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Advancing Timber for the Future Built Environment

Moisture monitoring of mass timber building - study of condition variation and building environment design

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ABSTRACT:

Exposure to moisture can occur either during building construction (heavy rain/flash flooding) or in-service (condensation/plumbing leaks). Mass timber products such as cross-laminated timber (CLT) have higher capacity to absorb and store moisture than other timber products. Prolonged moisture exposure can lead to decay, necessitating drying, repairs or replacement of building sections. It is crucial to incorporate moisture management/safety into building design and construction planning to prevent any moisture complications. To study the environmental condition of mass timber construction in hot and humid climates, wireless moisture monitoring sensors were installed in a mass timber building under construction in tropical Queensland. The project studied condition variations within the building layer up, exposed to indoor and outdoor micro-climates. MC data collected were used to simulate mould growth index (MGI) predictions and evaluate the panel condition after construction was completed and in correlation with building design, preventative measure applied and environmental factors. Comparative analysis showed that MC values dropped to acceptable levels after temporary exposure to moisture. Various preventive measures such as design with protection, roof installation as early as possible and application of weather resistant membranes (WRM) on the external face of the CLT wall panels were effective to keep moisture elevation minimal. Hygrothermal modelling showed that the model can predict MC in the range tested; however, further studies are required to examine the model accuracy in higher MC ranges. The MGI calculations for monitored locations showed slight elevation when there was moisture exposure. Further studies are recommended to determine MGI using external environmental values for the sections of CLT exposed to outdoor environment.

KEYWORDS: Mass-timber, Moisture content (MC), Mould Growth Index (MGI), Moisture monitoring, Moisture safety.

1 – INTRODUCTION

Moisture safety is a critical factor in timber buildings' design, maintenance, and service life. Due to the hygroscopic properties of timber products, exposure to moisture (either from free water or high humidity environmental conditions) can lead to mould growth and even reduced structural performance. When combined with insufficient ventilation and/or drainage paths, it can adversely affect indoor air quality and human health. The root causes of moisture problems in buildings can vary and may include unclear moisture safety standards, lack of condition monitoring, insufficient procedures and skills for detecting, managing, and addressing moisture exposure, impractical scheduling or miscommunication between and within construction stages, and inadequate attention to moisture safety [1]. Identifying moisture issues early in construction or at the onset of condensation and mould development can reduce the risk of failure and cost of necessary remedies [1, 2].

Early detection of moisture exposure and ingress requires specific protocols and methods, as well as the application of monitoring programs for moisture and environmental data collection to identify critical conditions and scenarios. Mass timber products such as cross-laminated timber (CLT) have different moisture ingress and egress characteristics compared to the light timber framing (LTF) [3-6]. Due to their layered structure, edge gaps,

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and glue-lines, there is higher possibility of moisture gain and slower drying rates when exposed to free moisture in CLT compared to LTF. For prefabricated CLT building elements, undetected moisture damage can be critical and often requires extensive drying, costly repairs or even section replacement. The swelling and shrinkage linked to moisture gain can cause internal stresses and crack development within the CLT, leading to further product condition changes. This checking and cracking could cause changes to the service life of the CLT if exposed to multiple instances of wetting and drying cycles [7, 8]. To contain this risk, it is crucial to monitor panel conditions and any changes in moisture levels of various building sections which, inevitably, are exposed to varying environmental conditions, both indoor (e.g., roof leaks or wet areas) and outdoor [9-11].

The work presented in this paper focuses on monitoring changes in moisture content (MC) and environmental conditions in a mass timber structure located in the tropical Queensland climate. The study included monitoring and analysis of moisture changes due to varying building environmental conditions and construction elements with different design layer ups. A pin-type electrical resistance, wireless sensing system was chosen for moisture monitoring, to capture the moisture changes and effects of environmental conditions on building elements during different phases of the buildings service life. The monitoring results were used to verify the moisture changes within the CLT assembly associated with certain design variables by calibrating hygrothermal simulations. This required accurately representing external and internal boundary conditions, and the initial MC within the CLT panels. Once the hygrothermal simulations were calibrated, the long-term durability and mould growth index (MGI) were calculated and evaluated to study the impact of the climate variations on the CLT structure.

2 – METHODOLOGY

2.1. Case Study details

A moisture monitoring campaign was conducted on a mass timber building in Maryborough, Queensland, Australian in 2021-2025. The monitored building is made of Australian CLT, glued laminated timber (glulam), laminated veneer lumber (LVL) and lumber glued laminated (LGL). CLT products were made from Australian radiata pine and used for floor, roofs and walls in various sections of the building.

The complex consisted of two buildings: a two story (ground level and level 1) admin building and an engine shed. The admin building comprises office space, conference and meeting rooms. This paper focuses on sensors data obtained from the two levels of the admin building.

2.2. Sensor set up

Wireless moisture sensors (OmniSense LLC, Ladys Island, SC, USA) were used to monitor changes in panel MC and environmental factors (relative humidity and temperature) in different sections of the building. The sensors used electrical conductance through two stainless steel screws embedded in the timber panels to measure MC. To monitor moisture changes in the panel structure different length screws were used targeting 20 mm from the surface (internal and external faces) of the panel for moisture reading (Figure 1).

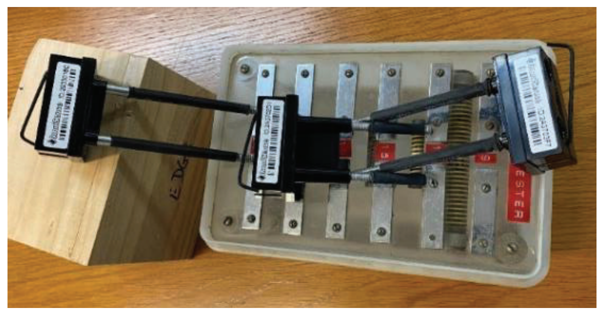

Figure 1: Sensor set up used for moisture monitoring.

In order to limit the moisture reading to the targeted location and depth, heat shrink tubes were used to insulate the length of the screws. To maintain wood contact, self-tapping wood screws were used. Moisture sensors were calibrated for Douglas fir species according to USDA standard. For the purpose of this project the data was converted to radiata pine according to AS 1080.1 and reported calibration by Blakemore et al [12, 13]. Due to limited access to parts of the building during construction and large timber surfaces exposed in the finish building design, sensors were installed only in areas with cavities, including external surfaces under cladding, internal walls under studs, and on the floors under the floating flooring.

2.3. Hygrothermal modelling: long term estimations and mould index calculations

This hygrothermal study aimed to develop a representative model of the building assemblies where the sensors were located, to then calculate and predict the MC at various panel depths. The model included design aspects such as exposure to indoor or outdoor conditions, application of a weather membrane on the external face of the panel, and the cladding cavity. The mould growth index MGI was assessed using the moisture design tool

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WUFI Pro (Wärme und Feuchte Instationär), to determine the impact of environmental changes on MGI increase. MGI provide an indication of possible mould activity on the surface of pine sapwood [14]; a MGI threshold criterion of 3.0 is accepted by ASHRAE 160:2016 and AIRAH DA07, which corresponds to a surface area greater than 50% mould coverage visible under a microscope [14, 15]. The WUFI modelling and hygrothermal simulation calibrations were designed using material properties and the methodology reported by Strang et al. [8, 16]. Outdoor climate data was determined for the case study location and monitoring duration from National Centres for Environmental Information (NOAA) [17]. The indoor data was extracted from relative humidity (RH) and temperature values recorded by the sensors. The building assembly boundary included CLT wall panels of three layers with 110 mm thickness, applied weather resistance barrier (WRB) on the external face of the panels, metal sheet cladding with a cavity of 35 mm, and a final finish of Surfmist Colourbond coating. There was no membrane applied to the internal face of the panels. Floor panels were 110 mm 3-layer CLT with a 20 mm thick compressed fibre cement floor substrate applied and an 80 mm air cavity.

3 – RESULTS

The sensors which were strategically placed in critical location of the monitored admin building provided valuable data to understand the impact of design choices and environmental conditions on MC and mould growth. Particularly relevant were two sensors which were installed on the external section of the CLT panel, near the plumbing area and targeted to record moisture content at 20 mm depth from the inside and outside surface of the panel - as shown in

Figure 2.

Figure 2: Sensor location close to plumping areas on external face of the panel.

The data collected from the sensor reading at the internal 20 mm depth of the panel is shown in Figure 3 (a).

The MC and RH values recorded during the pre-construction phase of the project were higher, leading to higher MGI calculations. Both sensors, as shown in

Figure 2, were installed on the external side of the CLT wall panel within the cladding cavity. The higher RH values recorded during the construction phase dropped once the cladding was installed and building construction progressed. MC recorded at both sides of the wall panel stayed around 15% pre and post construction; however, the initial MC sensor readings for the external side of the panel were higher, at around 17% (Figure 3 (a) and Figure 4 (a)).

The wall section monitored in this part of the study was semi protected under the overhanging higher level of the building (as shown in

Figure 2), leading to minimal exposure to moisture during construction (Figure 3 (b) and Figure 4 (b)), thus the calculated MGI was very low. Construction planning and the implementation of effective moisture safety protocols during construction prevent moisture gain and further complications during and after construction [9, 18]. Design consideration and further mechanisms, such as roof installation, semi-protected overhang sections, WRB applied on external face of CLT and minimum storage of material on construction site to prevent moisture exposure are equally important [10, 11]. For this case study specifically, the application of an external membrane, and the design strategy to protect the exposed CLT panel in this location of the building helped minimise moisture gain and mould growth. The comparison between the sensor recorded MC and the calculated MC using WUFI modelling is shown in Figure 3 (c).

The data collected from the sensor in the same location but recording values at the 20 mm depth from the outside face of the panel is shown in Figure 4. Similar to the environmental conditions recorded by the internal reading sensor, the measured values showed a slightly higher MGI during the pre-construction phase, likely due to higher RH exposure. Figure 4 (c) shows that the WUFI predicted MC provides a good representation of actual MC including the high and low peaks recorded by the sensors.

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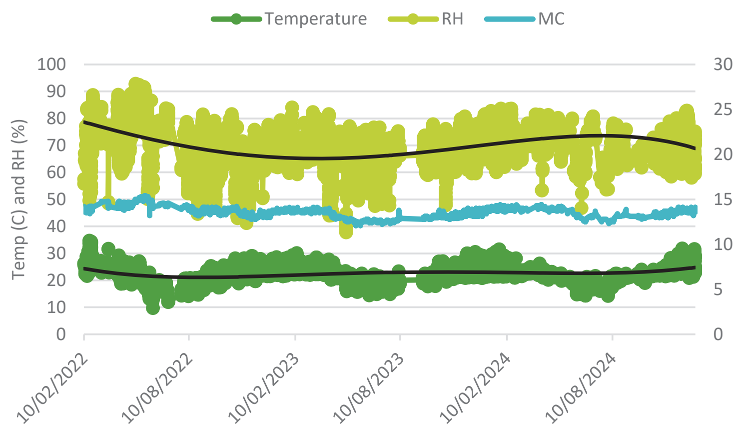

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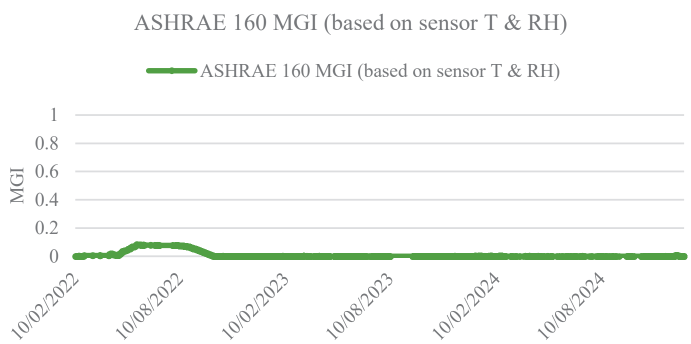

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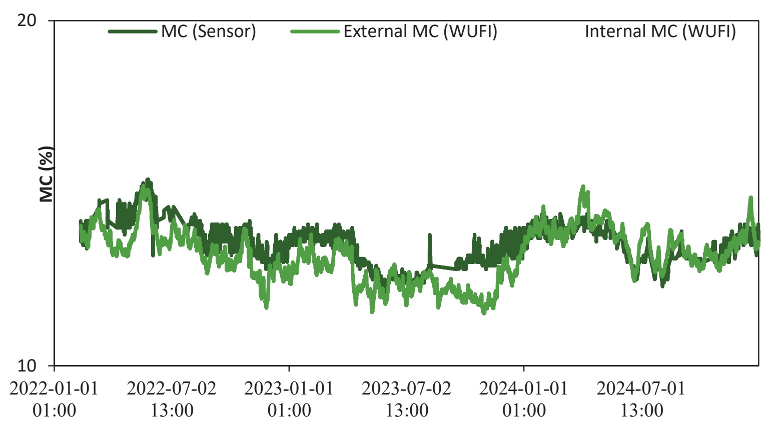
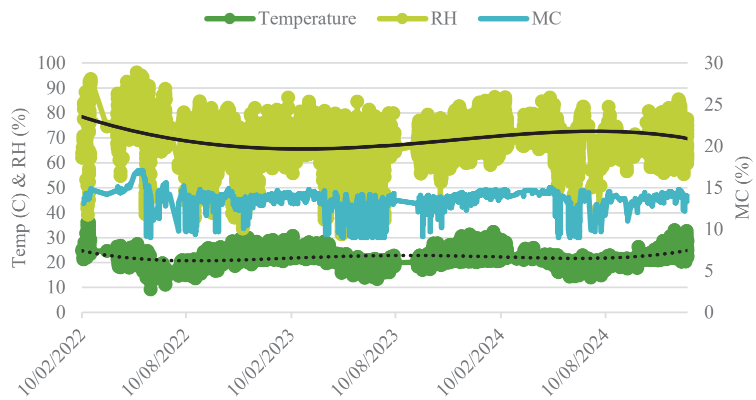


(c)

Figure 3: (a) Sensor recorded temperature, relative humidity and MC; (b) calculated MGI from the sensor data; and (c) comparison between measured and calculated MC values for the sensor located near the plumbing and reading the internal side of the panel at 20 mm depth.



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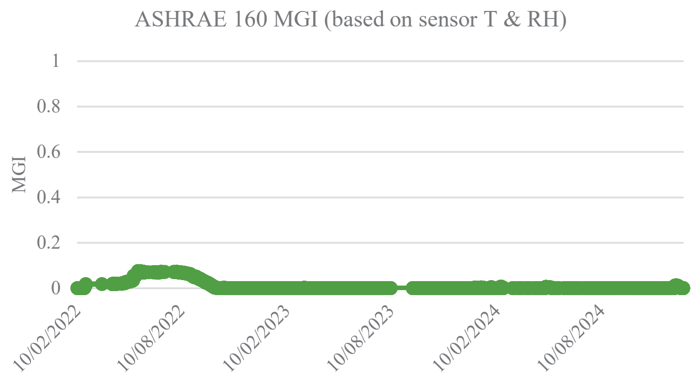

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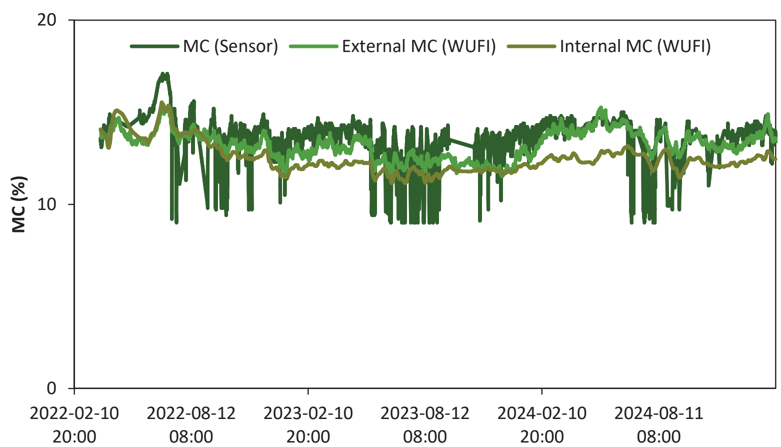

(c)

Figure 4: (a) Sensor recorded temperature, relative humidity and MC; (b) calculated MGI from the sensor data; and (c) comparison between measured and calculated MC values for the sensor located near the plumbing and reading the external side of the panel at 20 mm depth.

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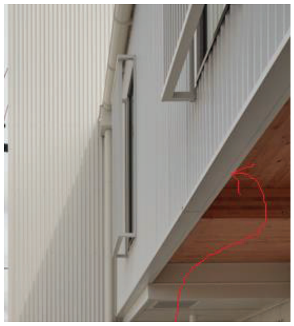
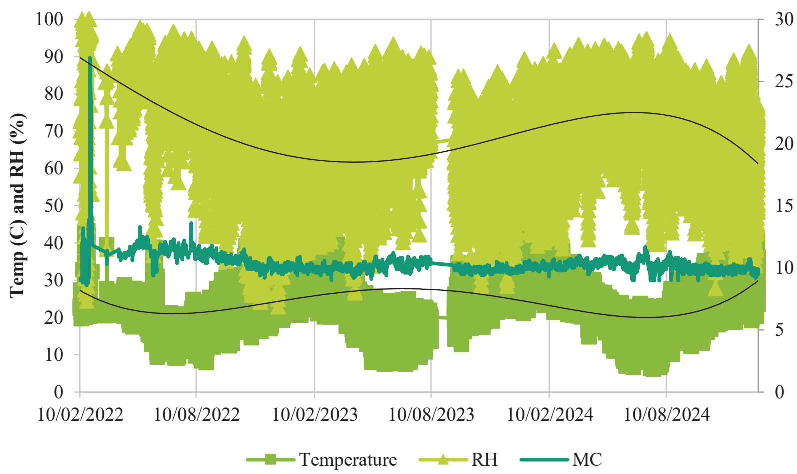


Figure 5: Exposed overhang section of the floor panel.

Figure 6 and Figure 7 present the recorded sensor data for the floor panel of an overhang section of the building which is exposed to external environmental conditions (Figure 5). It can be seen that there was a spike in MC recording for both reading depths during construction, with MC values reaching above 20%. However, the MC dropped to around 10% for internal reading of the floor, as shown in Figure 6 (a). The MC values for the external side of the panel, which remained exposed to the environmental conditions, were higher, at around 15%, as shown in Figure 7 (a). The MGI calculation for both panel sides, based on RH and temperature data from sensor recording, did not show any high-risk values; however, it is recommended to use the outdoor weather data for calculating the MGI of the external, exposed face of the panel in the future. The location of sensors being installed in the interior condition of the building, due to limitation for not exposing sensors, could have led to moderated values for MGI calculations.



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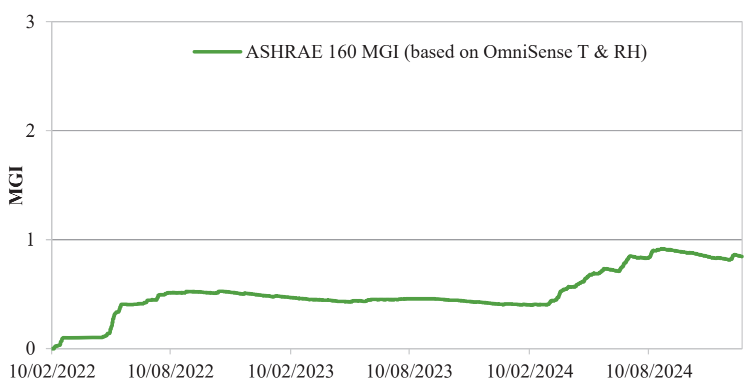

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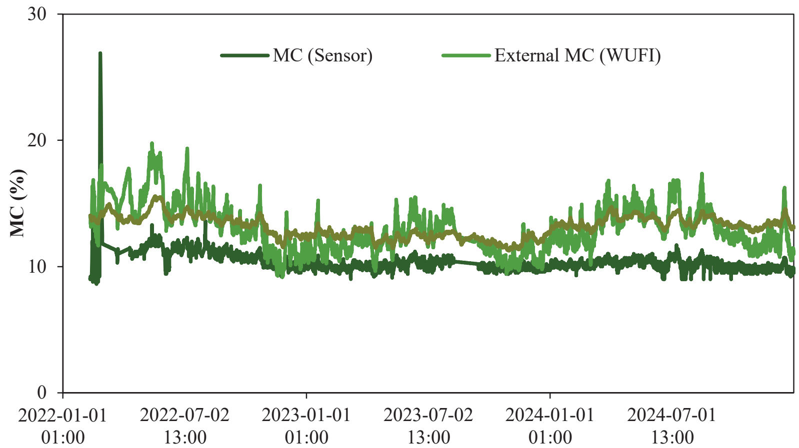

(c)

Figure 6: (a) Sensor recorded temperature, relative humidity and MC; (b) calculated MGI from the sensor data; and (c) comparison between measured and calculated MC values for the sensor located on the exposed floor panel and reading the internal side of the panel at 20 mm depth

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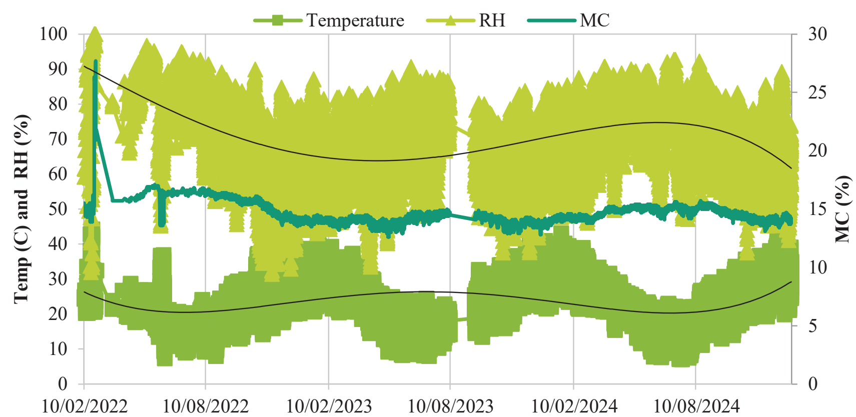

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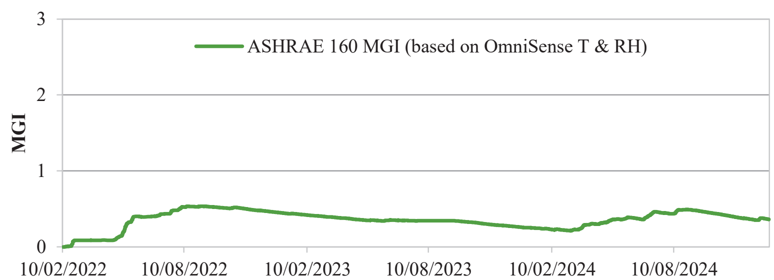

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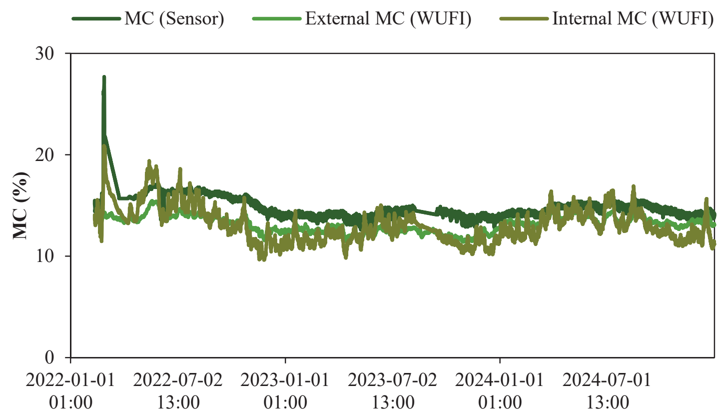
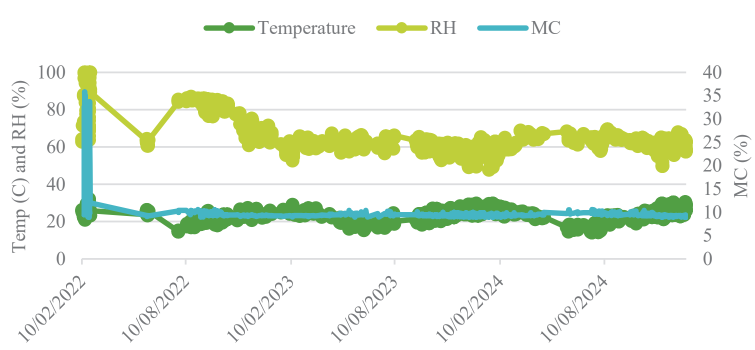


(c)

Figure 7: (a) Sensor recorded temperature, relative humidity and MC; (b) calculated MGI from the sensor data; and (c) comparison between measured and calculated MC values for the sensor located on the exposed floor panel and reading the external side of the panel at 20 mm depth

Figure 8 shows the wall and floor sections monitored for MC reading on level one of the buildings. Figure 9 and Figure 10 show the recorded values and calculated MGI for the wall panel with a large window opening, and the floor next to the wall respectively. As shown in Figure 9 (a) and Figure 10 (a), the recorded MC peaked during construction due to heavy rainfall entering the site through the large opening (Figure 8). However, as rain exposure stopped and building construction progressed, the MC remained at lower levels in both wall and floor panels. The MGI values, calculated using the sensor data, were very low, with only a small peak at the beginning of the recording period due to the moisture exposure. The small peak recorded in MGI calculations demonstrates the sensitivity of the predictive tool in determining areas at risk and also its effectiveness to highlight areas that might require further maintenance would the moisture exposure continued, or in case of construction delays where preventive measures are not applied in time

Figure 8: Wall panel with large window opening.



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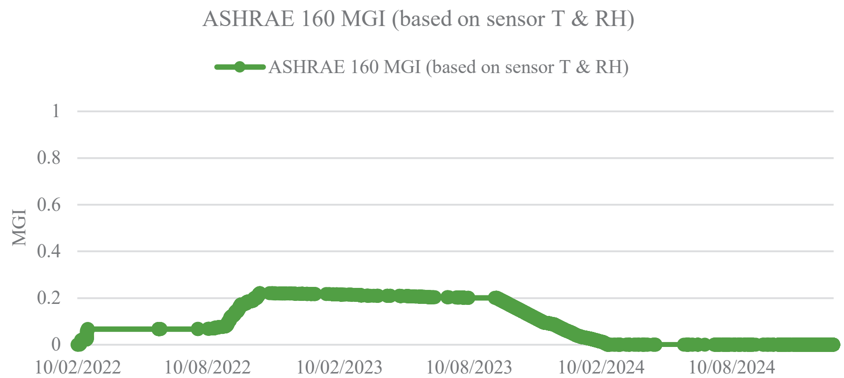
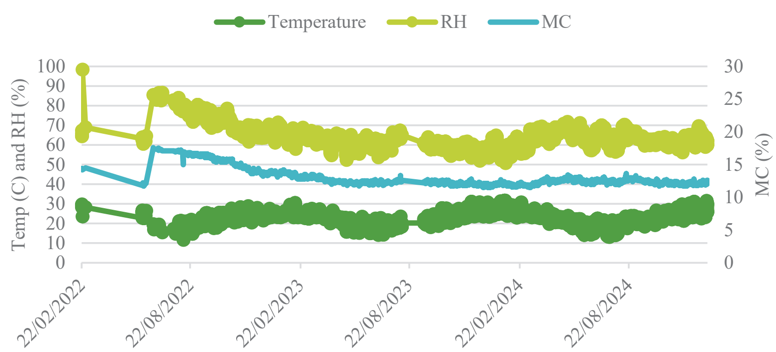


(b)

Figure 9: (a) Sensor recoded temperature, relative humidity and MC; and (b) calculated MGI from the sensor data for the sensor located on the wall panel with a large window opening and reading the external side of the panel at 20 mm depth.



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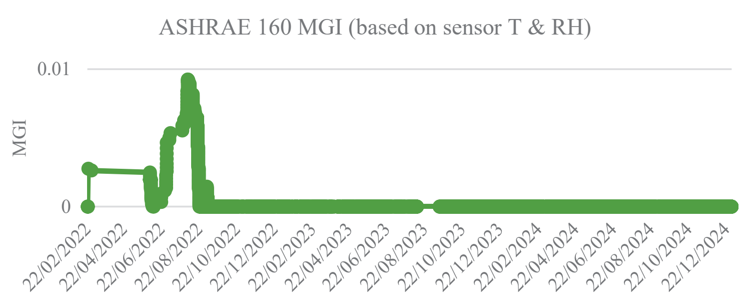

(b)

Figure 10: (a) Sensor recorded temperature, relative humidity and MC; and (b) calculated MGI from the sensor data for the sensor located on the floor panel next to the wall with a large window opening and reading the external side of the panel at 20 mm depth.

4- CONCLUSIONS AND RECOMMENDATIONS

This paper presents methodology and results of a MC monitoring campaign and discusses the impact of moisture safety planning as well as the effectiveness of design and moisture exposure prevention. Data collected using wireless sensors and produced through WUFI modelling of critical building sections, and calculated MGI values were compared to that of areas where without exposure to moisture during construction. The results show that the preventive measures such as the implementation of weather resistant membranes on the external face of wall panels, rapid installation of panels as they arrived on site, and installation of roof as early as possible led to minimising moisture exposure and moisture gain [10, 11]. The calculated MGI showed a slight increase in case of recorded moisture exposure for a short period of time; however, the MGI values dropped

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to zero when the moisture exposure ceased, as the result of design factors and effective moisture protection. The WUFI model proved effective in predicting the MC for the range considered in the study presented in this paper.

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