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MOISTURE AND TIGHTNESS MONITORING WITH DIFFERENT MEASURING SYSTEMS AND METHODS - EXAMPLE APARTMENT BUILDING

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ABSTRACT: Moisture monitoring is becoming an increasingly relevant technique to ensure that buildings remain in good quality. Building with wood, whether it is for family homes or mid-rise buildings, is more popular than ever. Rising prices, high-quality requirements and calls for swift construction completion are impacting contemporary modern architecture. These changes are far-reaching: after all, simple, straight structures offer enormous advantages in terms of systemisation, prefabrication and the mounting of buildings. Consequently, there has been a visible change from sloping roofs to flat roofs. In addition, even storey levels offer further advantages: compliance with distance regulations to neighbouring properties is facilitated. These areas can partly be used as terraces, gardens, and also for the installation of building service equipment (heat pumps, ventilation equipment, etc.). Concerning moisture issues, natural building materials must be handled with great care in order to ensure the durability of a building structure. Despite great craftsmanship in the construction of buildings, unforeseeable problems due to moisture penetration occur time and again. To counter such issues, a range of moisture and tightness monitoring systems have come onto the market in recent years. How do they work, which system is best suited for which monitoring purpose? Which dangers arise from installing additional structures? With the support of the Province of South Tyrol/Italy and the company Ligna Construct for this research project, it can be shown how important monitoring systems can be. The measurement results of the three installed monitoring systems show that already in the construction phase, but also in the later use phase, a high degree of safety is given with regard to moisture penetration and water ingress.

KEYWORDS: Moisture monitoring, area sensors, point sensors, wood moisture measurement, timber construction, flat roof, terraces

1 INTRODUCTION

Research institutions and companies have been working on the topic of moisture and tightness monitoring for years. The aim is to bring systems to the market for monitoring moisture and tightness in the sealing and insulation level, in addition to material moisture in order to increase moisture protection in wood buildings. In this research work, three quality-assuring active monitoring systems are presented, with which moisture-prone building components can be monitored. Components at risk of moisture penetration are e.g. roof and terrace sealings, insulation layers in warm roofs as well as the supporting wooden structures located under the sealing levels. Furthermore, measurement monitoring of water-bearing installations in floor and wall constructions is an important aspect. Active measurement monitoring involves monitoring with automated evaluation and alarming systems in case a defined threshold value is exceeded. Questions that arise in the context of leakage and material moisture monitoring are: How do active moisture monitoring systems work? Which systems are best suited for which monitoring tasks? Which risks arise from installing measuring systems? In order to provide answers to these and other questions, three active monitoring measurement systems were used in an apartment building. This research project, with a two-year time frame, was developed in cooperation with the timber construction company Ligna Construct from St. Pankraz in South Tyrol/Italy and with the financial support from the Province of Bolzano/Italy. The official research project ended in September 2022. The monitoring by means of the three measuring systems will be continued for the time being in order to obtain long-term data about the moisture behaviour in the specified areas.

2 PROJECT DESCRIPTION

The apartment building is a newly constructed three-storey building with five residential units, a garage in the basement and an adjacent existing single-storey building with a green roof. The two upper floors and parts of the floor slab on the ground floor were built in cross-laminated timber. Due to the multiple levels (flat roof, terraces, balcony, etc.) as well as changing materials (reinforced concrete, cross laminated timber, bitumen sheeting and plastic waterproofing) and the exposed location, this building is particularly well suited for

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investigations of this kind. Planning and investigations began in September 2020.

Figure 1: *Investigated Apartment Building*

The first step is to determine which and how many measuring systems are to be used in and on the building. When determining the number of systems, special attention is paid to monitoring those areas of the building where there is a higher risk of moisture or water ingress. The number and types of measuring systems used are to be installed in such a way that leakage and moisture monitoring is provided for all flat or slightly sloping external surfaces such as roofs, terraces and greened areas. Furthermore, it is important that the measurement results of the installed monitoring systems can be compared with each other. The aim has been to obtain as many results and findings as possible for future timber buildings. In consultation with the timber construction company Ligna Construct, the following three moisture monitoring systems were used:

- Measurement of wood moisture content
- Measurement with area sensors
- Measurement with point sensors

Before installing the moisture and leakage monitoring systems, detailed installation plans are drawn up for all three measuring systems. They are discussed with the project partner on site and checked for completeness. All three measuring systems are equipped with a remote monitoring modem so that monitoring and reading data are accessible at any time.

2.1 MEASUREMENT OF WOOD MOISTURE CONTENT

The electrical resistance measuring method of the company Scanntronik Mugrauer GmbH is used to monitor wood moisture. Electrodes in the shape of stainless-steel screws of different lengths are mounted to measure the wood moisture distribution. The screw shaft is insulated with a shrink sleeve so that the moisture is only measured at the tip of the screw. This makes it possible to measure the wood moisture specifically at different depths of the wood. The distance between the electrodes is 30 mm. The measuring electrodes are connected to the material moisture meter with shielded coaxial cable, which may have a maximum length of 15 metres. Up to eight measuring points can be monitored with one device and, depending on the pre-setting, forwarded to a data logger and stored every second, minute or hour. Furthermore, it is possible to record the temperature (e.g. wood, air) and the relative humidity via a data logger in combination with a sensor unit. The measured values stored with the data logger can be received by e-mail. If there is a power connection to the measuring systems the data can be accessed via telephone. Otherwise a specified time interval is set and the data are sent via email. The output value of the wood moisture is provided in percent or in ohm. In addition, the temperature in the wood and the relative humidity in the interior of the building were recorded.

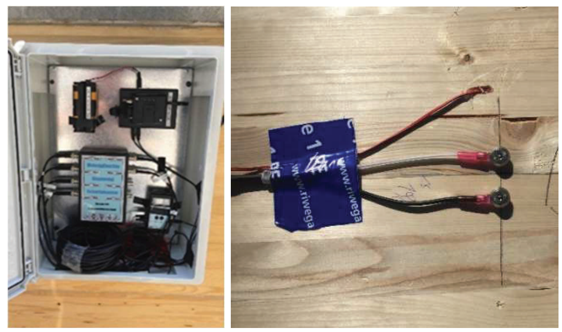

Figure 2: *The wood moisture measurement equipment, left data storage, transmission modem, right moisture sensors (below) and temperature sensor (above)*

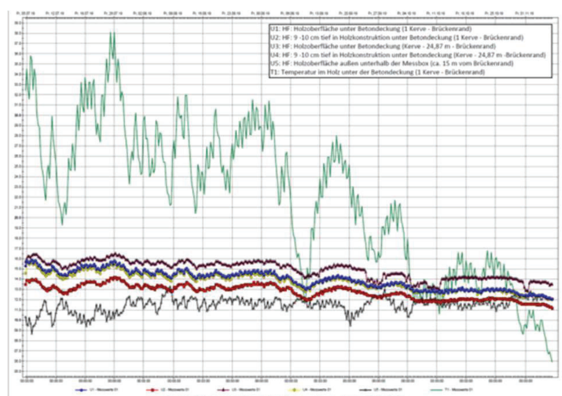

Figure 3: *Wood moisture data*

2.2 MEASUREMENT WITH AREA SENSORS

The Optidry® Monitoring System (OMS) is an active building monitoring and warning system for the early detection of hidden water damage. The area sensors are installed on the diffusion-inhibiting or vapour-blocking (warm roof) level as the flat roof covering is attached. Before installing the area sensors, the roof is divided into different zones (edges, main area, risky spots). Installation is straight forward and it depends on the waterproofing membrane used (bitumen, plastic, raw ceiling), whether the area sensors need to be glued or nailed. Up to eight

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independent monitoring areas (area sensor units) can be connected via a bus system and the data saved in a control centre. If the specified upper humidity limit, gauged in digits, is exceeded, an alarm is triggered by the central unit and forwarded to the customer. The current moisture status at the sealing level can be accessed and evaluated directly on a smartphone, tablet or PC using the OMS Inspector app. Water ingress can thus be detected at an early stage and localised. In addition to flat roofs and terraces, the system is also used in wet rooms from service class W3. The Optidry Monitoring System can be integrated into smart-home systems or into the building technology equipment.

Figure 4: *Area sensor measurement*

The belt or area sensors are approx. 5 cm wide fabric strips containing two stainless steel wires. The moisture content in digits is determined via the resistance between the two wires.

Figure 5: *Area sensor measurement*

2.3 MEASUREMENT WITH POINT SENSORS

The system used, the RPM ROOF PROTECTOR, is a simple and efficient device to immediately detect moisture in roof structures and to take timely action. Indicators evenly laid out over the roof surface measure the moisture and temperature. This allows gaining insight into the moisture condition of a roof package (insulation package). The measuring system can be applied to all commercially available roof layers (waterproofing, insulation, etc.). The system also fulfils the additional measure required in ÖNORM B 3691 for the monitoring of flat roofs of use category 3. The recorded measurement data are stored on a central server of RPM Gebäude Monitoring GmbH and can be retrieved permanently and at any time via a web browser. The measuring sensor is located in the warm roof structure just above the sealing membrane (vapour barrier). In addition to measuring the humidity, which is indicated in digits, the temperature is also measured in the area of the vapour barrier and on the outside at the surface of the roof structure. The sensor is usually installed after the top waterproofing layer has been laid. The insulation material in the warm roof structure is drilled out with a so-called box drill, which has the same diameter as the point sensor, and the fully insulated point sensor is inserted there. The system used is battery-powered and is therefore self-sufficient and can be used wherever there is a radio contact for data transmission. The system measures the humidity and temperature in the insulation level and also on the sealing level of the raw ceiling.

Figure 6: *Point sensor measurement*

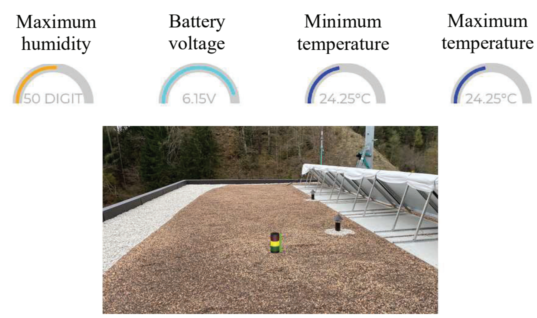

Figure 7: *Point sensor measurement*

3 INSTALLATION OF THE MEASURING SYSTEMS

The measuring systems are installed on three levels of the apartment building: on the flat roof (humidity measurement, area sensors, point sensor), on the first floor (area sensors) and on the ground floor (area sensors, point sensor). Area sensors are also installed in the six bathrooms. In this paper, however, only the measurement systems in the outdoor area are dealt with.

3.1 MEASURING SENSORS ON THE FLAT ROOF

Figures 8, 9 and 10 show the floor plan of the flat roof with the arrangement of the measuring circuits and measuring points. To provide a better overview, the related systems and measuring areas are shown individually in the floor plans.

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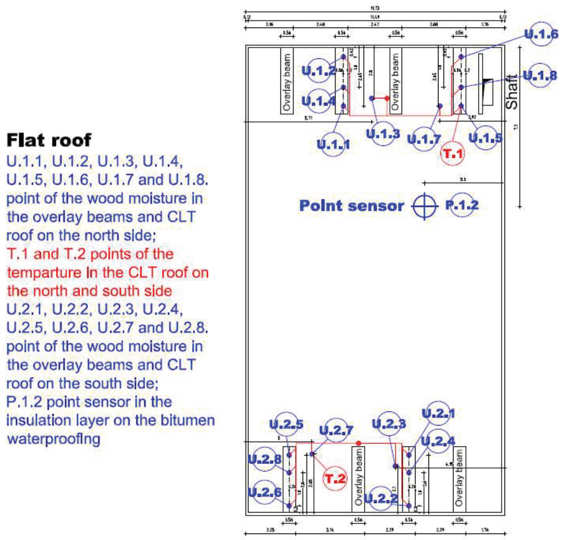

Figure 8: One point sensor and 16 measuring points of the wood moisture and temperature measurement.

The first flat roof plan shows the measuring points for the wood moisture measurement, of which eight measuring points each (label U) were installed on the south and north sides of the roof. The two temperature sensors used are marked T in red. The point sensor is also shown on this flat roof plan. The position was placed slightly outside the centre of the roof surface, in the north-east area. The reason is that the roof slopes to the east (water drainage) and an installation shaft penetrates the roof in the northeast. Thus, this area is considered to be the most vulnerable in terms of possible leaks.

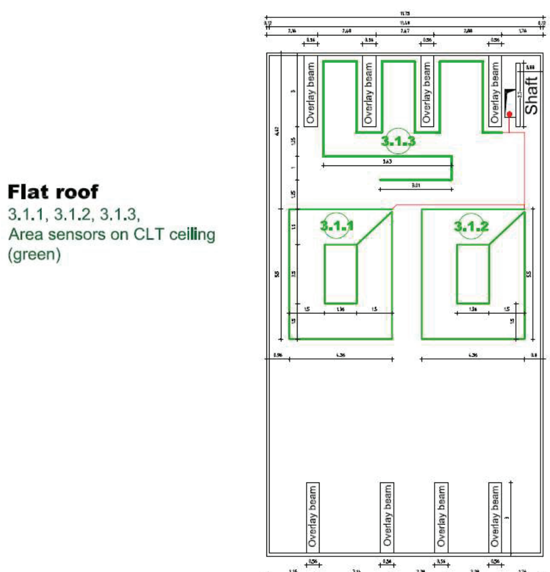

Figure 9: Three area sensors on the solid wooden roof

This flat roof plan shows three measuring circuits with area sensors mounted directly on the solid wooden roof. This arrangement was chosen because the deflection is greatest in the central area of the roof surface, i.e. in the event of water ingress, this area is likely to be the first to suffer moisture penetration. The measuring circuit on the north side was laid close to the statically required overlay beams. These beams have only a small amount of insulation on the above surface, i.e. the risk of condensation at low outside temperatures below the waterproofing layer is very high. Therefore, it should be monitored whether this minimal insulation also impacts the moisture situation on the surface of the supporting structure (cross-laminated timber) screwed to the overlays.

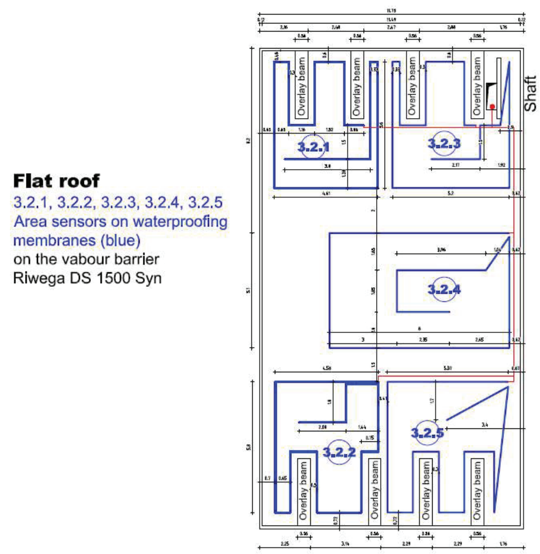

Figure 10: Five area sensors on the waterproofing membranes

This flat roof plan shows five measuring circuits with area sensors on the first sealing level (vapour barrier). The arrangement was chosen due to the roof pitch (towards the east) and to be able to monitor the entire roof surface for moisture.

3.2 MEASUREMENT SENSORS ON THE 1st FLOOR

On the 1st floor, area sensors were installed on the terraces and in the sanitation facilities. Three measuring circuits were attached to a bitumen seal on the terrace (west side) above the living space below. Further measuring circuits (shown in green) were installed in the three sanitation rooms directly on the raw ceiling made of cross-laminated timber. On the north side there is a roof-covered terrace with a passageway below. The measuring circuit was attached to the bitumen seal. This spot is interesting, because the temperature differences in this part of the building are significantly lower and due to the north-facing orientation little solar radiation can be expected in

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the winter months. The investigation aim at this floor level is also to monitor the overall humidity and tightness. Furthermore, the monitoring should also provide information about the influence of the different thermal conditions.

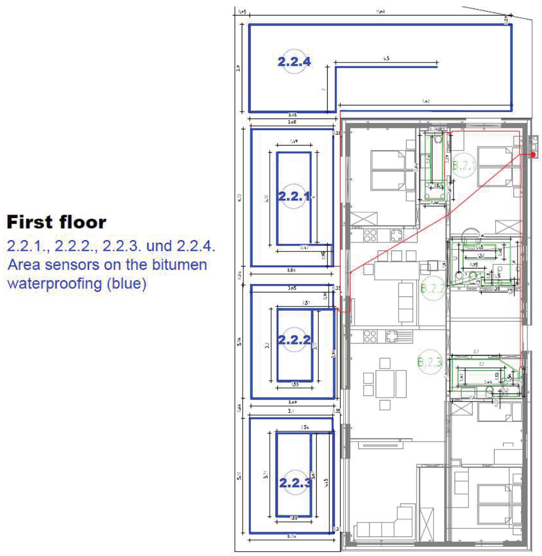

Figure 11: First floor - area sensors on bitumen (blue) - sanitation areas sensors on solid wood (green)

3.3 MEASUREMENT SENSORS ON THE GROUND FLOOR

On the ground floor, the three sanitation rooms were also equipped with area sensors. The sensors were mounted on a reinforced concrete ceiling in the two bathrooms on the north side and on a cross-laminated timber ceiling in the bathroom on the south side. The area sensors in the outdoor area were arranged in such a way that they again enable extensive monitoring of the main building. The measuring circuits 1.2.2, 1.2.3 and 1.2.4 are mounted on the first bitumen sealing layer. Measuring circuits 1.2.2 and 1.2.4 are located above a roof-covered entrance and on a cantilevered balcony. In measuring circuit 1.2.3, the area sensors are partly installed above the living area and partly in the cantilevered area of the storey ceiling. The raw ceiling of these three measuring circuits is made of cross laminated timber. Measuring circuit 1.1.1 was laid directly on the reinforced concrete ceiling. The underground car park is located below this measuring circuit. Measuring circuit 1.2.1 was laid on a plastic membrane (vapour barrier) on the existing single-storey building. Originally, inside this building there was a swimming pool. At the time the measurement sensors were specified, it had not yet been decided whether the swimming pool would be put back into operation or whether it would be used as a fitness room. In addition to the flat roof sensor, another point sensor was installed on the west side of the newly built warm roof on the west side of the single-storey existing building. The position was chosen because this area of the green roof surface is usually without sun in winter due to the terrain formation.

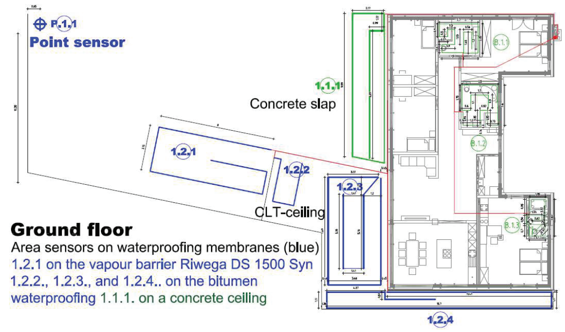

Figure 12: Ground floor - area sensors on waterproofing membranes (blue) - on the raw ceilings (reinforced concrete; green), point sensor - single-storey existing building

4 RESULTS FROM MOISTURE AND TIGHTNESS MONITORING

The diagrams and measurement results show an overview of the measurement process up until January 2023. It should be mentioned that due to the lockdowns that occurred during the investigation period, construction completion and therefore the commissioning of the measurement systems and the moving-in was delayed by approximately one year. From September 2021 to January 2022, there was partly no data transmission because the internet connection at the location of the building was inadequate and the installation of the fibre optic cables was delayed by several months. Therefore, there are no consistent area sensor measurement results for this period. The winter of 2022 to 2023 was the first season the premises were lived in. Thus, no meaningful results are yet available regarding the moisture behaviour in the sanitation rooms, on the roof and on the terraces. This means that it is not yet possible to answer the question whether in addition to the mere tightness monitoring of the waterproofing membranes, the habitation and use of the rooms, because of differing temperatures and relative humidity values, has an effect on the moisture conditions in the areas monitored.
The recordings to date show clear differences in humidity between summer and winter. The following diagrams give an overview of the measurement period and feature special conditions.

4.1 MATERIAL MOISTURE MEASUREMENT

The measurement diagram from the south side of the flat roof (Fig. 13) shows the wood moisture content of the eight measurement points (U 2.1 - U 2.8) as well as the temperature curve in the wood (T 2.1) and in the living room area of the first floor (T 2.3) where the data logger is located. The Y-axis of the diagram shows the temperature and wood moisture and the X-axis depicts the time progression. All other diagrams have the same structure. The measuring system was put into operation on 08 April 2021. The measurement data in the diagram show the course of the wood moisture from the time of commissioning until 31January 2023. The course of the wood moisture lies in the normal range between approx. 8% and 15%. The differences in the wood moisture content can be explained by the different depths of the inserted measuring electrodes. At measuring point U 2.6, a steady increase in the wood moisture content of up to 15% can be seen from May 2021 to the beginning of October 2021, before it drops again in the winter months. At low temperatures, it is noticeable that the measuring system repeatedly experiences disturbances in data storage, as can be seen at measuring point U 2.7 from mid-December 2021 to mid-February 2022. The measured values have a high fluctuation range due to the temperature changes. It is also noticeable that in the winter months the temperature in the cross-laminated timber drops below 10°C, i.e. into the dew point range, despite the external insulation.

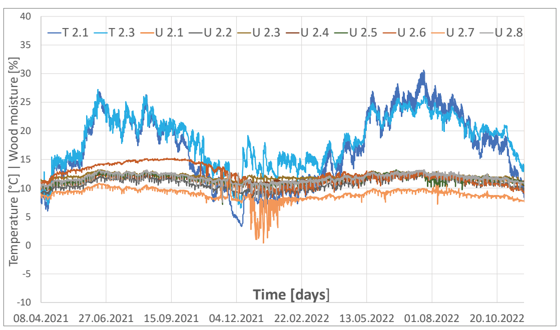

Figure 13: *Flat roof (south side) - wood moisture measurement U 2.1 - U 2.8; temperature in cross laminated timber - T 2.1; temperature interior 1st floor - T 2.3;*

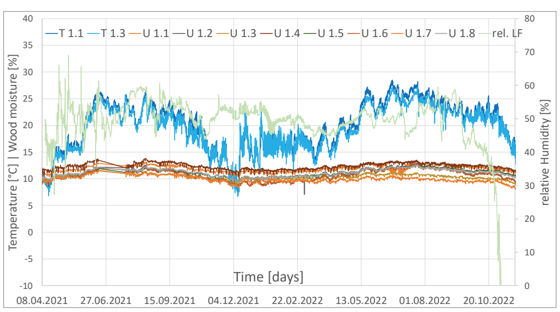

Figure 14: *Flat roof (north side) - wood moisture measurement U 1.1 - U 1.8; temperature in cross laminated timber - T 1.1; temperature and relative humidity in interior 1st floor - T 1.3 and relative humidity;*

The measurement period on the north side of the flat roof is the same as described for the south side (Fig.14). The wood moisture content is very even and inconspicuous over the entire measurement period. It can be seen, however, that the wood moisture content decreases somewhat over the course of time shown (April 2021 to November 2022). This also corresponds in principle to the behaviour of wood: The material becomes drier when professionally installed under the typical living room climate of 22°C and approx. 40 % relative humidity in the heated and occupied interior. In contrast to the south side, to check the indoor climate, the relative humidity in the interior of the 1st floor is also measured at this measuring station. In the period from 16-06-2021 to 15-08-2021, there was an interruption in the measurement recordings, because a cable was unintentionally detached from this measuring device during construction work.

4.2 AREA SENSORS

Not all area sensors on the flat roof, on the 1st floor and on the ground floor could be installed and commissioned at the same time due to the construction progress. This explains why for some measuring circuits the basic voltage is 120 digits. During commissioning, a steep increase in humidity can be seen in some cases, as in the case of measuring circuit 1.2.1 in Fig. 17. In each of the three diagrams (Fig. 15-17) it can be seen that there is one or more measuring circuits at each monitored floor level where there is already a high moisture content at the sealing level from the start. The reason for this is that water ingress occurred during the installation of the roof superstructures due to rain and snowfall and therefore the specified limit range of 11500 digits (laid on waterproofing membranes) was exceeded in some cases. Furthermore, it should be mentioned that there was no network connection from mid-September 2021 to the end of January 2022 and therefore no online access was available. However, it can be seen that the moisture content in the building components became significantly lower over the winter months. In spring, from around mid-March 2022, the moisture content on the waterproofing membranes (vapour barriers) begins to rise again. However, the increase is significantly lower than in the first year of monitoring in 2021. In the autumn months from September 2022 onwards, a clear reduction in moisture on the waterproofing layer is again evident. With the increase in outdoor temperatures, the moisture content on the sealing levels also increases in February 2023. In the coming months and years, monitoring will show which level the moisture content will adjust to over the course of the year (summer, winter). The measuring circuit 1.2.1 in Fig. 17 should be mentioned separately, as it shows a moisture behaviour that is not yet comprehensible. From about April 2022, there is a strong increase in humidity to about 10000 digits. This remains almost constant until the beginning of November 2022, after which the moisture content of this measuring circuit drops to approx. 1000 digits within 2.5 months. Measuring circuit 1.2.1 will therefore be monitored in particular over the next few months to find out whether the increase in humidity is possibly related to leaks in the upper sealing level. If the strong moisture fluctuations continue, the sealing level in the area of this measuring circuit will be opened, dried and resealed

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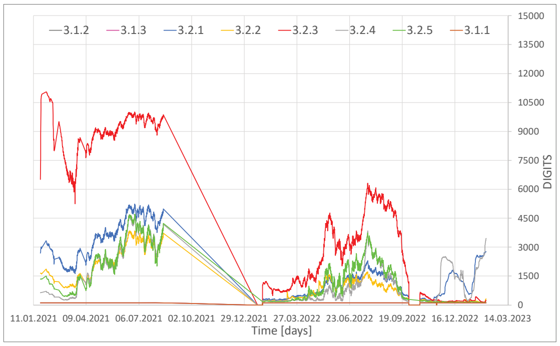

Figure 15: *Flat roof area sensors 3.1.1 - 3.1.3 on the cross laminated timber ceiling; area sensors 3.2.1 - 3.2.5 on the first sealing level (vapour barrier - plastic sheeting)*

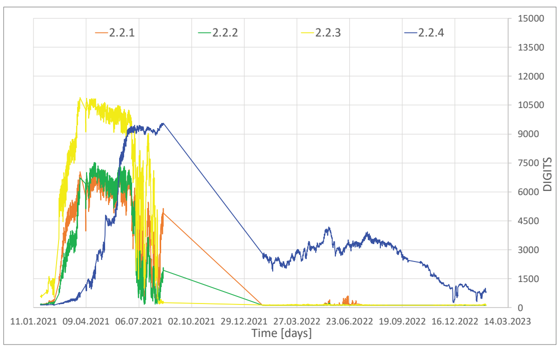

Figure 16: *First floor - area sensors 2.2.1 - 2.2.4 mounted on bitumen sheeting*

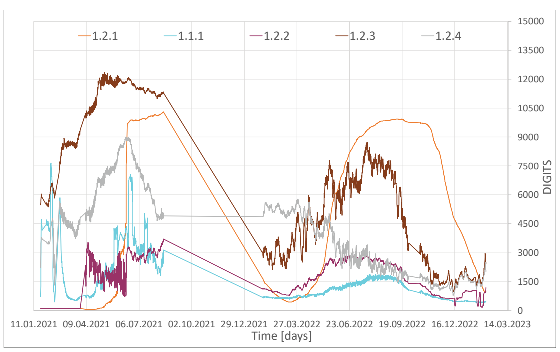

Figure 17: *Ground floor - area sensors 1.1.1 mounted on reinforced concrete ceiling; 1.2.1 - 1.2.3 mounted on bitumen sheeting; 1.2.4 mounted on plastic sheeting - vapour barrier*

4.3 POINT SENSORS

The point sensor on flat roof 1.2 (Fig. 18) is installed near measuring circuit 3.2.3 (area sensor). In the area of this measuring circuit, moisture penetration occurred when sealing the top sealing level. The increased moisture content is also indicated by the point sensor. At the end of January 2022, however, a very rapid drop in moisture occurred within a few days. This means that there must have been a strong drying process within this short time in the insulation level and on the sealing level. If we look at the moisture curve one year later, in February 2023, there is again a sudden sharp drop in moisture. This time, however, it is already in November. In December 2022, there is a brief intensive rise followed by a sharp drop in the measurement curve. The moisture behaviour in the insulation level is difficult to interpret using the point sensor as the measurement period is still relatively short. Questions as to how these very rapid increases in humidity and drying phases can occur still need to be investigated in detail. For point sensor 1.1 (on the green roof of the single-storey existing building), no changes in moisture or conspicuous moisture occurrences can be detected in the first year of monitoring. From June 2022 to mid-October 2022, there is a slight increase in moisture of up to 20 digits. Compared to the area sensors, the limit value for liquid water for the point sensors is 80 digits. Therefore, the value of 20 digits is considered a dry component. However, the reason for this slight increase in moisture has yet to be determined. One reason could be that the measuring device is subject to fluctuations. Otherwise, no other abnormalities can be detected in the insulation level of the green roof.

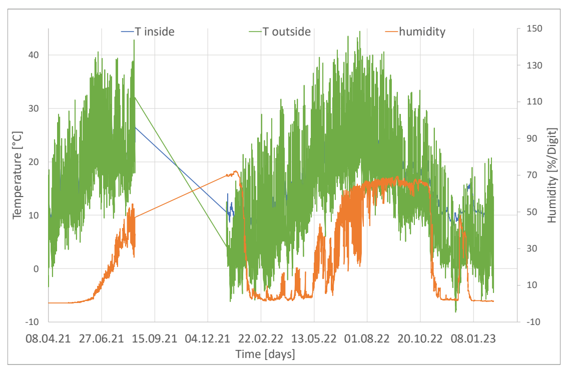

Figure 18: *Point sensor 1.2. on the flat roof*

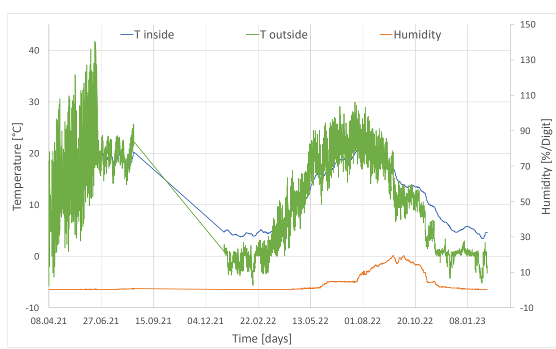

Figure 19: *Point sensor 1.1 on the green roof surface of the existing single-storey building*

5 CONCLUSIONS

The research results so far are as follows: The planning, installation and commissioning of the measuring systems could be carried out without difficulties. Immediately after commissioning the measurement technology, leakages at the sealing levels could be detected and immediately repaired. Therefore, the positive effect of moisture and tightness monitoring systems was already evident during the construction phase. The interpretation and comparison of the measured values is still somewhat complex due to the different scaling units (percent, digits) of the measuring devices. Depending on the system or materials used (waterproofing, wood, concrete, etc.), the scaling of the measured values also changes.

The wood moisture is expressed in percentage points, the limit value, which must not be exceeded, is at a maximum of 20% wood moisture. Higher values lead to insect and fungal attack and thus to the destruction of the supporting wooden structure.

The moisture content of area and point sensors is displayed in digits. However, in different orders of magnitude. For the point sensors, the measuring range is between 0 and 150 digits. This measuring range is also known for determining the moisture on concrete surfaces. The limit value that should not be exceeded is approx. 80 digits. If the values are higher, there is increased moisture in the building material.

With the surface sensors, the measuring range is higher by a factor of 100. A distinction must be made here as to whether the sensors are installed on the raw material (wood, reinforced concrete) or on a sealing membrane (bitumen, plastic sealing). The measuring range starts at 120 digits and goes up to 15000 digits. The limit value with regard to increased moisture status is 11500 digits for waterproofing membranes and 3500 digits for installation on the raw material. The lower value for the raw material can be explained by the fact that the material can already absorb moisture and therefore a low moisture content, measured on the surface, is already sufficient to have increased building material moisture in the component. This is not the case with waterproofing membranes, as the material cannot absorb moisture.

Therefore, the use and installation of moisture and leakage monitoring systems requires precise documentation and recording of the measuring results and on which materials the measuring sensors are laid or installed in order to be able to carry out a professionally viable moisture assessment.

Of the five residential units in the apartment building, the first flat on the ground floor was occupied in autumn 2021. The remaining four flats were occupied in spring 2022. These four flats are rental flats or holiday homes. This means that they are not occupied throughout the entire year. At the time of the evaluation, the building has only been occupied for approximately one year. More precise interpretations and statements about the measurement results are usually only possible after three to five years of monitoring. Therefore, the monitoring will be continued in the coming years.

Based on the state of the investigation so far, the following can be stated:

- The planning, installation and commissioning of the measurement systems was simple and straight forward.
- Shortly after commissioning the area sensors, leakages in the sealing due to increased moisture could be detected. The quick repair of the defects in the sealing prevented future moisture damage.
- The interpretation of the measured values is still somewhat challenging due to the different scaling of the measuring devices and scarce empirical values. In addition, the limit values (area sensors) change when used on different materials. Therefore, accurate and complete documentation is essential during planning, installation and monitoring.
- At the beginning of the monitoring, the moisture values for some measuring circuits (area sensors) were in the limit range during the summer months resulting from increased component moisture. Therefore, it is not clear whether the moisture content is reduced or evened out over the year or whether the top sealing level should be opened in order to start drying measures.
- Due to the fact that the entire building has only been occupied for one year, results from the sanitary areas as well as the measuring circuits on the flat roof, which were laid on the cross laminated timber elements, are still missing as to what effects this has on the moisture content in the solid wood elements.
- The results so far show that, especially for the area and point sensors, several years of recordings and experience are needed in order to better assess the aforementioned challenges regarding to the evaluation of the results.

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