily relative humidity in a year (Table. 134.).
The thresholds are compared below (Table. 150. and Table. 135.).

4.5.3. RESULTS AND DISCUSSION HEIERSTAD LOFT

Only the most relevant damages have been represented in the representation of the building in AutoCAD.

The facades in which the sun falls are discolored, these are those of the east and the west, since it is where the sun rises and sunset.

What stands out the most on the entire facade are, without a doubt, the green areas with algae, fungi, and holes made by insects.

The first log at the bottom is the most critical, as different holes, cracks, discolorations, lack of material and green algae can be found (Figure 136.).

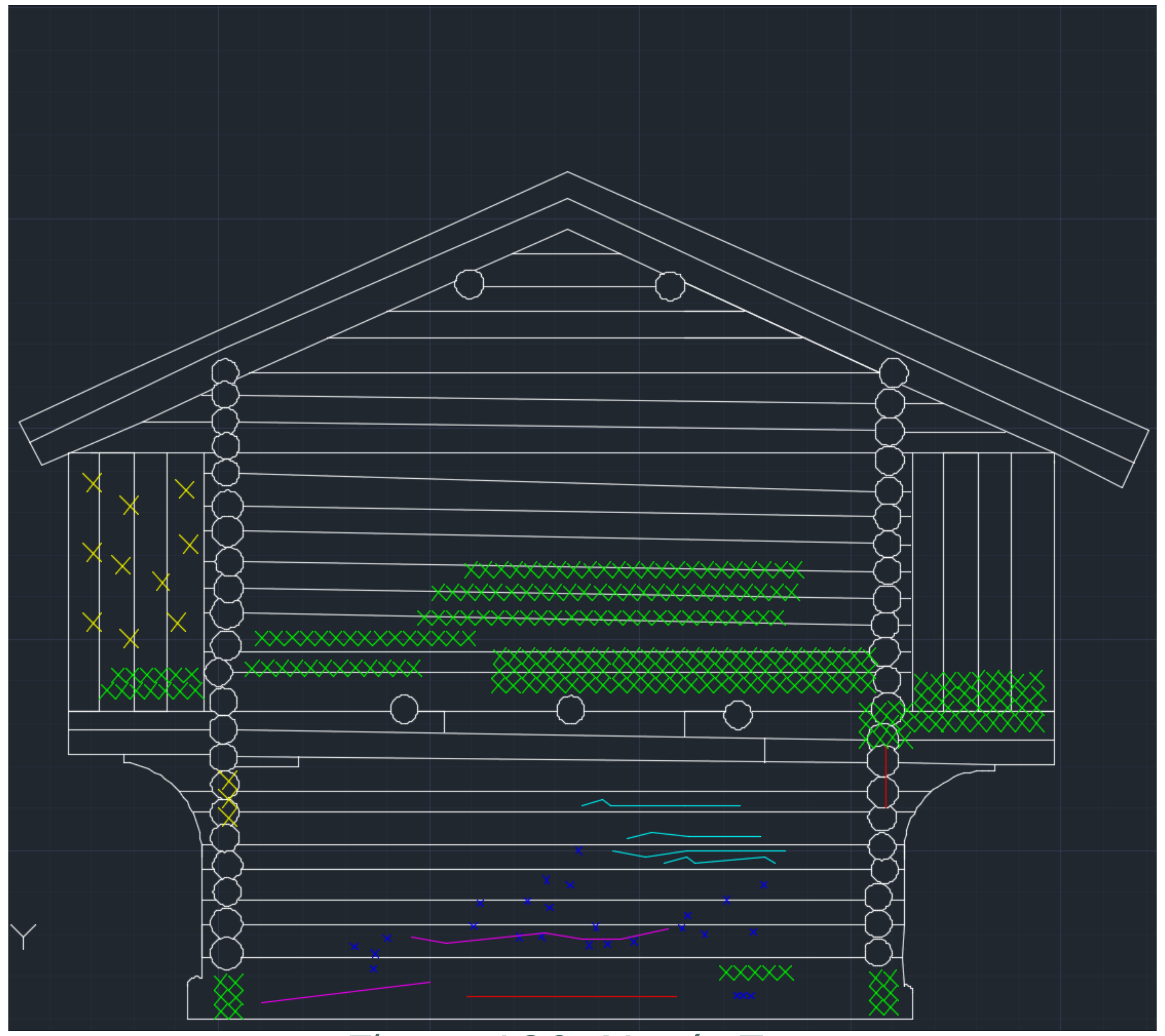


Figure 136. North-East.

- In the first log, the lack of material has the following dimensions: 1.4m in length and 0.5m in height (Figure. 137.).
- In the second log, the crack has the following dimensions: 1.6m in length and 0.04m in-depth (Figure. 137.).

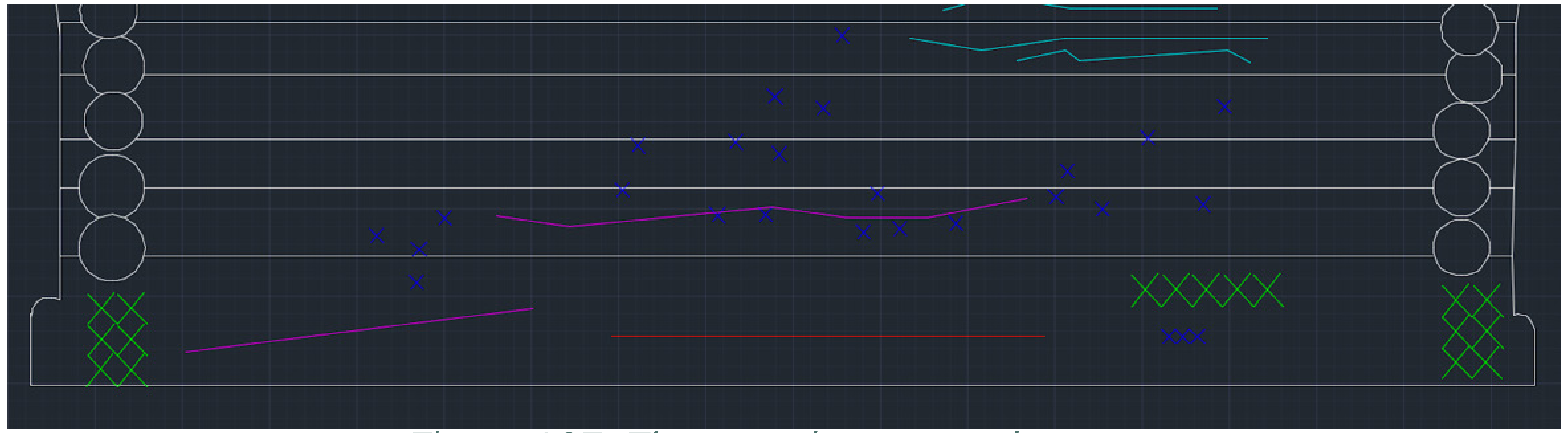


Figure 137. The most important damages.

What stands out the most on the entire façade are undoubtedly the discolored area and the cracks.

The fifth log from the bottom is one of the most damaged, and we found both fungi and a crack in this log. On the other hand, the eighteenth log (located at the top) is also one of the most damaged, with a crack and discoloration (Figure 138.).

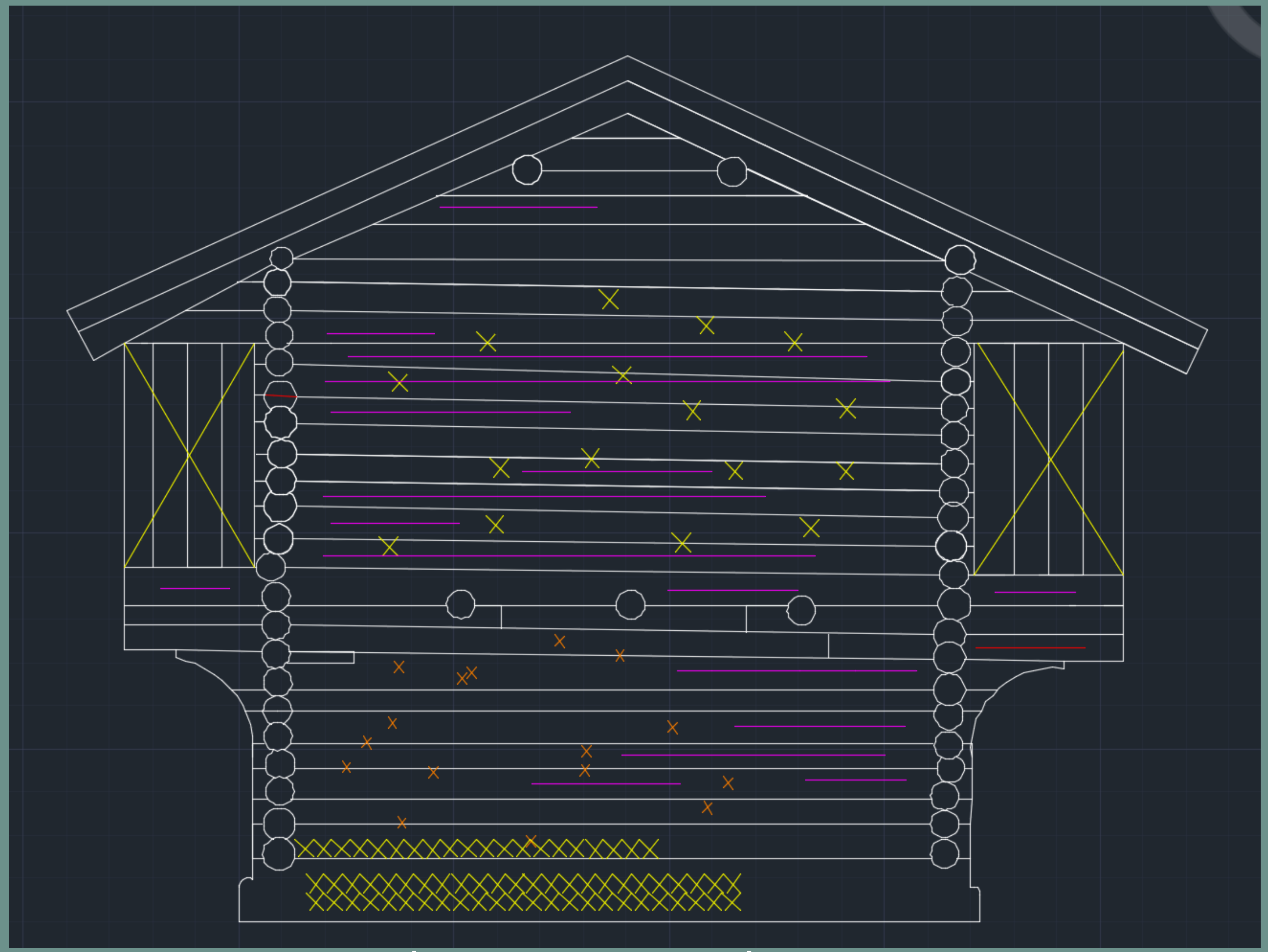


Figure 138. South-West.

- In the eighth log, the crack has the following dimensions: 2.7m in length and 0.1m in-depth (Figure. 139.).
- In the sixth log, the crack has the following dimensions: 2.05m in length and 0.08cm in-depth (Figure. 139.).

Figure. 139. The most important damages.

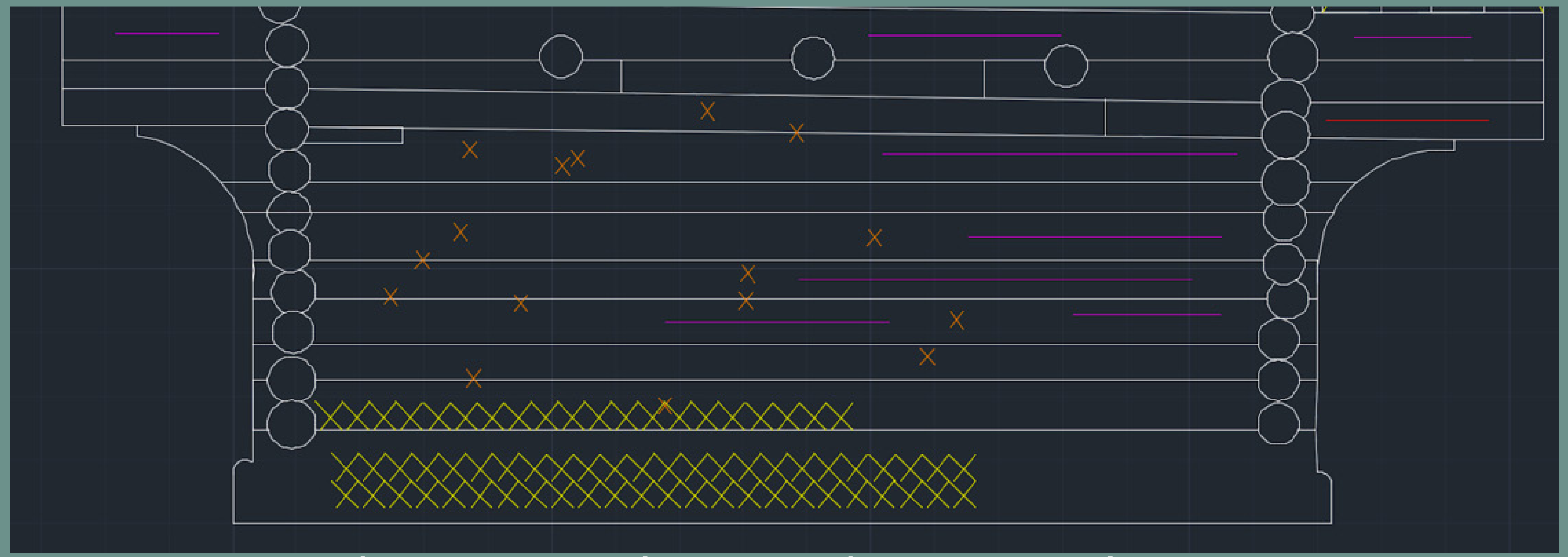


Figure 139. The most important damages.

What stands out the most on the entire façade is undoubtedly the discolored areas.

The eleventh log is the most damaged of this facade, with discoloration and two cracks (Figure 140.).

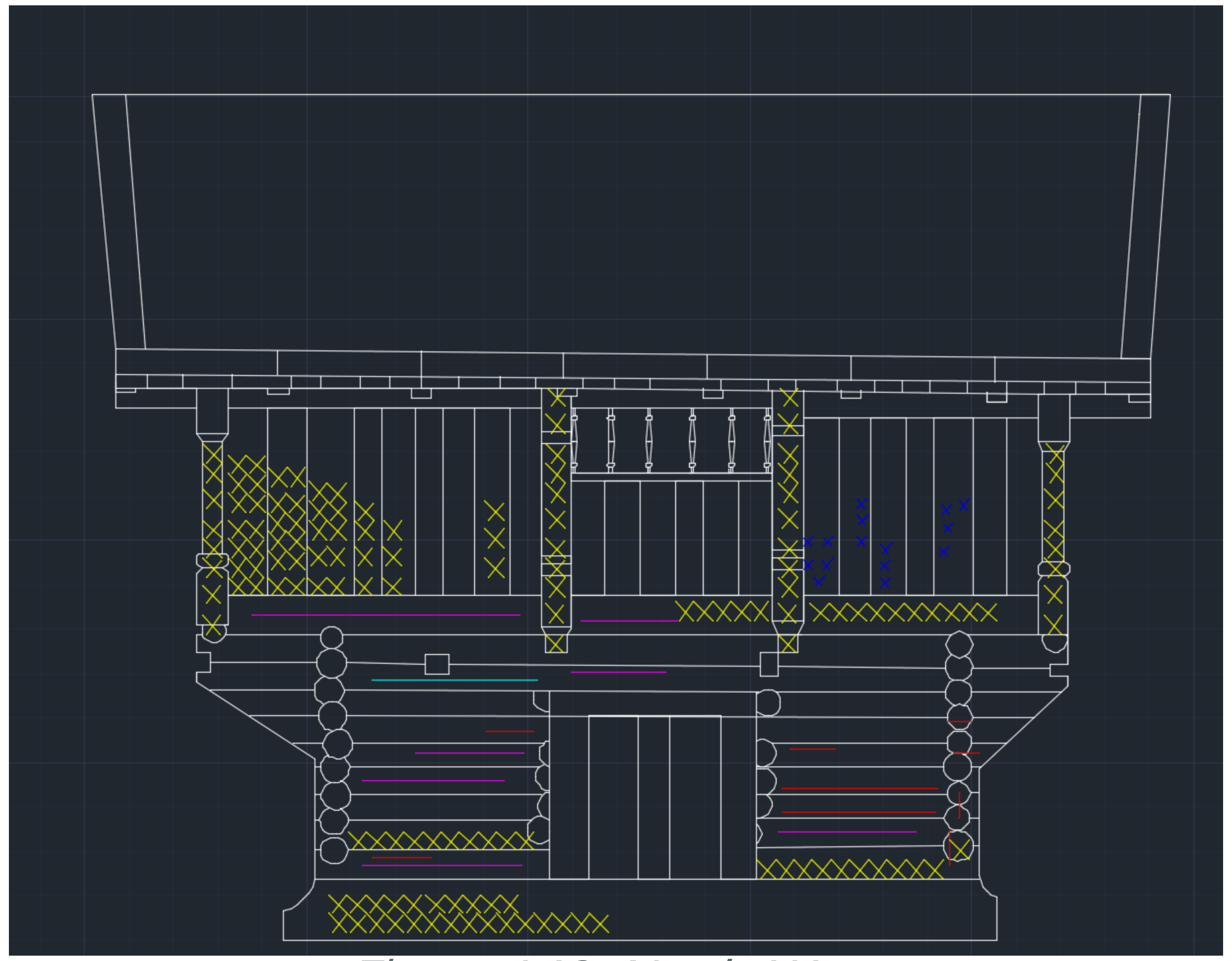


Figure 140. North-West.

- In the second log, the crack has the following dimensions: 1.8m in length and 0.05m in-depth (Figure. 141.).
- In the fifth log, the crack has the following dimensions: 1.8m in length and 0.1m in-depth (Figure. 141.).
- In the seventh log, the material loss has the following dimensions: 0.138m in length and 0.08m in-depth (Figure. 141.).
- In the sixth log, the crack has the following dimensions: 0.17m in length and 0.05m in-depth (Figure. 141.).
- In the ninth log, the crack has the following dimensions: 0.15m in length and 0.06m in-depth (Figure. 141.).

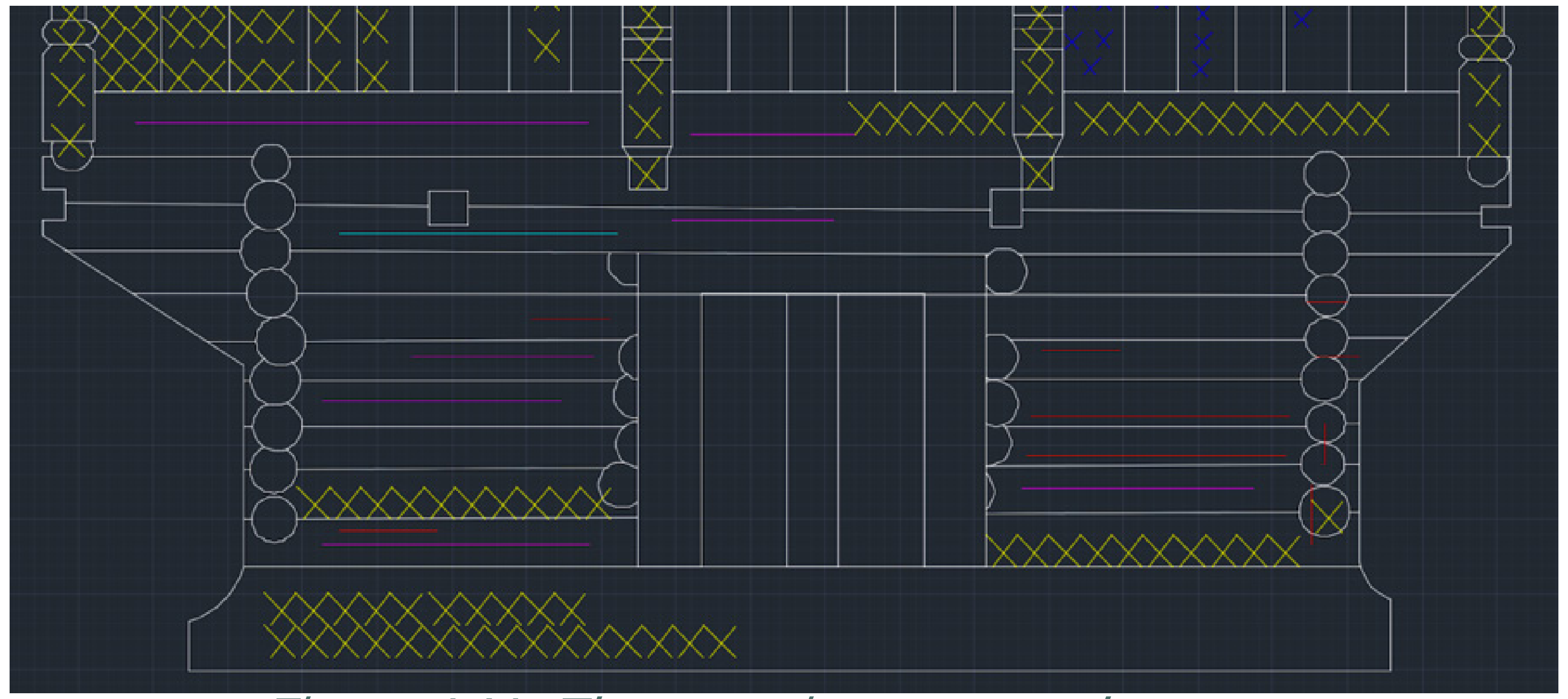


Figure 141. The most impoertant damages.

What stands out the most on the entire façade is undoubtedly the area with discolorations.

The upper part is the most critical, as there is a large amount of discoloration (Figure 142.).

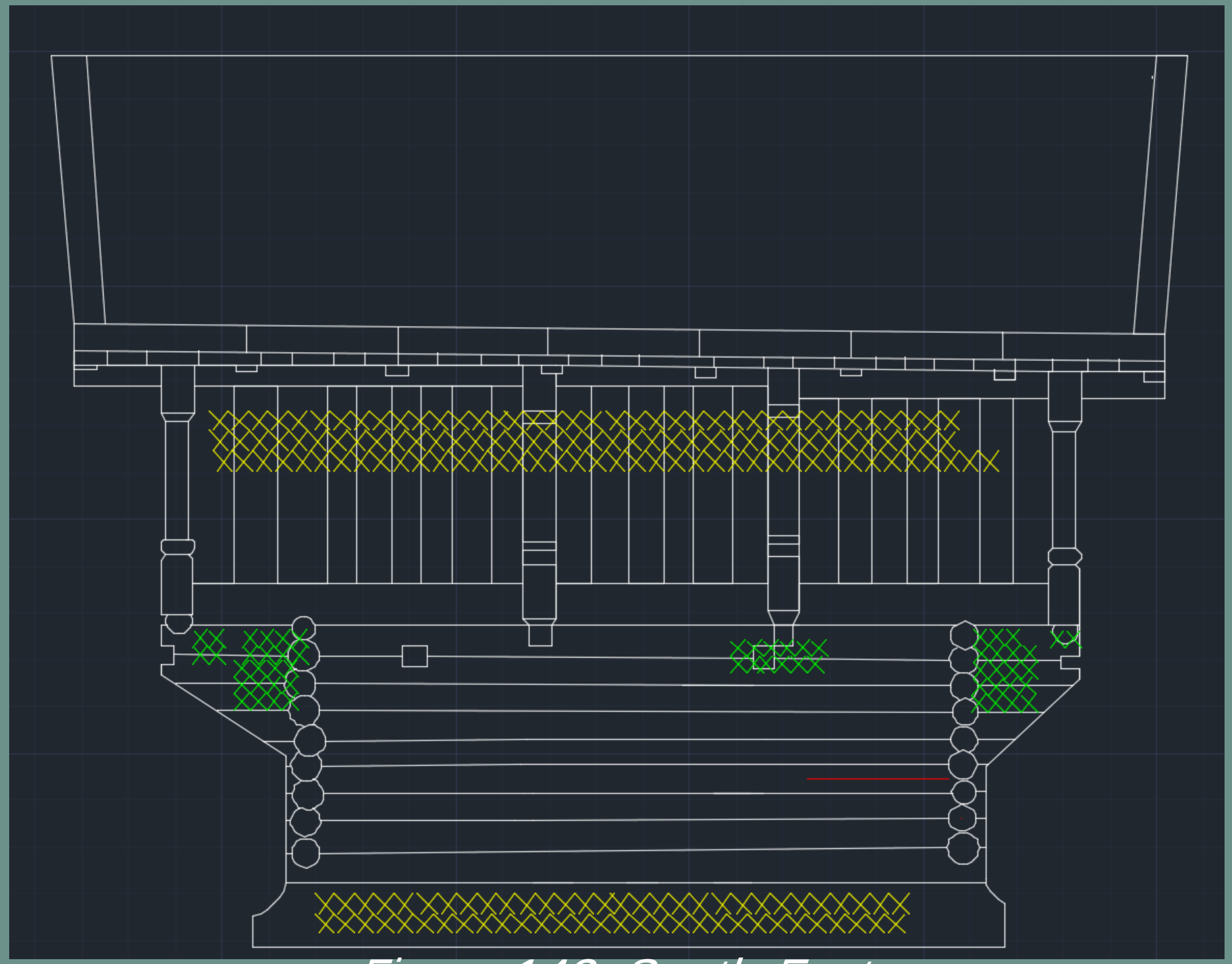


Figure 142. South-East.

FADUM STOREHOUSE
Only the most relevant has been represented in the representation of the building in AutoCAD.

The facades in which the sun falls are discolored, these are those of the east and the west, since it is where the sun rises and sunsets.

What stands out the most on the entire façade is undoubtedly the lichen areas.
The lower ceiling is the most critical since different amounts of lichen can be found. However, in the upper part of the roof, there is an area with discoloration due to the rains (Figure 143.).

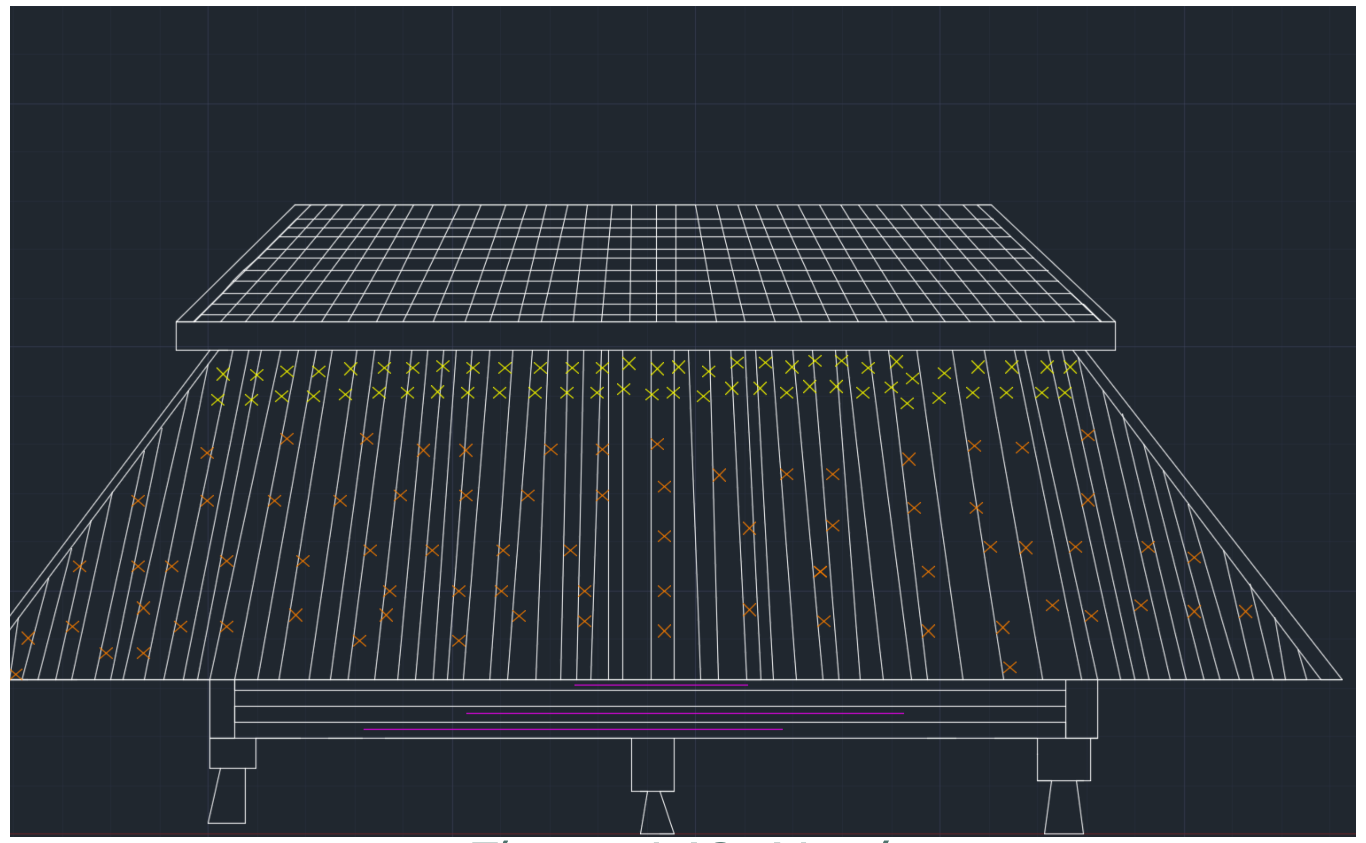


Figure 143. North.

- In the first log of the bottom, the crack has the following dimensions: 5.55m in length and 0.02m in-depth (Figure. 144.).
- In the second log of the bottom, the crack has the following dimensions: 4.2m in length and 0.02m in-depth (Figure. 144.).
- In the fourth log of the bottom, the crack has the following dimensions: 3m in length and 0.15m in-depth (Figure. 144.).

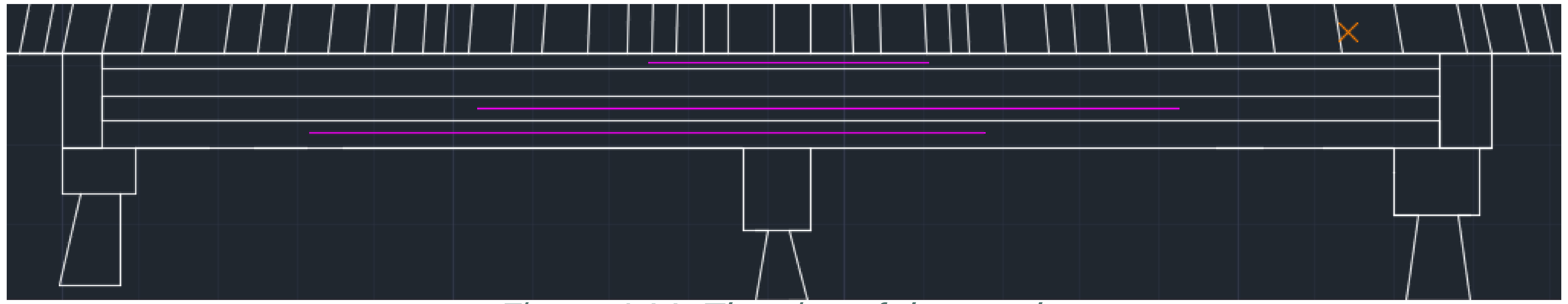


Figure 144. The size of the cracks.

What stands out the most on the entire façade is undoubtedly the discolored areas (Figure 145).

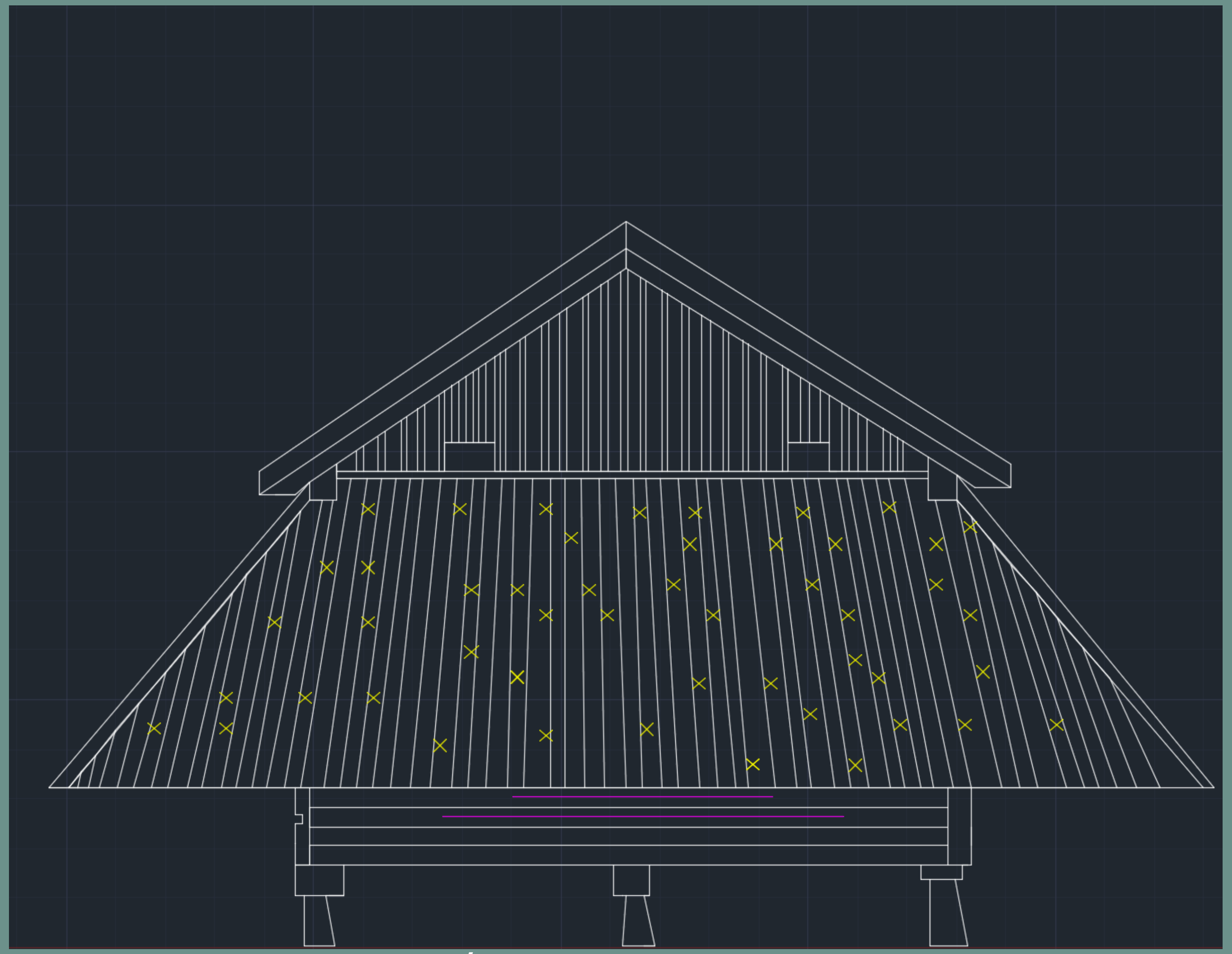


Figure 145. East.

- In the third log of the bottom, the crack has the following dimensions: 3.6m in length and 0.04m in-depth (Figure. 145.).
- In the fourth log of the bottom, the crack has the following dimensions: 3m in length and 0.02m in-depth (Figure. 145.).

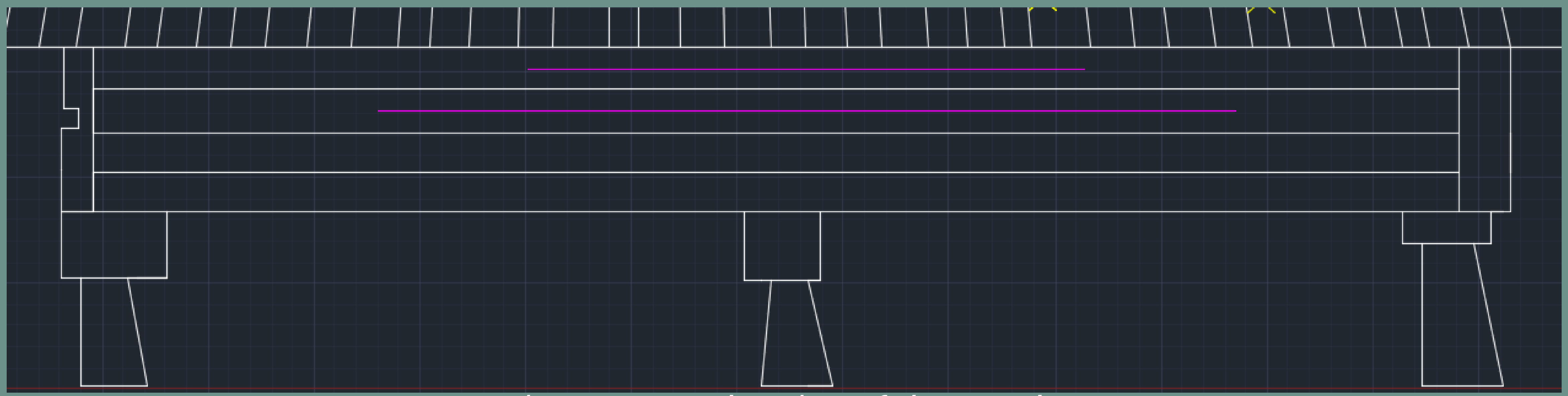


Figure 145. The size of the cracks.

What stands out the most on the entire façade is undoubtedly the discolored areas and the holes created by insects. The bottom of the roof is most critical for the amounts of discolored areas (Figure 146.).

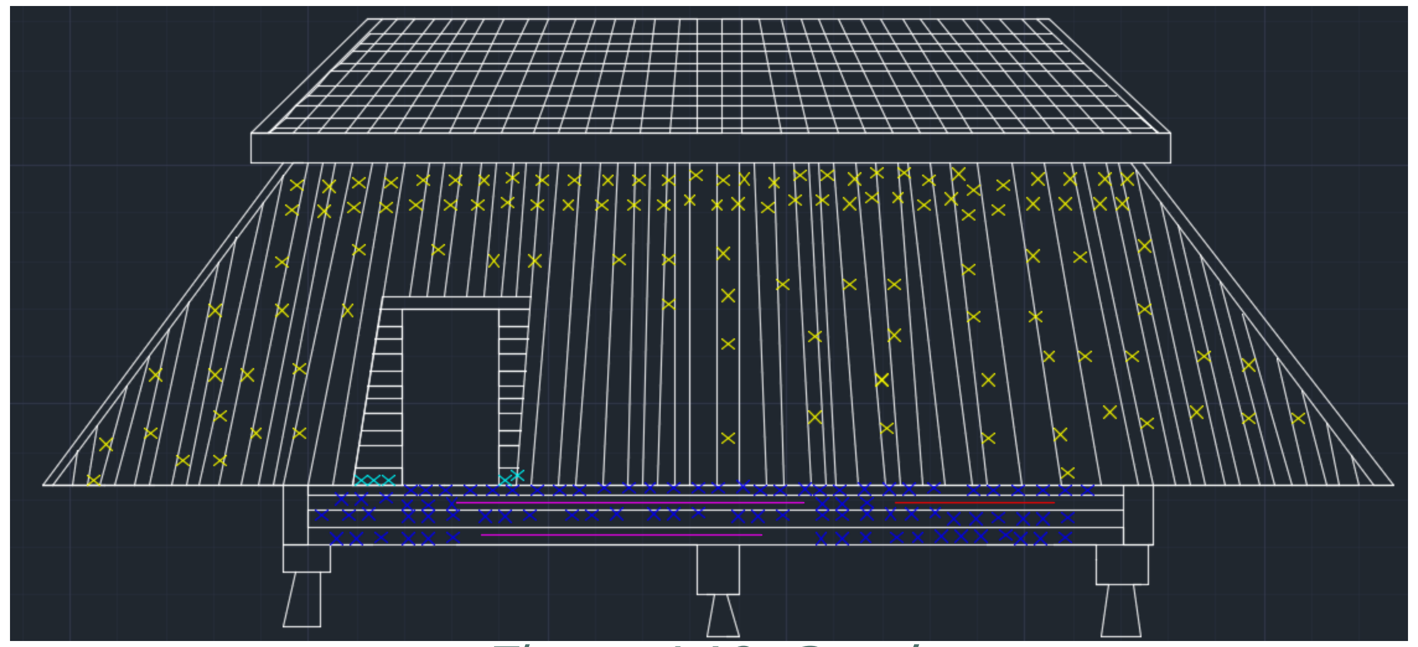


Figure 146. South.

- In the first log of the bottom, the crack has the following dimensions: 1.70m in length and 0.04m in-depth (Figure. 147.).
- In the third log of the bottom, the crack has the following dimensions: 1.84m in length and 0.04m in-depth and material loss 1.28m in length (Figure. 147.).

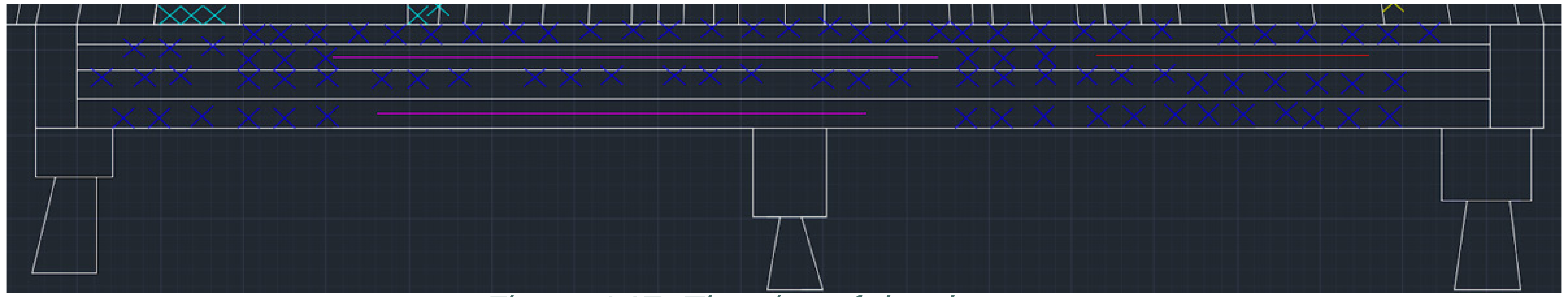


Figure 147. The size of the damages.

What stands out the most on the entire façade is undoubtedly the discolored areas. The bottom of the roof is most critical for the amounts of discolored areas. (Figure 148.).

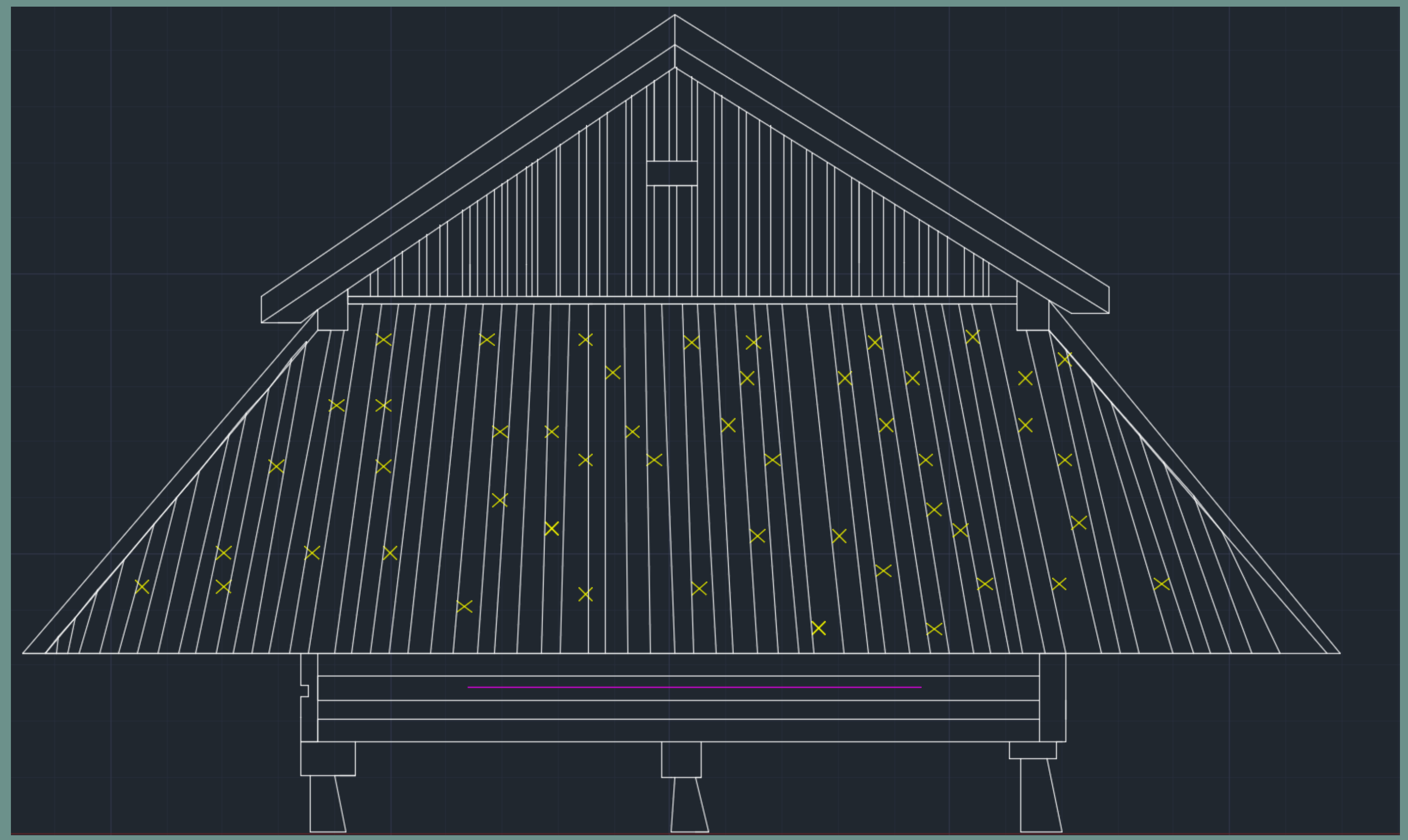


Figure 148. West.

In the third log of the bottom, the crack has the following dimensions: 3.7m in length and 0.04m in-depth (Figure. 149.).

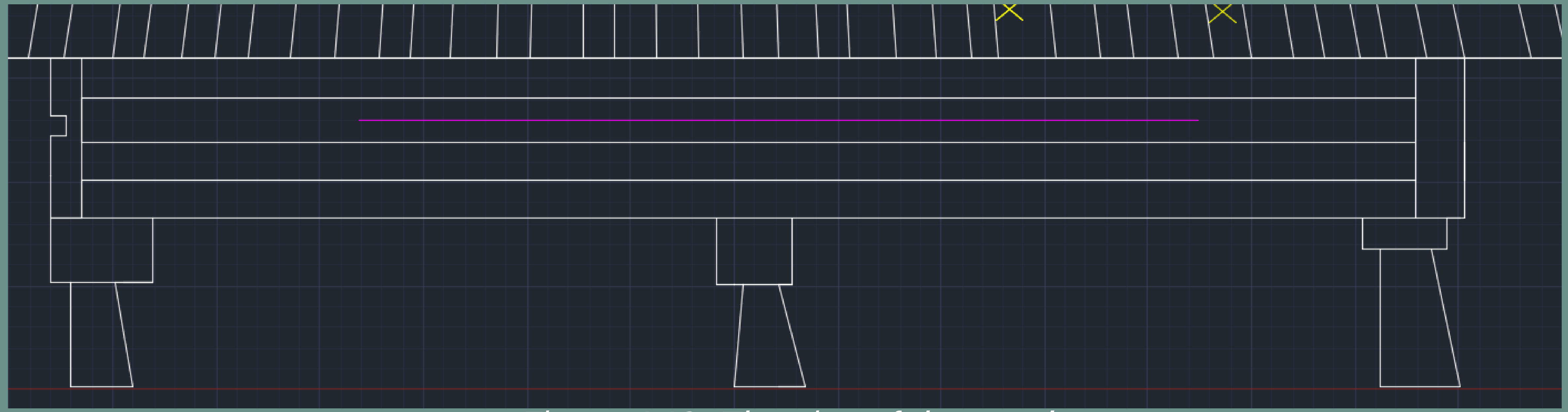


Figure 149. The size of the cracks.

EXPLICATION

Based on the analysis we did it is possible to arrive at the following table which shows (Table. 150.).

Type of damage	Basis of calculation	Thresholds	Reference
Biodeterioration (Fungi, Lichen, Green algae)	Climate index $= \frac{[\sum(T_{mean}-2)(D-3)]}{16.7}$ Where: · T_{mean}: mean monthly temperature [ºC] · D: mean number of days in the month with daily RR≥0.25mm	· ≤24 (low decay risk) · 24~28 (medium decay risk) · >28 (high decay risk)	Scheffer, T.C. (1971) Lisø, K.R. et. al. (2006)
Insects attack (temperature dependent insects)	Annual 'degree-days 1' above 15ºC, with 15ºC <T<30ºC degree-days = days x (T-15) Where: T: mean daily temperature [ºC].	One growth cycle corresponds to 490 degree-days	Lankester and Brimblecombe (2….)
Insects attack (humidity dependent insects)	Annual 'degree-days 2' above 15ºC, with 15ºC <T<30ºC and RH >75% (degree-days = days x (T-15)) Where: T: mean daily temperature [ºC]. RH: mean daily relative humidity [-]	One growth cycle corresponds to 490 degree-days	Lankester and Brimblecombe (2….)

Figure 150. Table Explication.

CRACK

Wood is a hygroscopic material that absorbs or loses water depending on the environmental conditions, mainly relative humidity and temperature. In turn, the moisture content produces a variation in dimensions. If humidity increases, the wood swells and if it decreases.

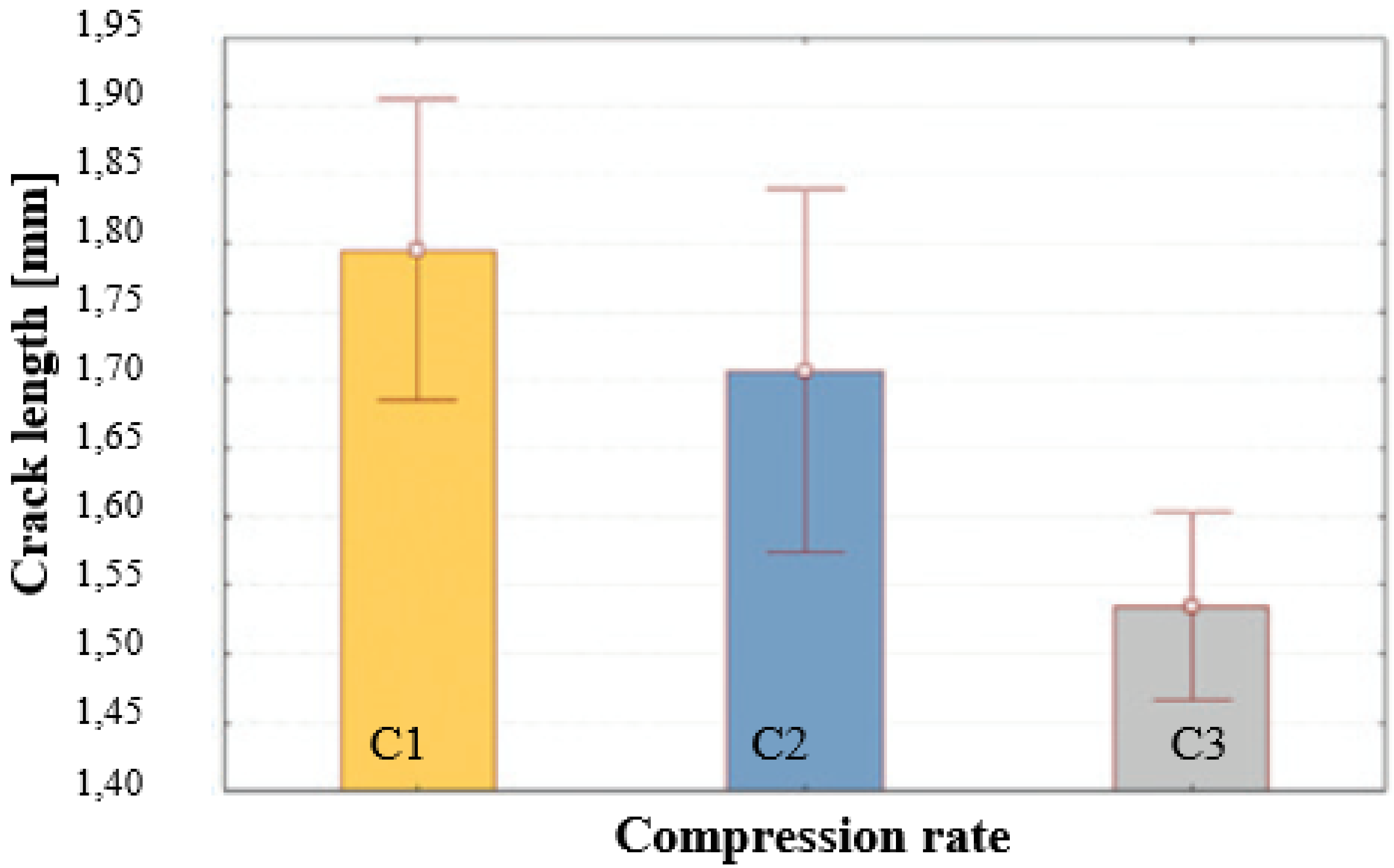


Figure 151. Crack graph.

Compared to the sheets subjected to a compression rate of 5%, a higher number of linear cracks was observed, that is, at greater C the length of cracks decreases.

*Discoloring: sunrays and low temperatures cause wood defects such as discoloration and cracks.

4.5.4. CONCLUSIONS AND FUTURE STUDY

Then the previously explained basis mathematics (Table. 149.) will be applied to two climate data documents (one in the past and the other in a prediction of the future).

CLIMATE DATA IN THE PAST

INSECT ATTACK

There is a correlation between the degrees day and the life cycle of insects. An insect's life cycle is approximately 490 degree-days.

In this case, since we have approximately 200 in both cases, it only reaches 2/5 of the life cycle of an insect. It can be concluded that the insect attack is insignificant (Table. 152.).

Increasing temperature increases not only the number of life cycles but also the amount of eggs laid in each generation and the speed at which the larvae feed.

CLIMATE INDEX

The first and fourth columns show the monthly temperature and precipitation. On the other hand, the third column shows daily rainfall in one year (Table 153.).

It is observed that the climate index is less than 24, therefore it has a very low risk (Table. 154.).

SUM	203,05	200,70
GROWTH CYCLE YEARS≈	2/5	2/5

Table 152. Table Insect Attack.

TM	TM-2	RND	RNM	RN>0,25
-0,68	-2,68	0,00	2,24	0
-0,87	-2,87	0,00	1,70	0
1,26	-0,74	0,00	1,23	0
6,05	4,05	0,00	1,77	0
11,43	9,43	0,00	2,15	0

Table 153. Climate Index.

E	D-3	(TM-2)*(D-3)	CLIMATE INDEX
2,24	-0,76	2,03	0,12
1,70	-1,30	3,72	0,22
1,23	-1,77	1,31	0,08
1,77	-1,23	-5,00	0,30
2,15	-0,85	-8,04	0,48

Table 154. Climate Index.

≤24 (low decay risk)	TM:	mean monthly temperature
24~28 (medium decay risk)	RND:	daily
>28 (high decay risk)	RNM:	monthly
	TRUE=	0,00
	FALSE=	1,00

Table 155. Climate Index.

CLIMATE DATA IN THE FUTURE

INSECT ATTACK

There is a correlation between the degrees day and the life cycle of insects. An insect's life cycle is approximately 490 degree-days.

In this case, since we have approximately 300 and 90, it only reaches 3/5 and 1/5 of the life cycle of an insect. It can be concluded that the insect attack is insignificant (Table. 156.).

Increasing temperature increases not only the number of life cycles but also the amount of eggs laid in each generation and the speed at which the larvae feed.

CLIMATE INDEX

The first and fourth columns show the monthly temperature and precipitation. On the other hand, the third column shows daily rainfall in one year (Table 157.).

It is observed that the climate index is less than 24, therefore it has a very low risk (Table. 158.).

SUM	337,99	96,20
GROWTH CYCLE YEARS≈	2/3	1/5

Table 156. Table Insect Attack.

TM	TM-2	RND	RNM	RN>0,25
-0,14	-2,14	0,00	2,03	0
0,11	-1,89	0,01	3,40	0
3,36	1,36	0,00	2,28	0
7,24	5,24	0,00	2,21	0
13,23	11,23	0,02	2,62	0

Table 157. Climate Index.

E	D-3	(TM-2)*(D-3)	CLIMATE INDEX
2,03	-0,97	2,07	0,12
3,40	0,40	-0,76	0,05
2,28	-0,72	-0,98	0,06
2,21	-0,79	-4,15	0,25
2,62	-0,38	-4,24	0,25

Table 158. Climate Index.

5. DISCUSSION

To determine the effects of climate change on the examined buildings, several hygrothermal simulations have been executed. Based on the change of air temperature, relative humidity, moisture content and mold index within the buildings, a prediction for future risks will be made. It is difficult to compare the results from the two future scenarios. As presented in a previous chapter, they have completely different values for the individual parameters. The results of the simulations using data for current climate conditions are the reference and reflect the current conditions of the buildings. The simulations for mold index were only run for the RCP8.5 scenario. However, a significant increase of the mold index should be expected. While the mold index for the current situation is below one for most cases of the buildings, the mold index under the RCP8.5 scenario is six in nearly every component. The mold index can be considered significant when the results reach the level of around 1.5 to 2. The change from mostly not significant mold index in the current climate to significant mold index in every case in the future RCP8.5 scenario is due to the warmer temperature and the increase of rainfall. The results from the RCP8.5 scenario are the worst case results and reach easily over the significance of 1.5 to 2. These amounts of mold index will cause a fast deterioration of the wooden buildings.

When it comes to the moisture content, the results show big differences for the future scenarios. The current situation and the A2 scenario have a similar range of values. The moisture content is even becoming less for the A2 scenario. However, under the RCP8.5 the water content approximately doubles.
The buildings themselves are badly isolated. The are no major differences between the outer and inner conditions in terms of air temperature and relative humidity. Regarding the differences between the future climate files and the results of the simulations, it can be assumed that large changes of the climate conditions have an enormous impact on building materials. It is also important if the components are under direct influence of the outer conditions or if they are protected from some influences.

Due to wider range of moisture content in the components, the shrinkage and swelling caused by the fluctuations of the moisture content will occur more heavily. The fluctuations are mainly caused by solar radiation, rain and air temperature. As a result of this, the existing cracks will expand and new cracks can arise. In addition to that, the more moisture there is in the building components, the more fungi and green algae will grow. Discoloring is mainly caused by solar radiation. However, to make a precise statement whether it is getting worse or not, a detailed comparison for solar radiation and cloud cover would be necessary.

6. CONCLUSION

The objective of this research is to understand the behavior of the two timber buildings of the case study in Tønsberg facing climate change. After the investigation was generated, it can be stated that an increase in the air temperature and the relative humidity occurs in the site where those buildings are located. Under the influence of these alterations, a faster biodeterioration of the building materials for both structures was predicted. Nevertheless, not all the components of the buildings are affected by mould with the same intensity. Accordingly, it can be affirmed that climate change has an impact on timber buildings with similar characteristics and it affects directly the building materials, under some specific climate conditions.

This paper is a study of an European Project Semester (EPS) at Oslo Metropolitan University that collaborates with Hyperion, a project funded by the European Union. The EPS will have a further impact on Hyperion, and it will help to provide data and generate conclusions.

7. GROUP REFLECTIONS

MAUD GRUYTERS

Sustainability is of great importance in my personal life, so going into this project I was highly motivated. I chose this project to improve my knowledge about climate change since I aspire to become a responsible and conscious product developer. Moreover, I wanted to challenge myself to participate in a project that isn't directly in line with my field of study.

This EPS-project was carried out by four bachelor students and two internal supervisors. Our supervisors, Dimitrios and Petros, supported us through the whole project. Dimitrios was from the beginning able to determine the strengths and weaknesses of each team member, which resulted in a great division of the tasks. During the first part of the semester, we had one consistent weekly meeting to discuss the progress we made and the struggles we faced.

Halfway March Oslo Met had to close, due to the Covid-19 situation. However, against my expectations, this didn't affect the final result. With the help of our supervisors we were able to overcome this unusual situation. Dimitrios and Petros were both very approachable and willing to help us reach the deliverables.

At the start of the project I was exited to work in an international group, since group work is a focus point in my study field. I was curious to experience the different learning methods and see how each student carried them out. Looking back, I'm glad to write that my overall experience was positive. Nevertheless, there were some issues in our group dynamics which caused for some concern on my behalf. After some segregation measurements were taken, the issue became manageable and we could start working effectively again. The working environment I experienced after these measures was highly constructive and productive, which I'm very grateful for.

This project enriched my knowledge about the specific effects of climate change greatly. Since this topic interest me, I already read a great deal about the theoretical aspects of climate crisis and the impact humans have on it. However, this project gave me the opportunity to investigate the actual effects of climate change on practical case studies. The scope of the project was more scientific than I expected, nevertheless, it turned out to be a challenge worth taking.

Besides the main project, there were two supported courses, English and Academic Writing and Working In Projects. I enjoyed the English class, teached by Kristin, since it gave me the chance to get a clearer view of what the other EPS-students were working on. Kristin was very encouraging and never failed to help us out. The content of the class was useful, however, several classes were a repetition for me.

The European Project Semester has been incredibly educational, both the project itself as the working in group. Dimitrios and Petros gave us the freedom to challenge ourselves to our own account and helped us face many obstacles. Even though there was an issue, the positive aspects outweigh the negative. I feel satisfied with the report we delivered and the personal improvements I made.

ADRIANA MARTIN

Now that this European Project Semester is about to end, it is very useful to analyze the personal experiences related to working in teams, solving problems, and other different challenges we have been facing since it started. It has been very enriching to be part of this project, being able to learn and to improve some of my personal skills which might be interesting for my professional career in the near future.

One of the biggest issues we have had to confront during the past months is the global pandemic of COVID-19. This situation has affected the whole world in different ways. We, as students, have had to cope with many unexpected changes in the learning process and to be more flexible to adapt to the new circumstances. During the first two months, we got used to working face to face on our project, to attempting classes and workshops, and sharing most of our time together. All of a sudden, everything turned into an absolutely different reality. Meetings were not allowed anymore and campuses remained closed until the end of the semester. It was very important for us to adopt a responsible position in order to keep going on with the project to achieve the goals we set at the beginning, but now following a different path.

Communication always has been one of the keys to success while working on teams. With COVID-19, it became a problem we needed to solve. Exchanging information had to be carried out in a virtual way. That led to misunderstandings and some technical problems, so it was required to be more understandable and patient with others. Another aspect to take into account is the fact of working at home. It affected our productivity and our personal lives because we did not make a difference between the working and relaxing space. Sometimes it was very stressful to stay in the same place working for too long.

The uncertainty of the future was also very tense to live with. We did not know how the situation was going to be in the near future, so we needed to be prepared to be flexible enough to handle changes.
It was indeed a very challenging situation. However I am glad to say I avoided the obstacles successfully and I learned what works for me in terms of coping with stress and extreme work circumstances.

Although I faced challenges along the way, I had positive experiences throughout the semester. My EPS project is part of Hyperion, a program funded by the European Union where many countries and universities around Europe are taking part. I feel very lucky to collaborate hand in hand with my supervisors contributing with our part to this big scale project. It is very inspirational and it will boost my future career to more ambitious goals.

This project has helped me in a variety of aspects. It developed my working in teams abilities and it provided me other diverse values. It has been very interesting to share this experience with people all around the world. Being in a multicultural team has been complex, but also a grand experience. I noticed that I’ve improved my English communication skills and I gained confidence in myself. I am willing to work on other multicultural teams and keep developing personal and professional skills.

MATTHIS SOPHA

The European Project Semester was a very important experience for me. It confirmed me not only in the decision to do my master abroad, it also gave me the opportunity to learn a lot about teamwork and working in international teams. Our group consisted of four people, two from Spain, one from Belgium and me from Germany. I did not know what I should expect from the Semester since I never worked in an international group. It turned out that this was not a problem at all. Initial language difficulties quickly vanished as I got more used to it to speak English instead of German. Despite the differences in culture and way of working most of us were able to find a good way of working together. However, we also faced some problems within the group which we were not able to solve on our own. Therefore, we involved our supervisors to find a solution. Unfortunately we had to split up the group in the end and one person got an own assignment related to the project. I think it was the best decision because it is really exhausting to discuss over and over again with someone who can hardly reflect herself and who shows no insight to the situation we had. However, even if it got on my nerves, in the end it was an experience you can easily face in any other group work and therefore, I might be able to handle such a situation different the next time.

When it comes to our project, the topic was new to all of us and nobody did an scientific research before. Therefore, in the beginning of the Semester, it was not easy to understand what the main goal of this research actually was. However, our supervisors, Dimitrios and Petros, gave us a lot of help and together we were able to create a work plan for the Semester. I am highly interested in sustainability and the impact of climate change on our life. Nowadays, these themes play an important role in every part of modern life, also when it comes the development of new technologies. I learned a lot about it and I am sure it will help me in my future life.

From the start of the Semester we had a weekly meeting with our group and our supervisors to discuss results and divide working tasks for the next week. Dimitrios knew how to adapt these tasks to each individual's strengths. Even when it was sometimes more complicated, it was a nice challenge to solve problems. And in any case we were stuck we always could ask Dimitrios or Petros for help and were able to find a solution. Unfortunately, the Corona crisis broke out and the campus of OsloMet was closed. However, this had no significant impact on our work. We switched to online meetings and continued with our project.

I am glad I have stayed in Oslo despite Covid-19. The situation in Norway was not as bad as in other countries and we did not have that strict rules. Since we were still able to go outside and enjoy the life in Oslo it was no problem at all to stay focused on the project. Beside our project we had two supporting courses, Working in Projects (WiP) and English and Academic Writing. While WiP got cancelled due to Covid-19, Kristin's course continued with online meetings. This course was very helpful to write the final report. We could always ask her anything and she gave us a lot of positive feedback.

Overall, I have had many positive experiences during this European Project Semester. It was a pleasure to work with my group members and my supervisors. I would always do it again and I think every student should go for it, too.

ARIADNA TUBAU

EXPERIENCE IN EXCHANGE

I am glad I made the decision to do an exchange, specifically in Norway. I chose Norway to do my exchange because it has one of the best educational systems in Europe. Given that for Norway, the internationalization of studies is very important, they give priority to facilitating the adaptation and integration of foreign students, with a large number of masters and university courses in English.

Being a country with two mother tongues (Norwegian and English), I thought that I would have problems in my day to day since I do not speak Norwegian, but it was not. I think that I have matured, in the fact of living alone and living in a country where my mother tongues are not spoken.

Norwegian culture is quite interesting, its inhabitants stand out for being kind and modest and a great peculiarity to name is their commitment to human rights and the conscience of society to recycle and conserve the environment. My adaptation to life in Norway was easy, I thought it would cost me more since the time slot for meals is as follows: have lunch between 12pm and 1:30 pm and have dinner is usually between 6pm and 8pm. Business hours in Norway start at 9 a.m. and run until 5 p.m. or 7 p.m.

Norway has seemed to be one of the most beautiful countries in the world, I had a very different idea of Oslo, without a doubt I plan to return one day. It has been one of the best experiences that I have lived in my life, I think that every student would have to live this experience.

EXPERIENCE IN EPS (EUROPEAN PROJECT SEMESTER)

Unfortunately, my experience in EPS (European Semester Project) has been negative. I would repeat the experience but with another group. I have noticed that in Spain we are very used to working in a group (and to adapting to how each partner is), while in other countries they are not used to it.

The subject of the project seemed quite new to me because I had never worked in a sector that was not just about mechanics. The truth is that since I started working on the project, I have observed more how the weather affects buildings.

On the other hand, from the first day I arrived in Oslomet I thought that it would be difficult for me to follow the lessons since I had never had classes in English. I realized that it was not complicated at all, the more time I spent in classes the less it cost me.

ORGANIZATION

At the beginning of the semester, each week we had a meeting with the supervisors. In this meeting, we talked about different topics, and once discussed we carried out the distribution of tasks. Normally if they were very affordable tasks, we did them individually and if not in pairs. Most of the time the couples were Adriana and Ariadna, on the other hand, Matthis and Maud.

After hearing the news that Oslomet was to be closed by COVID-19, the supervisors decided to modify the distribution of the work. On the one hand, Maud and Adriana (Dimitrios was the manager) worked together, and, on the other, Matthis and Ariadna worked individually (Petros was the manager of the members who worked individually).

I would like to thank Petros, since, from the moment they separated me from the group, he has been guiding me towards my final task, having two weekly meetings. One of these weekly meetings was with the whole group. In this meeting, we explained what we had done during the week and all the problems that had arisen.

EXPERIENCE AT OSLOMET

All Oslomet students should feel very fortunate to have such a modern and well-equipped university. I have never been to a study center where you could have all kinds of tools and the latest generation at your fingertips.

Fig 1 - Oslomet.

Fig 2 - UPC (EPSEVG).

Oslomet addresses 20.635 students, the university I come from (EPSEVG) only about 1.398, it must be borne in mind that this university is only focused on the engineering sector. Instead, Oslomet covers many more specialties.

In Spain, most engineering lasts 4 years (and is based more on theoretical learning). In contrast, in Norway, it lasts 3 years (and is based more on quite practical learning).

COVID-19

From my point of view, Oslomet has carried out good academic management of COVID-19. Oslomet closed its doors on March 11, since then all classes and meetings were done online (ZOOM).

Obviously, we couldn't carry out everything we had planned, since from the first moment we wanted to 3D print the two buildings. But with everything and with that we have been able to continue with our project.

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FIGURE OUT HOW TO SOLVE THE PINK HIGHLIGHT

9. APPENDICES

8.1. Sustainable development goals

1.Introduction

Human activity has an increasing influence on the climate and the temperature of the earth. This project focuses on finding and studying the specific climate parameters that have an effect on cultural heritage buildings. The main goals of the research are to map the buildings, analyze the climate risk scenarios and investigate the biodeterioration of old building materials.
This EPS project will investigate three historic timber buildings in Tønsberg. The case studies will be used as a guide in the future to predict further deterioration of construction materials.

Figure. 1 - Fadum Storehouse; Heierstad Loft

2. The Sustainable Development Goals

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth, all while tackling climate change and working to preserve our oceans and forests.

3. Connection with the project

There are several goals strongly linked with the EPS project, according to the main objectives and the fields covered. The goals helped to approach to the purpose of the project and to have a better understanding of the overall progress.

GOAL 3 Good Health and Well-Being

Concerning the investigation of the effect of climate change on buildings. Moisture is the main effect that causes discomfort to humans since it generates fungi. Fungi can cause symptoms as chronic mucocutaneous candidiasis, which affects the skin and mucous membranes, or congenital candidiasis.

3.9: By 2030, substantially reduce the number of deaths and illnesses caused by hazardous chemicals and pollution and contamination of air, water, and soil. Figure 2 shows the samples taken during the inspection in Tønsberg from both buildings.

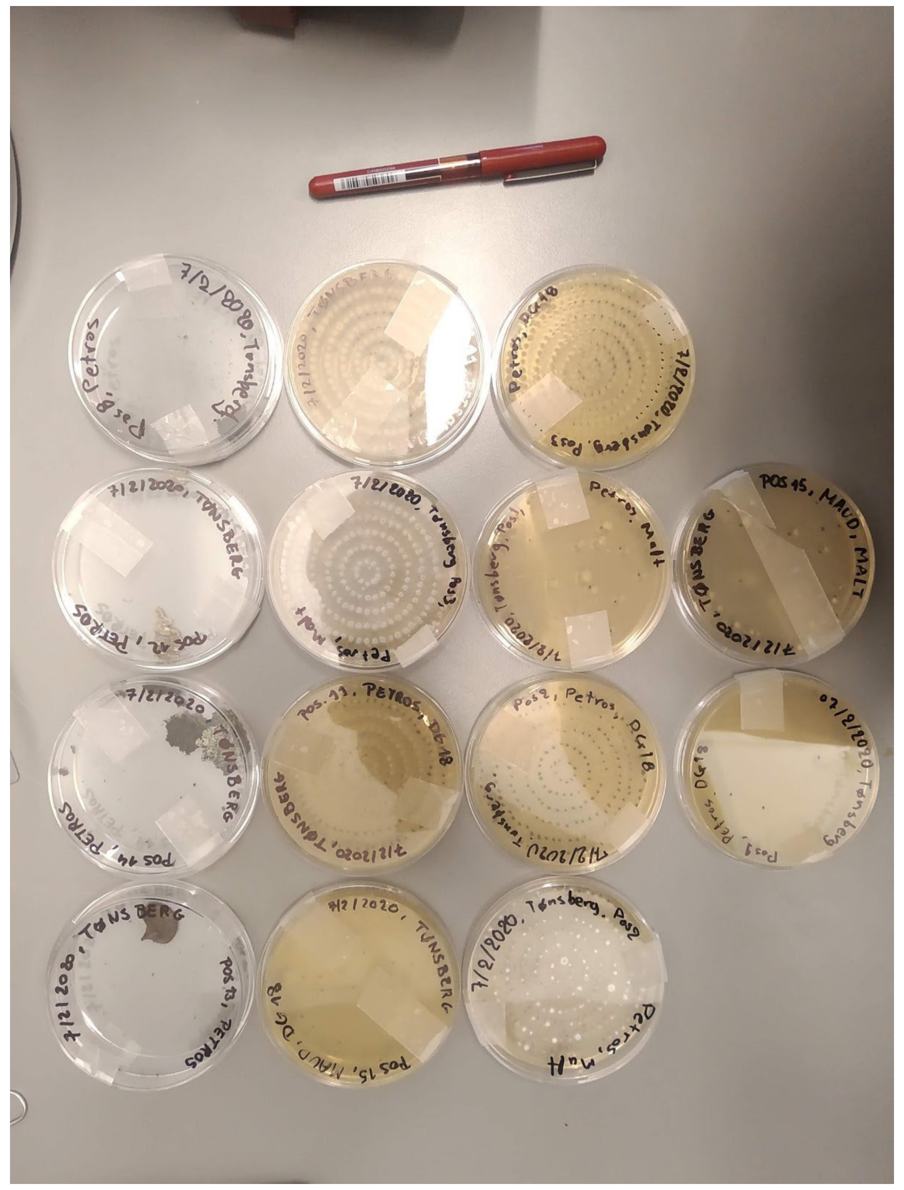

Figure. 2 - Samples of fungi

Figure. 3 - Physical inspection in Tønsberg.

GOAL 9 Industry, Innovation, and Infrastructure

Construction materials as well as deterioration of them is the key aspect of this project. The investigation of the historic timber buildings can give us important information about the humidity, the isolation and the temperature of the buildings. The two following goals are relevant for this project due to the connexion between infrastructure and humans.

9.1: Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all.

The data collected in this research can be used to construct buildings that are more resilient against climate impact. Timber houses are vulnerable to biodeterioration and the isolation of the buildings is very poor. This research and all the collected data will provide to architects, engineers, and designers with new knowledge to build climate accustomed buildings.

9.5: Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending.

On this point, the project is taking a step in the right direction. Not only because the project is funded by the European Union but also because this research takes place in different countries. As mentioned above enhancing research about the deterioration of materials is important to prevent or decrease the same phenomenon in the future.

GOAL 11 Sustainable Cities and Communities
Many cultural heritage buildings are located in cities or areas which are affected by man-made changes. That is why these buildings are exposed to a wide variety of influences every day. It is not enough to try to protect those buildings from deterioration and aging by making the cities sustainable. People must also achieve a sustainable lifestyle in order to preserve the infrastructure. Goal 11 describes a wide area of targets to make cities and communities sustainable. One point corresponds to our project.

11.4: Strengthen efforts to protect and safeguard the world's cultural and natural heritage.

The cultural heritage buildings are part of the history and the appearance of the city. Protecting them should be of general interest.

GOAL 13 Climate action
Climate change is affecting life on earth in many ways. The problem is that it is occurring faster than expected. Although progress is already being made with a positive step to limit this problem, a more ambitious plan is needed. Here are two remarkable targets that share the same goal as the EPS Project.

13.2: Integrate climate change measures into national policies, strategies, and planning.

It is very important to establish some limits and make strategies and plans to ensure proper development and a safe future. Some effects as global warming or the increase of intense rain may cause damage to the building materials, and therefore the cultural heritage buildings.

13.3: Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning.

Hyperion project studies the behavior of historic buildings in the future, but the whole population has to take part and reduce the climate impact. For that reason, effective education and a global consciousness are needed. It is essential to strengthening individual motivation and awareness to mitigate the global impact because humans have the biggest influence on the climate crisis.

GOAL 17 Partnerships for the goals
Globalization makes cultural heritage buildings accessible to a growing amount of people. To protect and preserve them for future generations, all the different countries must work together. Culture and History belong to everyone, so protecting them should be a priority for everyone. Project Hyperion is a joint project of the European Union. In this case, the EU already tries to implement some of the goals of sustainable development. In particular, there are two main points which coincide with our and similar projects.

17.3: Mobilize additional financial resources for developing countries from multiple sources.

Many cultural heritage buildings are located in countries with weak financial resources. These countries do not have the ability to preserve those buildings and protect them from aging and deteriorating. The industrial countries have the financial strength to provide assistance for the developing countries and should be in charge to do so.

17.13: Enhance global macroeconomic stability, including through policy coordination and policy coherence.

Through conflicts, political problems and poor economic conditions many developing countries are not able to preserve cultural heritage buildings. In addition to that foreign scientists are at risk when being in those countries due to dangerous political situations. With international cooperation, security can be increased and productivity can be improved. It is already being implemented with UN missions for example in African countries.

Figure. 4 - European Union Flag

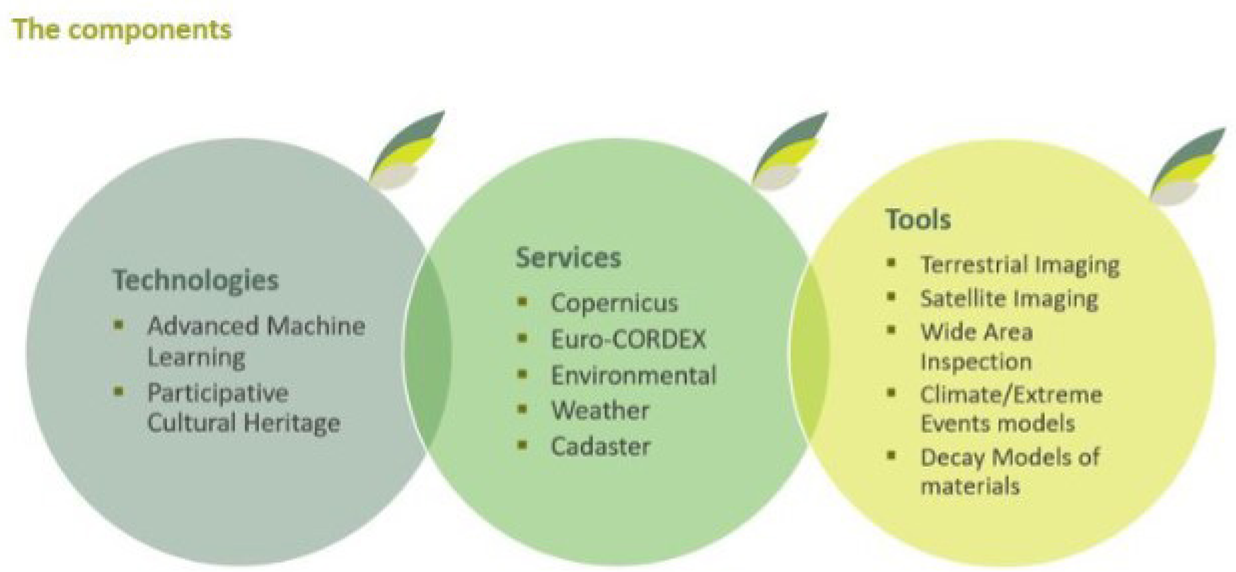

Figure 5 - Components of Hyperion.

8.1. WUFI PLUS RESULTS RCP8.5

Graphs moisture content

FADUM STOREHOUSE

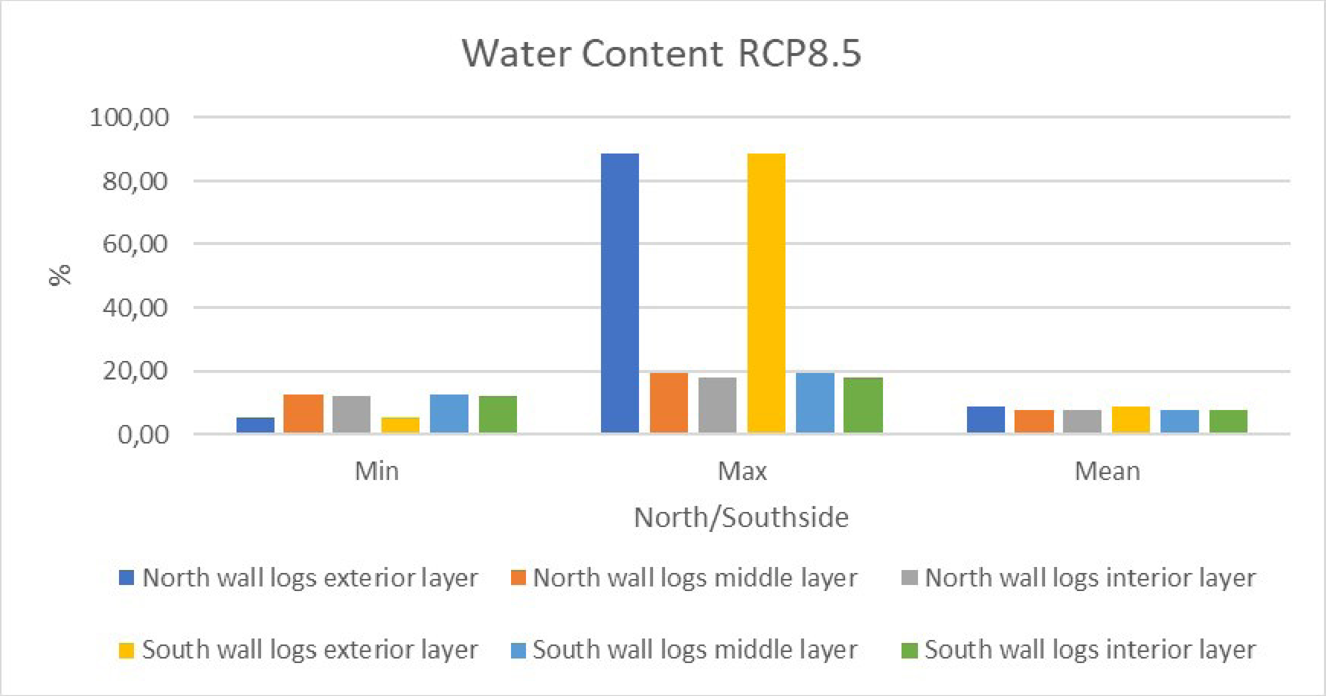

Figure 1 - North/Southside

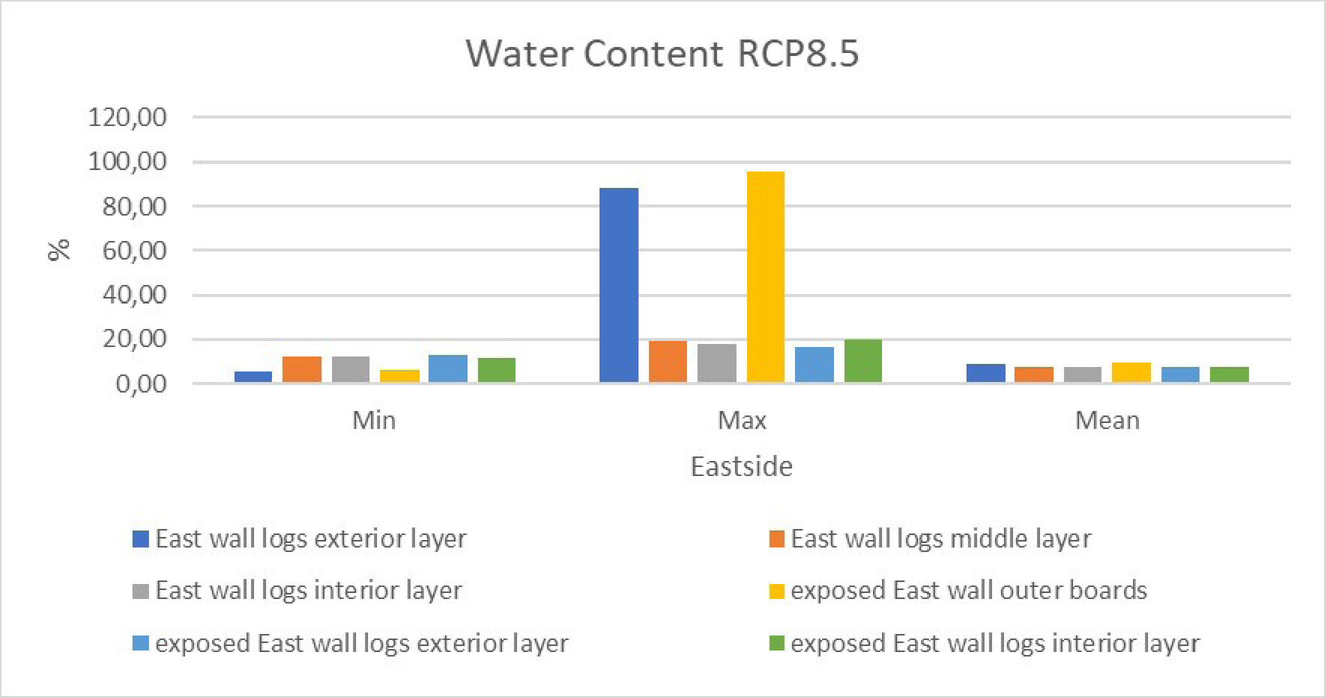

Figure 2- Eastside

HEIERSTAD LOFT

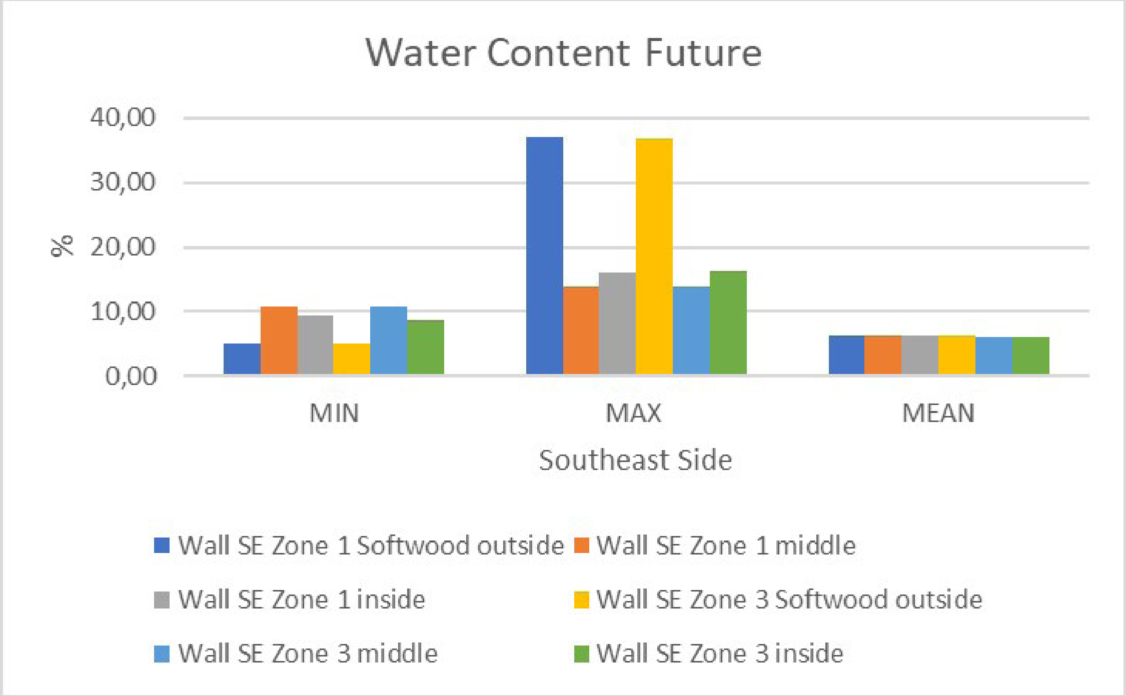

Figure 3 - Southeast side

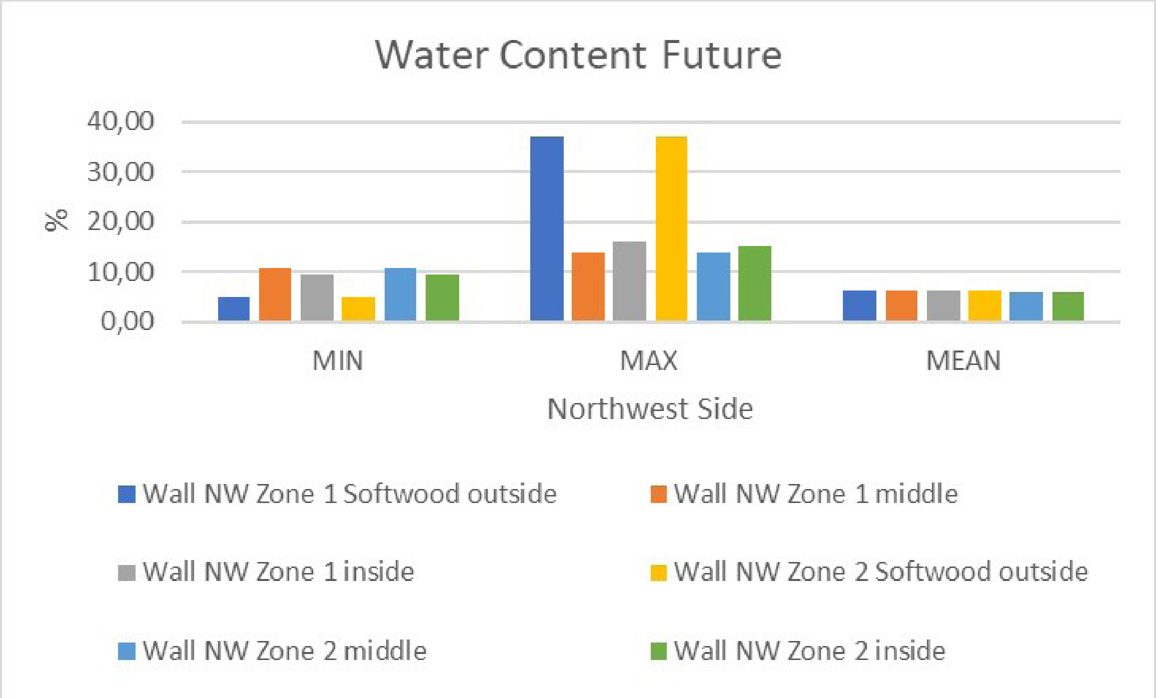

Figure 4 - Northwest side

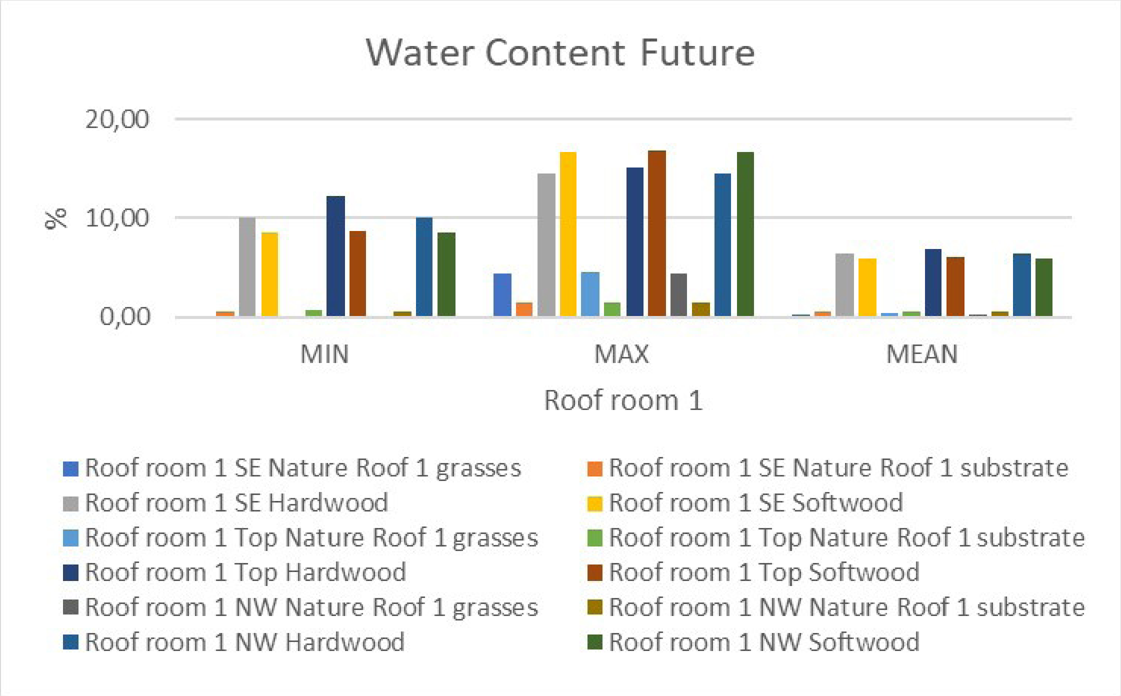

Figure 5 - Roof room 1

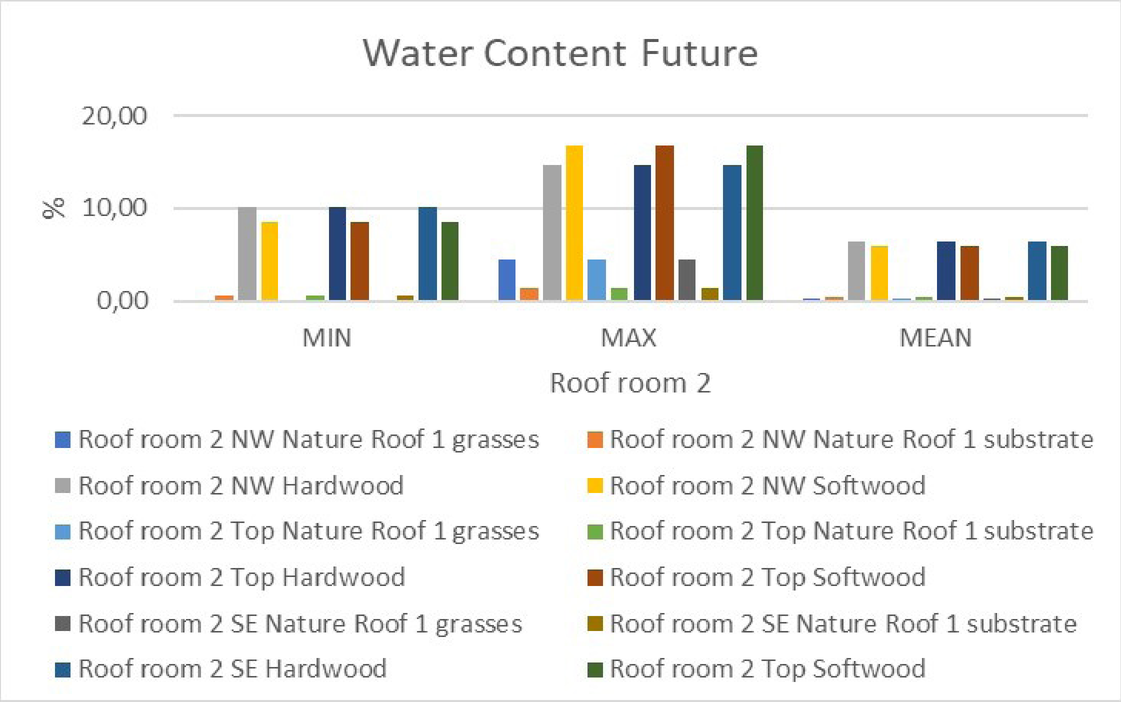

Figure 6 - Roof room 2

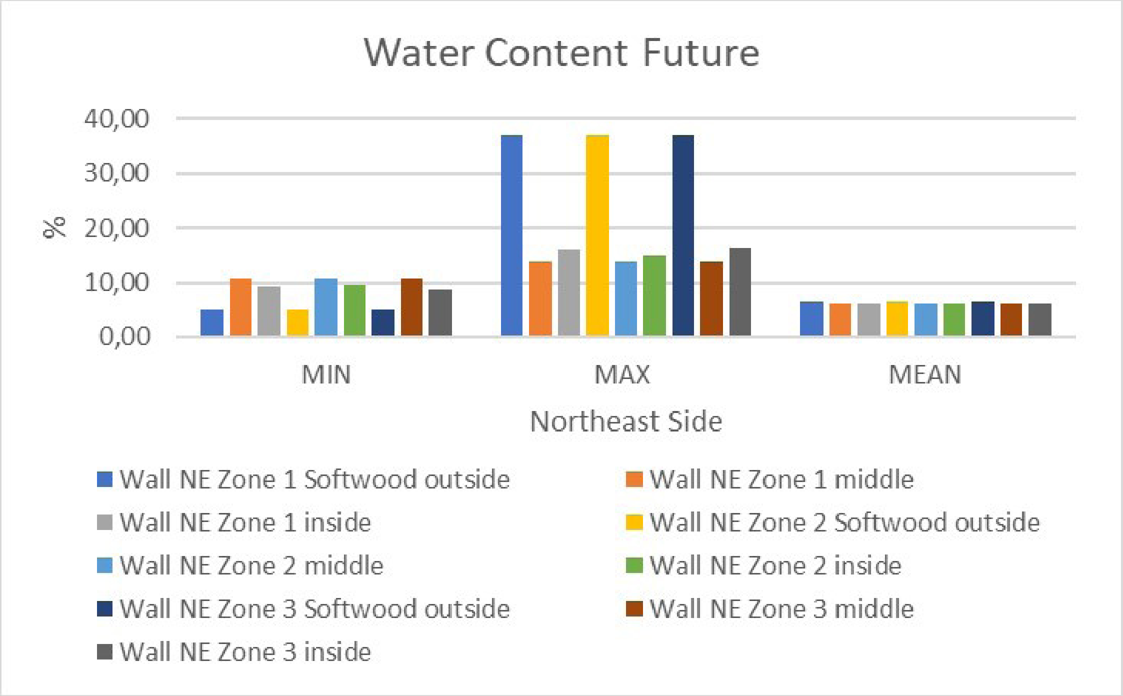

Figure 7 - Northeast side