OPERATIONAL PERFORMANCE OF CROSS LAMINATED TIMBER :

BROCK COMMONS TALLWOOD HOUSE

THE UNIVERSITY OF BRITISH COLUMBIA

sustainability

SEPTEMBER 2020

1. PROJECT CONTEXT

INTRODUCTION

The University of British Columbia is one of Canada's premier universities, with a strong commitment to sustainability. UBC's Vancouver Campus is home to a large portfolio of innovative mass timber buildings, including Brock Commons Tallwood House (Tallwood House), an 18-storey (54-metres) student residence. Tallwood House provides 404 student beds in studios and four-bed units, plus amenities for the campus community. The total construction took about 18 months from November 2015 to May 2017, and the building opened September 2017. It was the tallest contemporary wood building in the world at the time of its construction.

The structural system of Tallwood House is a hybrid mass timber structure. The foundation, ground floor podium, stair, and elevator cores are cast-in-place concrete. The primary structure on floors 2 to 18 is composed of cross-laminated timber (CLT) floor panels and glue-laminated timber (GLT) and parallel strand lumber (PSL) columns with steel connections. The building envelope is comprised of prefabricated, steel-stud frame panels with a wood-fiber laminate cladding, and a traditional SBS (styrene-butadiene-styrene) roof assembly on metal decking.

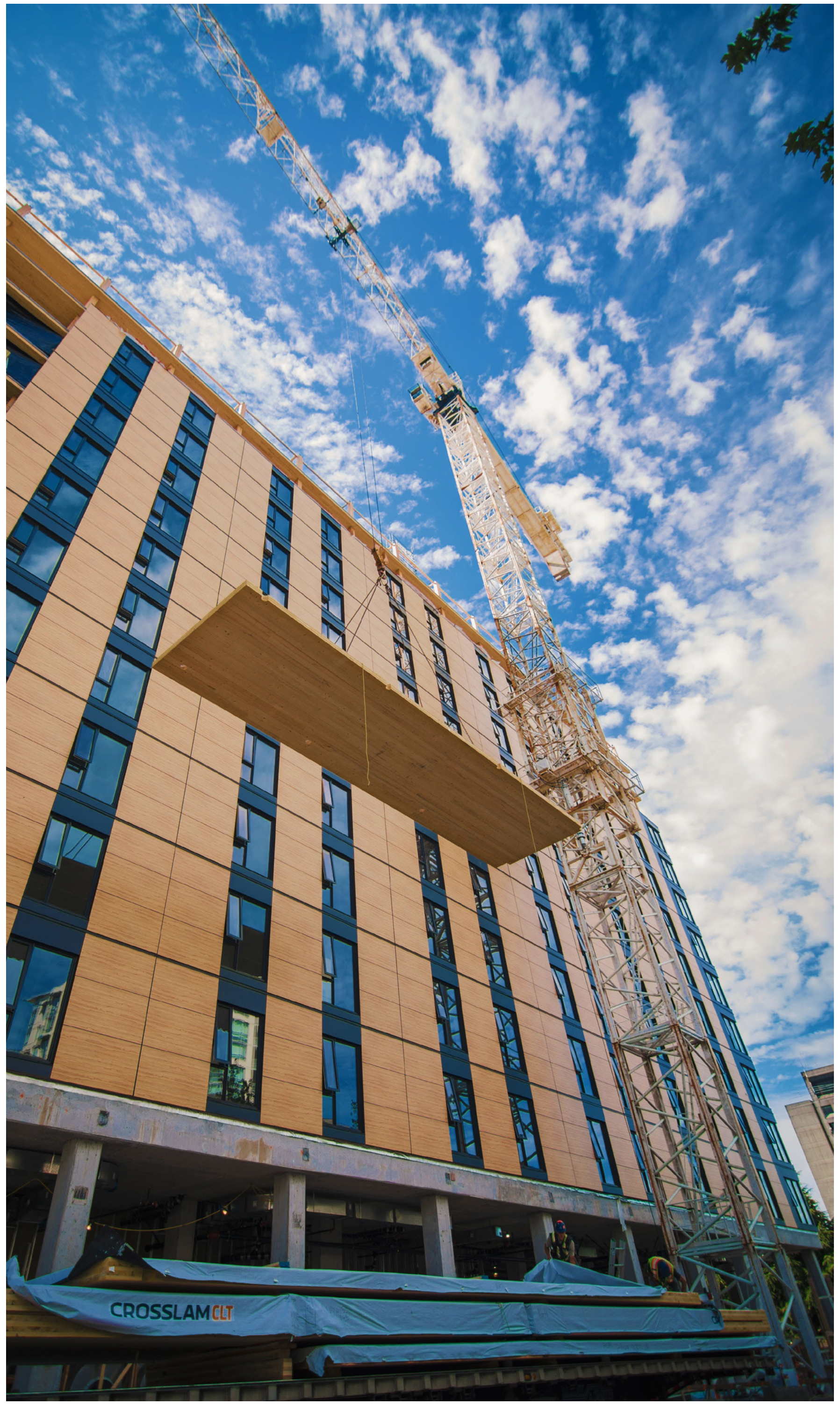
REPORT INTENT

The Tallwood House project was intended to advance the design and manufacture of mass timber products in Canada and demonstrate that mass timber is a viable structural option for mid-rise and high-rise buildings. The use of mass timber and engineered wood products in high-rise construction is becoming more common around the world leading to a growing interest in the performance of mass timber over time.

This report describes the performance of the mass timber structure in Tallwood House, between September 2017 and August 2019, based on measurements of the moisture content in the prefabricated CLT floor panels and the displacement of the vertical structural system. It is intended to initiate discussions on the performance of mass timber structure elements during building occupancy and lead to further research that can explore the influential factors.

PROJECT OVERVIEW	
Building type:	Residential with assembly spaces
Gross Floor Area:	15,120 m2
Building Footprint:	840 m2 (15 m x 56 m)
Total number of storeys:	18 (17 in mass timber)
Building height:	54 m
Typical floor to floor height:	Upper floor: 2.81 m / ground floor: 5 m
Total suites/total beds:	305/404
Project Completion:	August 2017

Photo Credit: naturallywood.com. Photographer: KK Law



PhotoCredit: Seagate Structures. Photographer: Pollux Chung

2. BUILDING MONITORING

Moisture performance sensors and vertical displacement sensors connected to data loggers were installed at various locations in Tallwood House, in order to acquire a diverse set of data to monitor the mass timber structure.

MOISTURE PERFORMANCE SENSORS

Since wood products can be susceptible to moisture damage, tracking moisture levels during construction and occupancy is valuable in determining appropriate water protection strategies. In order to study the moisture content of the CLT floor panels in Tallwood House, multiple moisture sensors were installed in select panels during their fabrication. Each monitored CLT floor panel has six moisture sensors (MC1A, MC1B, MC2, MC3, MC4, MC5) to measure moisture content at different layers, as well as two temperature sensors (T1 and T3) at different depths in the CLT panel, as shown in Figure 1.

The floor sensors were positioned on alternate floors, see Figure 3, with data from panels on Floor 4, 8, 12, 16 in North-South locations, and data from Floor 3, 6, 10, 14 data in East-West locations. The data acquisition systems are continually accessed through remote monitoring.

VERTICAL DISPLACEMENT SENSORS

Studying the differential vertical movement between different parts of buildings is important to understand the cumulative effects of the vertical settlement of wood structures. In mass timber and other wood structures, this downward movement can be the result of moisture-related shrinkage and the aggregate applied loads.

In Tallwood House, string pot sensors were installed to monitor the vertical movement of the mass timber columns. These sensors were assembled by connecting a no-stretch cable from the bottom of one floor to the top of the next floor above, see Figure 2. The displacement of each GLT or PSL column is measured (in millimeters) through cable movement by the sensor on the lower floor. The sensor assembly was repeated on one line of exterior columns continuously through all the 18 floors, allowing for the possibility of floor-to-floor comparison. Like the moisture data, the string-pot sensors are continually accessed through remote monitoring.

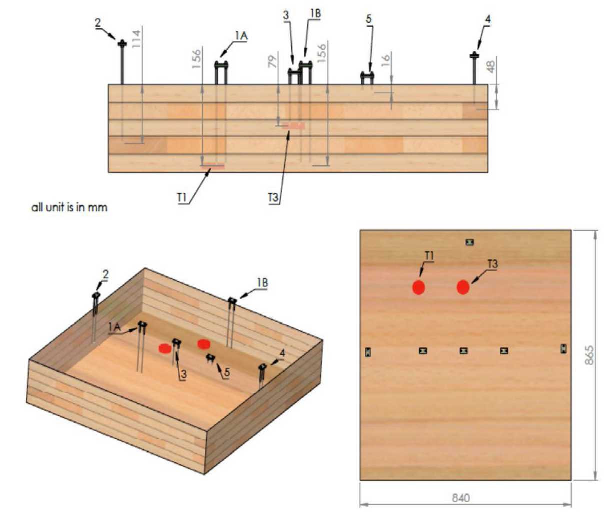


Figure 1: Location of the moisture content and temperature sensors within a CLT panel.

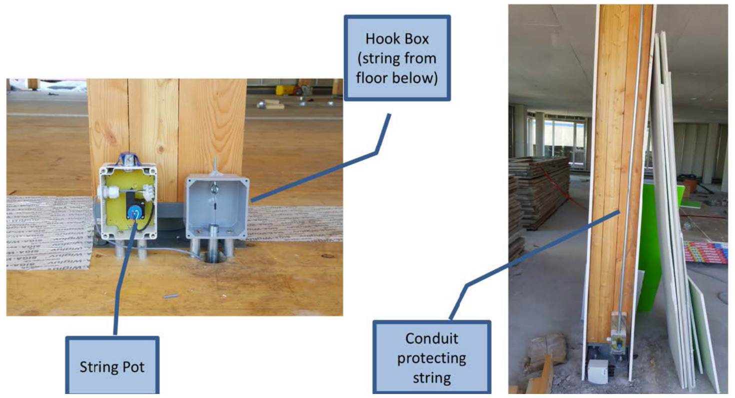


Figure 2: Arrangement of the string pot sensors along the columns.

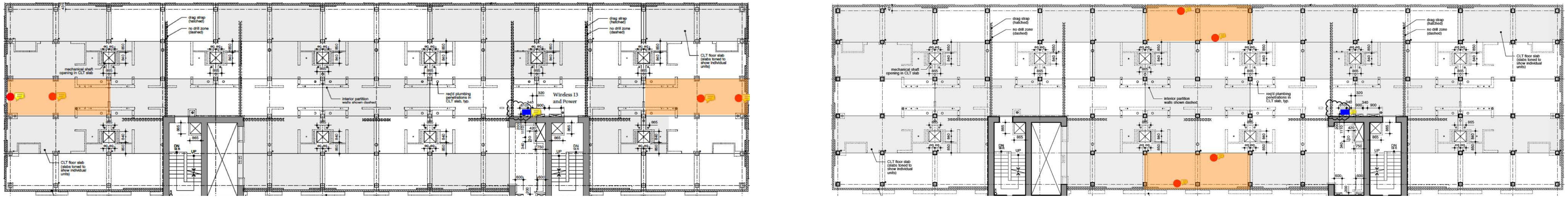


Figure 3 : Location of the moisture content and temperature sensors installed CLT panels on each floor. (LEFT: East-West moisture monitoring sensors, RIGHT: North-South moisture monitoring sensors)

3. STUDY METHOD & APPROACH

OVERALL TREND : MOISTURE PERFORMANCE

To understand the trends in the moisture content and the internal temperature of the CLT panels, daily data was plotted over the period between September 2017 and August 2019. In the graphs, the days were used as the x-axis and the corresponding moisture and temperature values for every day was plotted as the y-axis to review the trend with time. Figure X (left) presents the moisture data from one of the floors (Floor 3) in the Tallwood House, sourced from sensors in the East-West locations. Figure X (right) presents the moisture data from multiple floors (Floor 4,8,12,16), sourced from the North-South locations.

As seen in the graphs, the average moisture content (MC) from the CLT panels was about 10-20%, consistent across the floor locations. Moisture sensors on Floor 3 showed a diminishing trend from a range of 12-18% MC during initial months of occupancy to a range of 8-15% MC after two years in use, illustrating the drying of the CLT panels over the time. The moisture levels did not show any substantial spike or drop at any point during the monitored period, and a similar drying pattern as observed in the data from other floors.

The temperature data measurements indicated a visible variation with the internal temperature of the CLT panels on Floor 3, between 18 and 30 degrees Celsius with the highest temperature during the summer months and lowest during winter months. Similar trends were observed for the other floors, although the lowest spike in temperature on the higher floors reached 14 degrees Celsius.

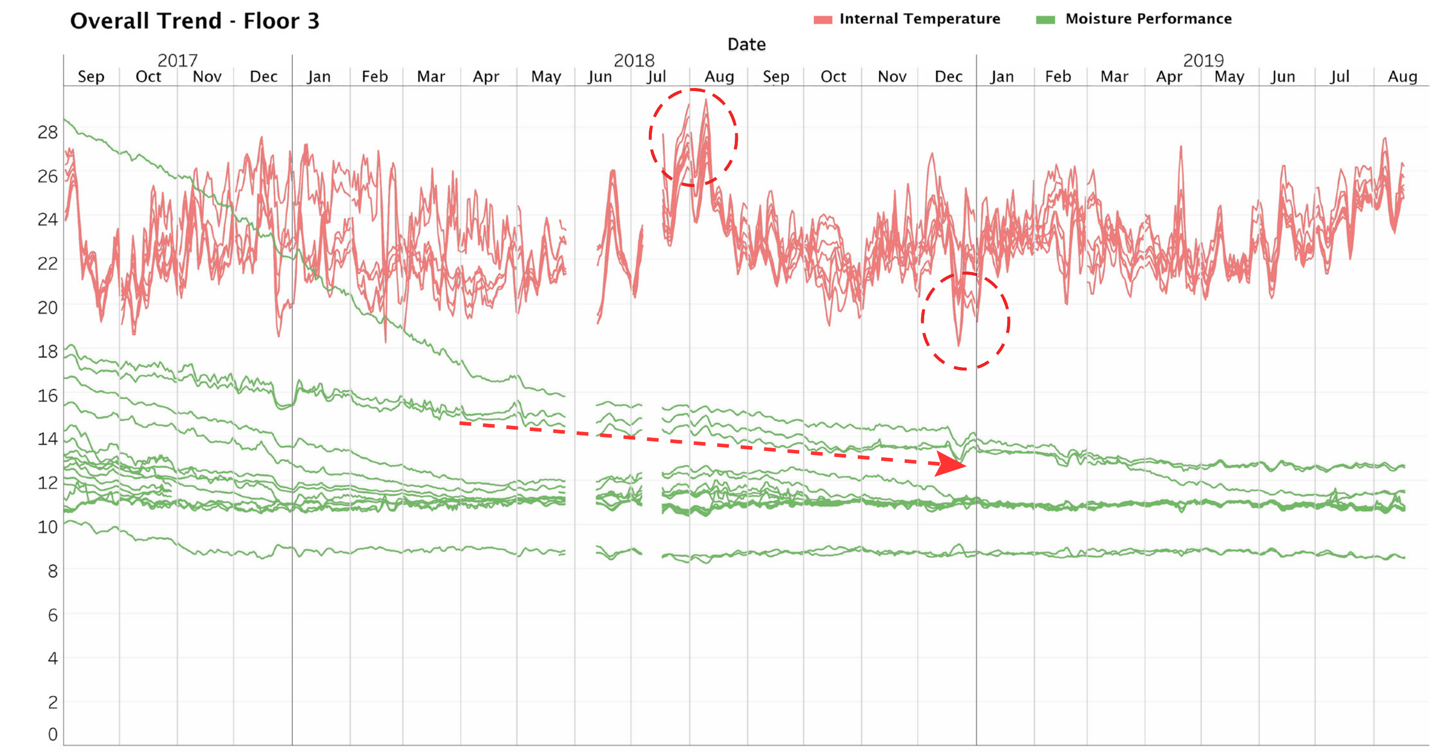


Figure 4: Overall Trend - Floor 3. The moisture content and internal temperature of the CLT panels plotted against the period from September 1, 2017, to August 31, 2019 for sensors at Floor 3, sourced from East-West locations.

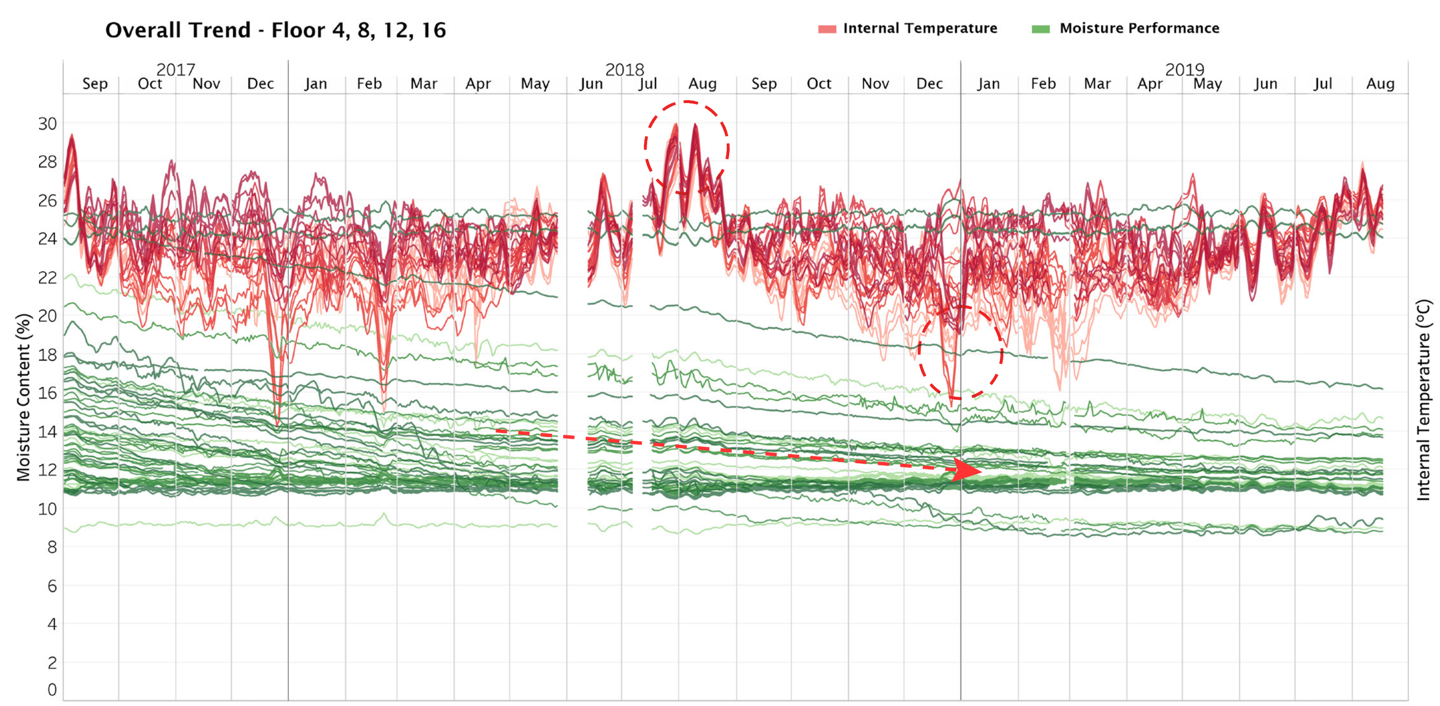


Figure 5: Overall Trend - Floor 4, 8, 12, 16. The moisture content and internal temperature of the CLT panels plotted against the period from September 1, 2017, to August 31, 2019 for sensors at Floor 4, 8, 12, 16 that were sourced from North -South locations.

RELATION WITH CLIMATE DATA

A study comparing the moisture content and temperature data with the local climate conditions at UBC was conducted for Floor 3 to investigate possible correlations to the CLT performance between September 1, 2017, and August 31, 2019. Daily data of the rainfall and the average outside temperature was taken from the [Haney UBC RF Admin Station](), an online platform that shares historical climate data with the public. The values of the average daily relative humidity were taken from the UBC climatology station located at the Totem field.

The 3 segment graph was plotted for Floor 3 with the days as the x-axis and the real climate conditions, separated as mean daily temperature, relative humidity, and rainfall as the y-axis. The moisture content (graph X) and temperature (Graph X) were also plotted as a second y-axis.

The analysis did not show any correlation between the overall drying trend in the moisture content of the CLT panel and the external climate conditions (at least the three used above). However, a small correlation was observed between the variations of the internal temperature of the panels with the outside temperature, with increased CLT temperature during the hotter periods in July/August. A few spikes in internal CLT temperature also occurred during certain days with high rainfall. No correlation was observed between the internal temperature of the CLT panels and relative humidity.

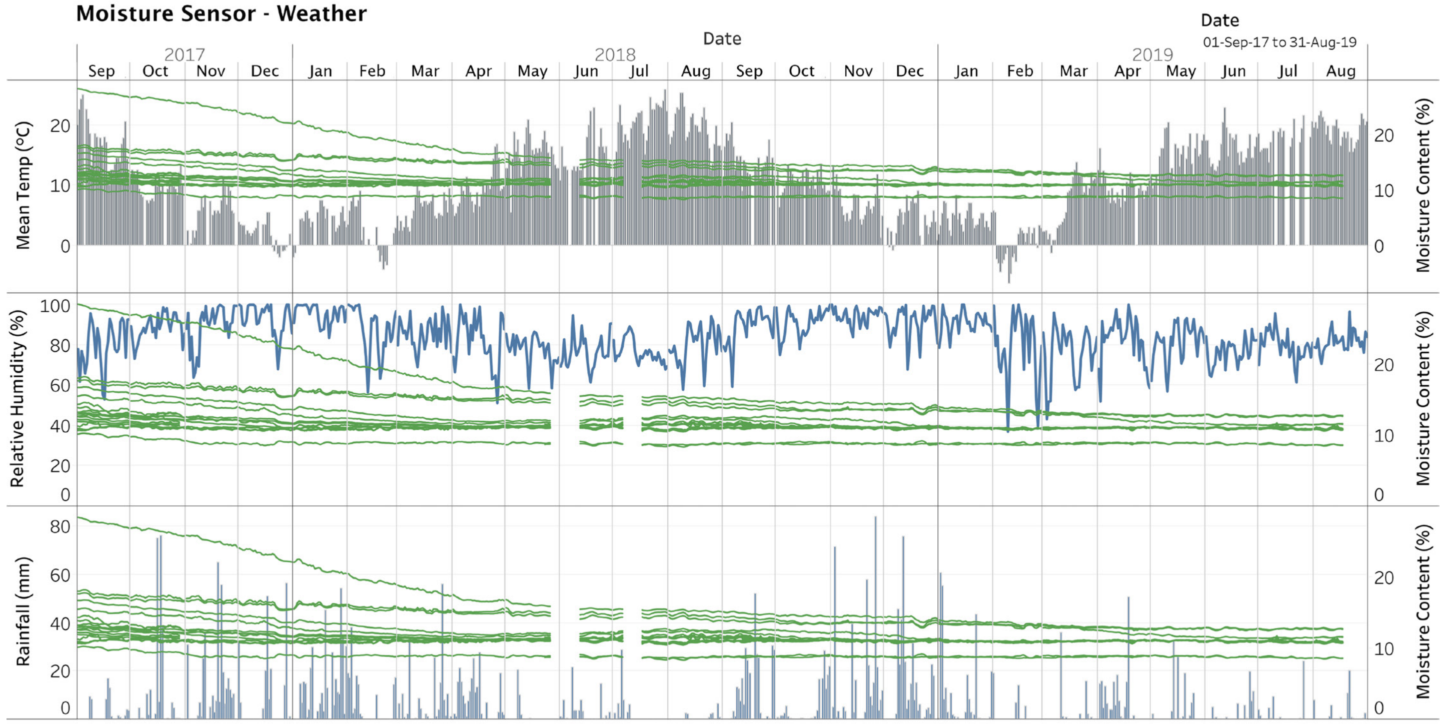


Figure 6: Moisture Sensor - Weather.
The moisture content of the CLT panels in Floor 3 and its relation to external climate conditions
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

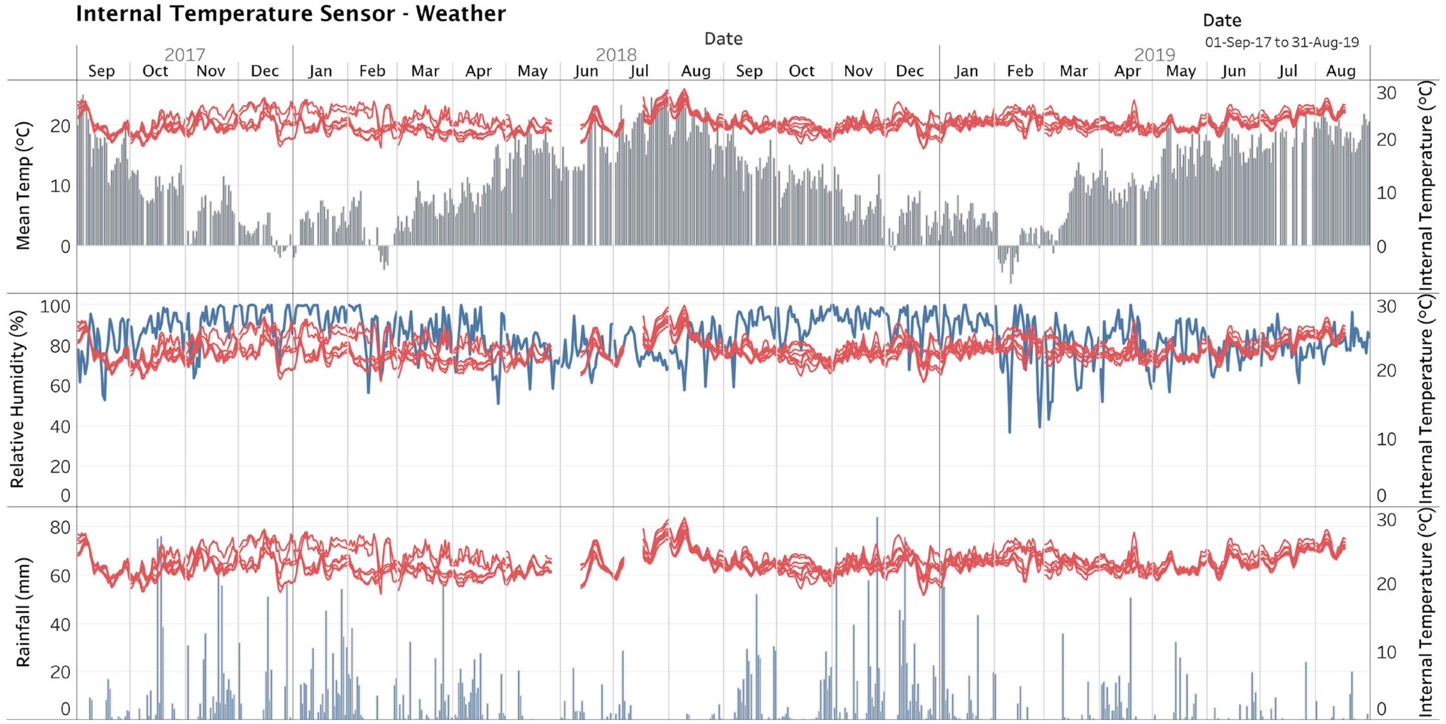


Figure 7: Internal Temperature Sensor - Weather.
The internal temperature of the CLT panels in Floor 3 and its relation to external climate conditions.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Internal Temperature values in °C)

MOISTURE CONTENT:
RELATION WITH FLOOR HEIGHT

The four graphs on pages 5 and 6 compare the moisture content in the CLT panels at different floor heights, against the local climate conditions, specifically mean daily temperature, relative humidity, and rainfall. The graphs on page 5 compare the measurements from sensors on Floor 3 and Floor 14, which were located in East and West sides of the building. The graphs on page 6 compare measurements from sensors on Floor 4 and Floor 16, which were located on the North and South sides. The comparisons assessed variations in moisture content due to floor altitude, or correlation to climate conditions.

This study showed that the moisture content of the CLT panels was slightly higher on the upper floors: the sensors on Floor 14 showed 3-5% higher MC compared to Floor 3. Both Floor 3 and Floor 4 had a similar drying trend, although there was greater variations on Floor 14 than Floor 3, and greater variation in the East sensor than the West sensor, including a small spike in winter 2019 in the moisture content of the east sensors. The overall trend in moisture content in all the floors did not seem to be affected due to external climate conditions.

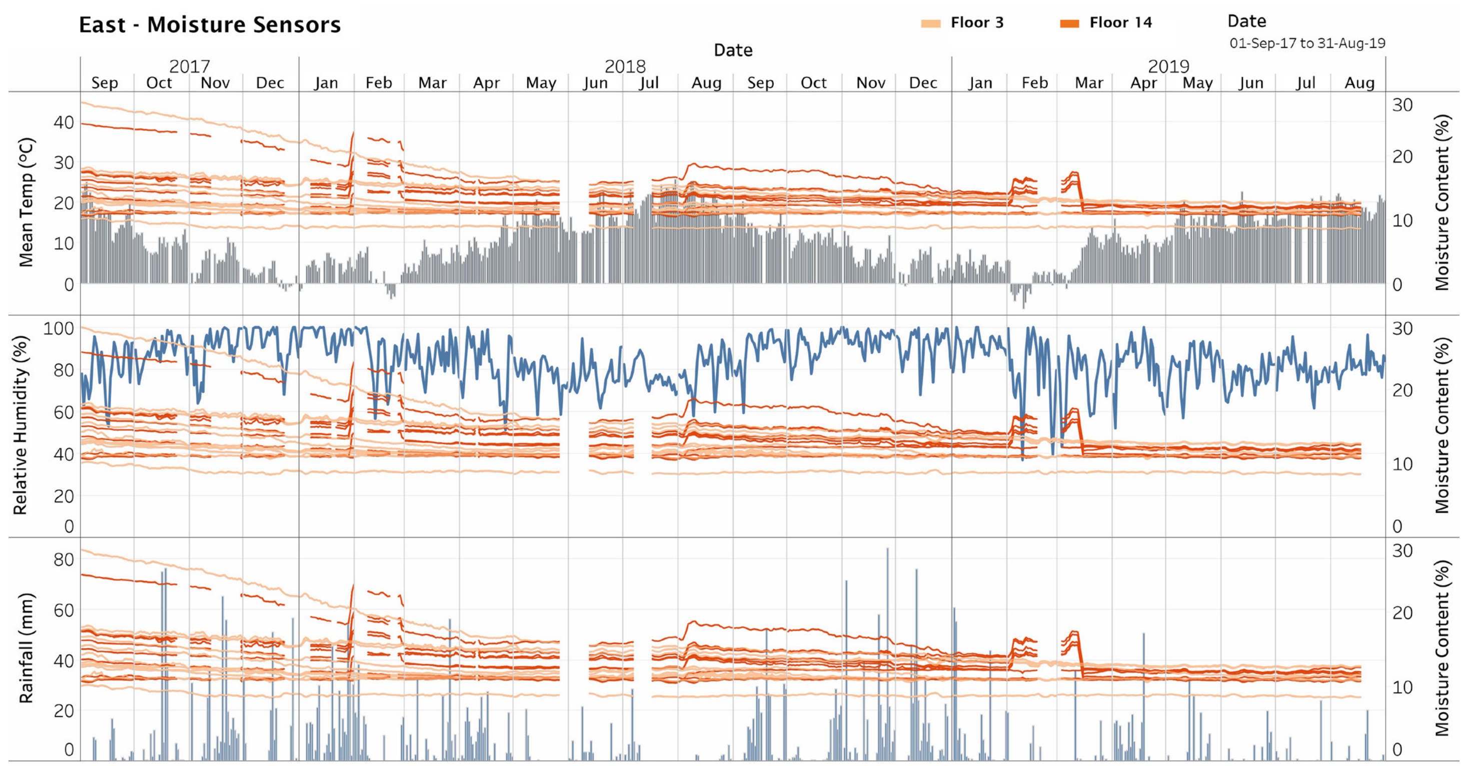


Figure 8: East - Moisture Sensors.
The moisture content of the CLT panels and its relation to the floor height, by comparing the data from the sensors at Floor 3 and Floor 14 in the East.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

Figure 9: West - Moisture Sensors.
The moisture content of the CLT panels and its relation to the floor height, by comparing the data from the sensors at Floor 3 and Floor 14 in the West.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

MOISTURE CONTENT:
RELATION WITH FLOOR HEIGHT

As noted on the previous page, the moisture content of the CLT panels was slightly higher on the upper floors: the sensors on Floor 16 showed 10-15% higher MC compared to Floor 4. This is a notable larger variation than between Floor 3 and 14. It should be noted that the sensors on Floor 16, position on the North and South of the building, are both a different orientation and two floors higher than the highest East-West sensors. Either orientation or additional height could be factor in the variation. Floor 16 also showed moisture data from the South location that did not follow the drying trend and maintained a consistent and higher moisture content than the other floors.

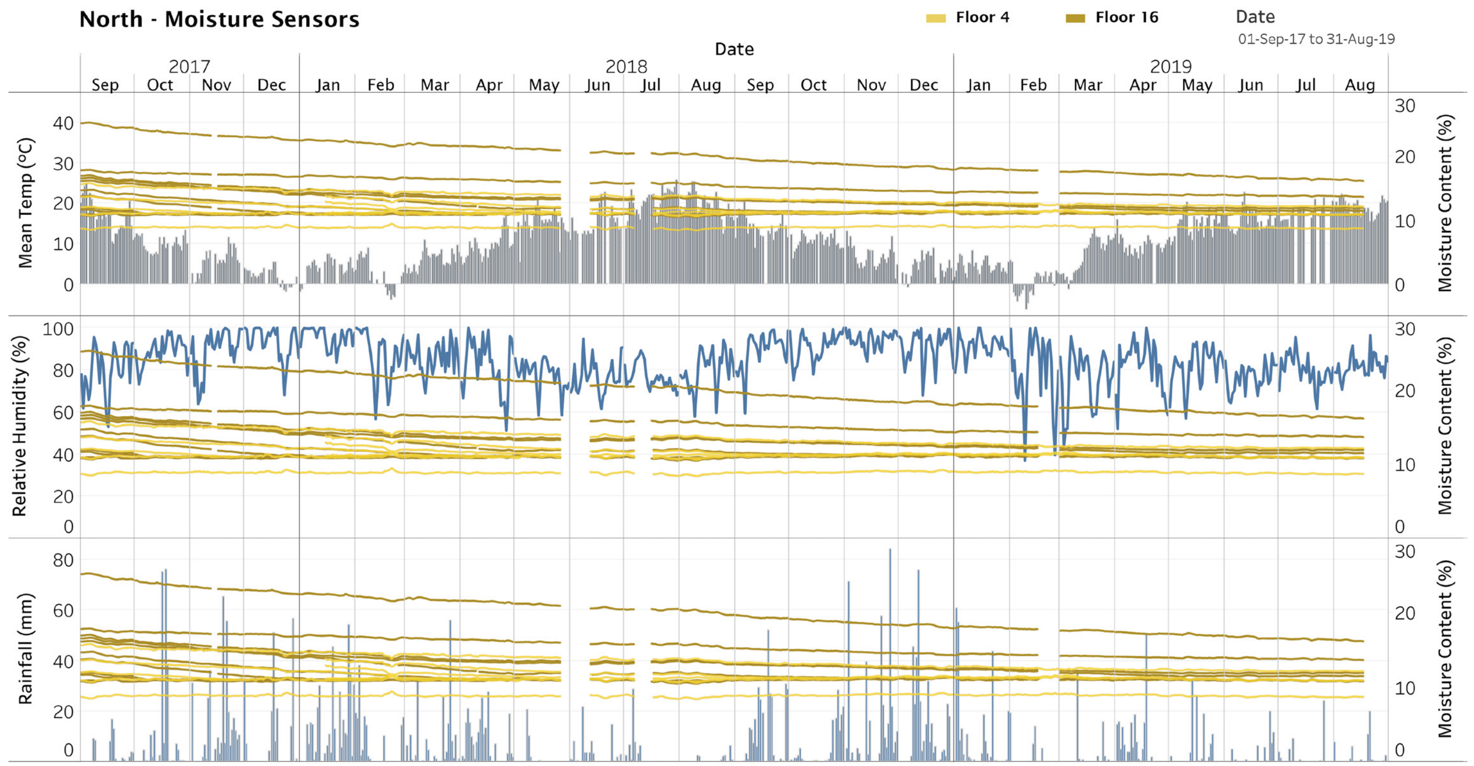


Figure 10: North - Moisture Sensors.
The moisture content of the CLT panels and its relation to the floor height, by comparing the data from the sensors at Floor 4 and Floor 16 in the North.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

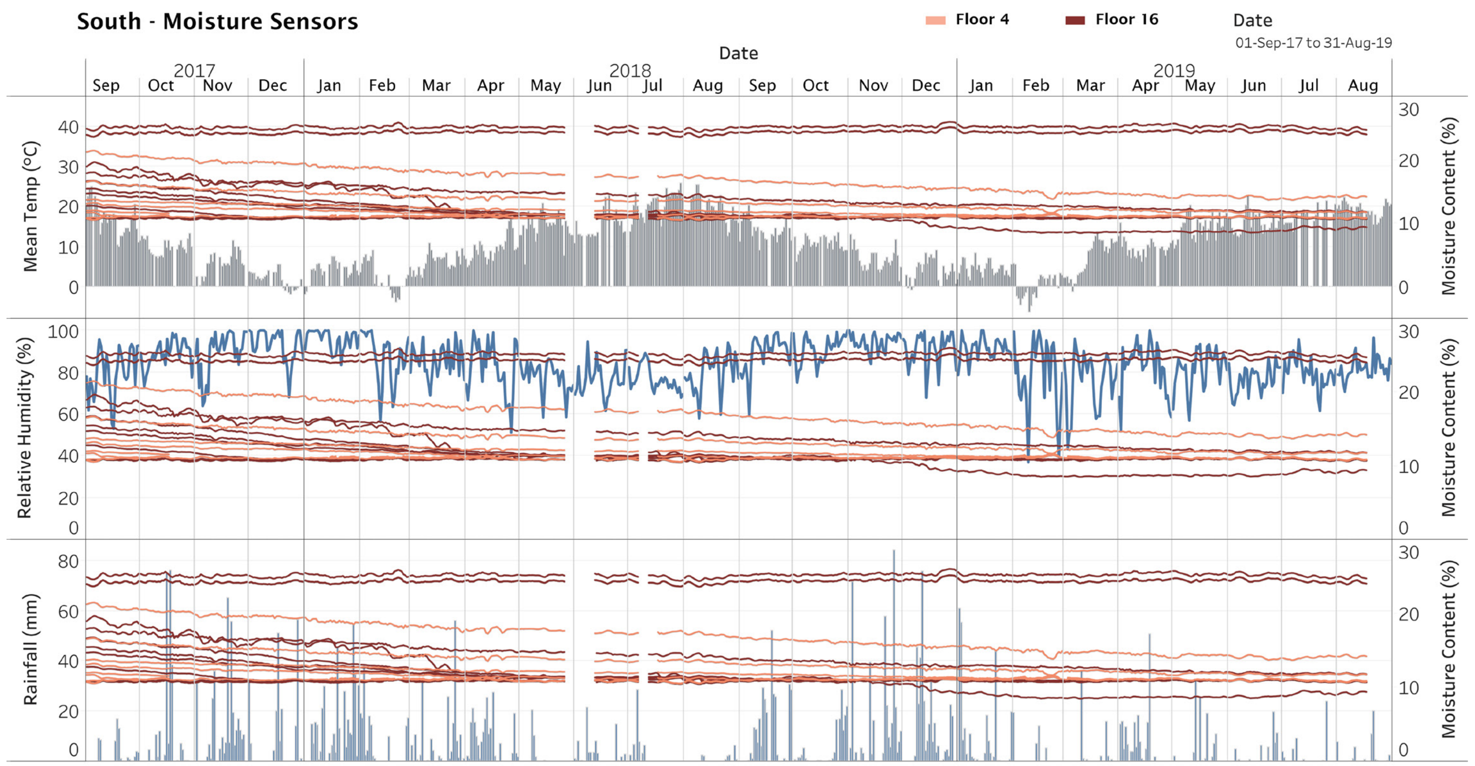


Figure 11: South - Moisture Sensors.
The moisture content of the CLT panels and its relation to the floor height, by comparing the data from the sensors at Floor 4 and Floor 16 in the South.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

MOISTURE CONTENT:
RELATION WITH ORIENTATION

The four graphs on pages 7 and 8 compare the moisture content of CLT panels in different orientations against the local climate conditions, specifically mean daily temperature, relative humidity, and rainfall. The graphs on page 7 compare the measurements from the East and West sensor locations in Floor 3 and Floor 14. The graphs on page 8 compared the North and South sensor locations in Floor 4 and 16. The comparisons assessed the influence of orientation and sun exposure on moisture content at different floor heights in the building.

This study showed that the moisture content in the East oriented panels was 3-5% higher than the West oriented panels, on both Floor 3 and Floor 14. . Floor 3 sensors in the East orientation showed a larger decrease in the first year and then a steady drying trend in the next two years. Floor 14 sensors in the East orientation showed a larger moisture decrease in the first year, but also a fluctuation in moisture content in 2018 and a small spike in winter of 2019. The data from the West- orientated sensors on both floors was more consistent and stable.

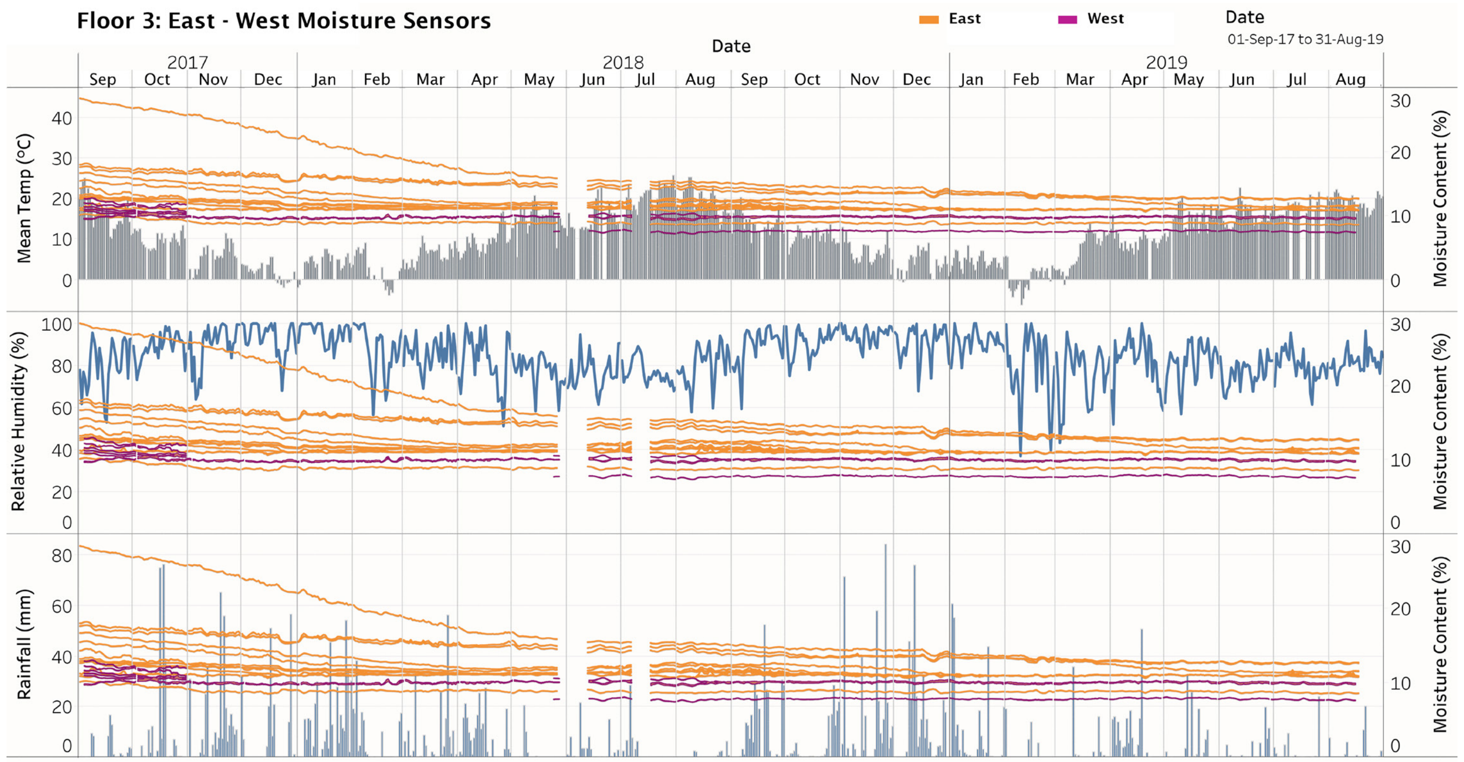


Figure 12: Floor 3: East - West Moisture Sensors. The moisture content of the CLT panels and its relation to the orientation, by comparing the data from the East and the West sensors at Floor 3.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

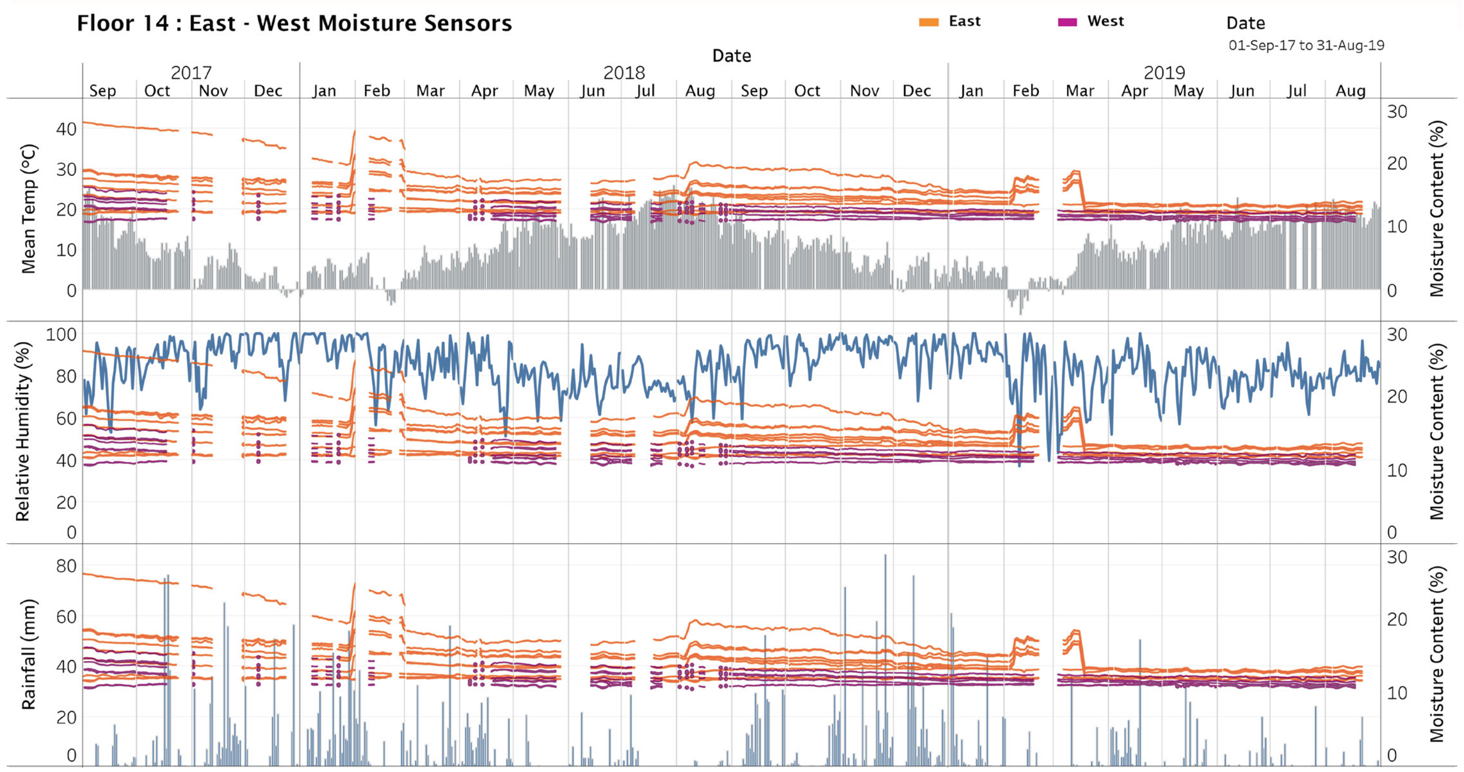


Figure 13: Floor 14: East - West Moisture Sensors. The moisture content of the CLT panels and its relation to the orientation, by comparing the data from the East and the West sensors at Floor 14.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

MOISTURE CONTENT:
RELATION WITH ORIENTATION

The study showed the moisture content in the South oriented panels was 1-3% higher than the North-oriented panels, on both Floor 4 and Floor 16, a smaller difference than the East-West sensors on Floors 2 and 14. Some sensors in the South location on Floor 16 maintained a consistent and higher moisture content, while the sensors in the North location followed the drying trend. On both Floors, the data from the North and South oriented sensors was generally more consistent than data from the East and West-oriented sensors, with no major spike or fluctuations. For all floors and orientations, the moisture content had no clear correlation with any of the climate data.

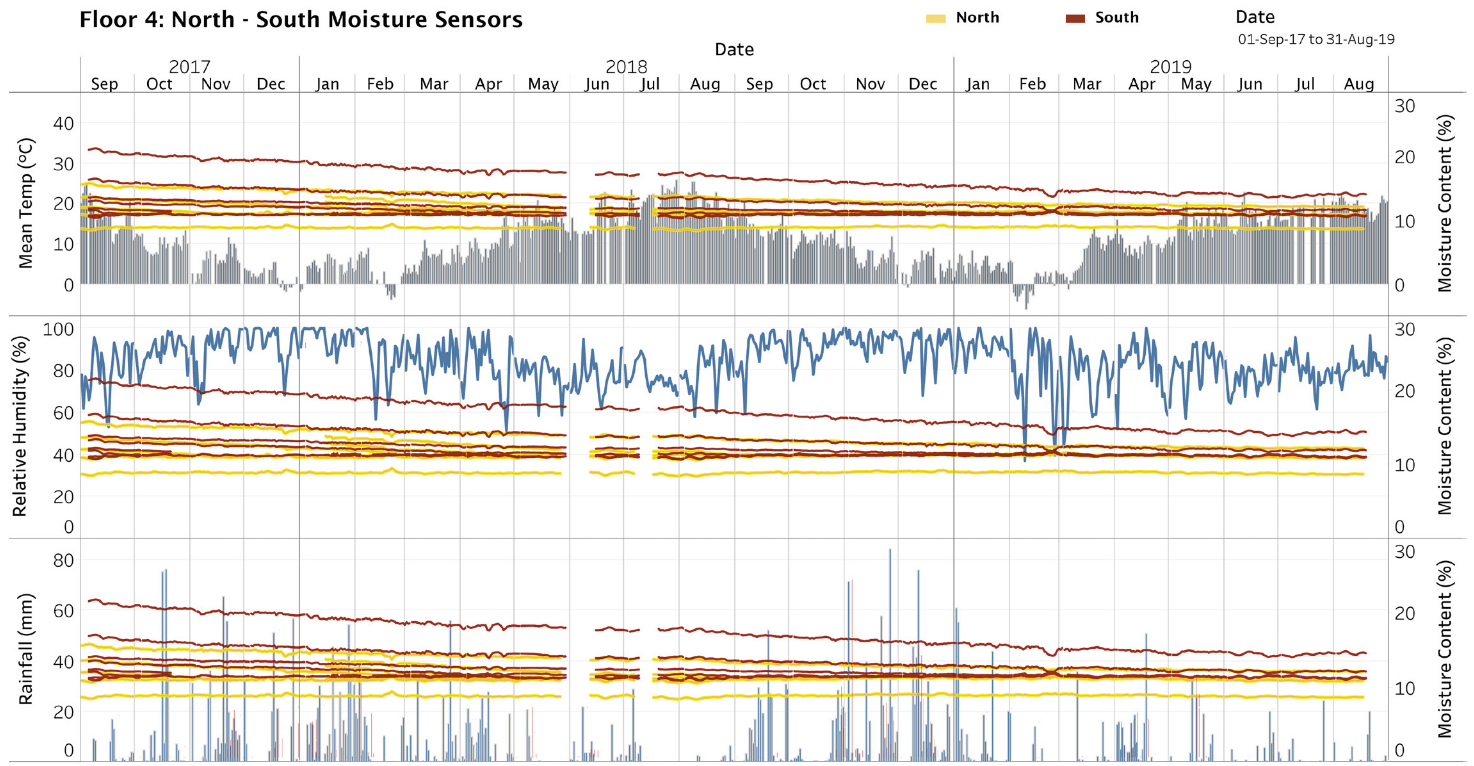


Figure 14: Floor 4: North-South Moisture Sensors. The moisture content of the CLT panels and its relation to the orientation, by comparing the data from the North and the South sensors at Floor 4.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

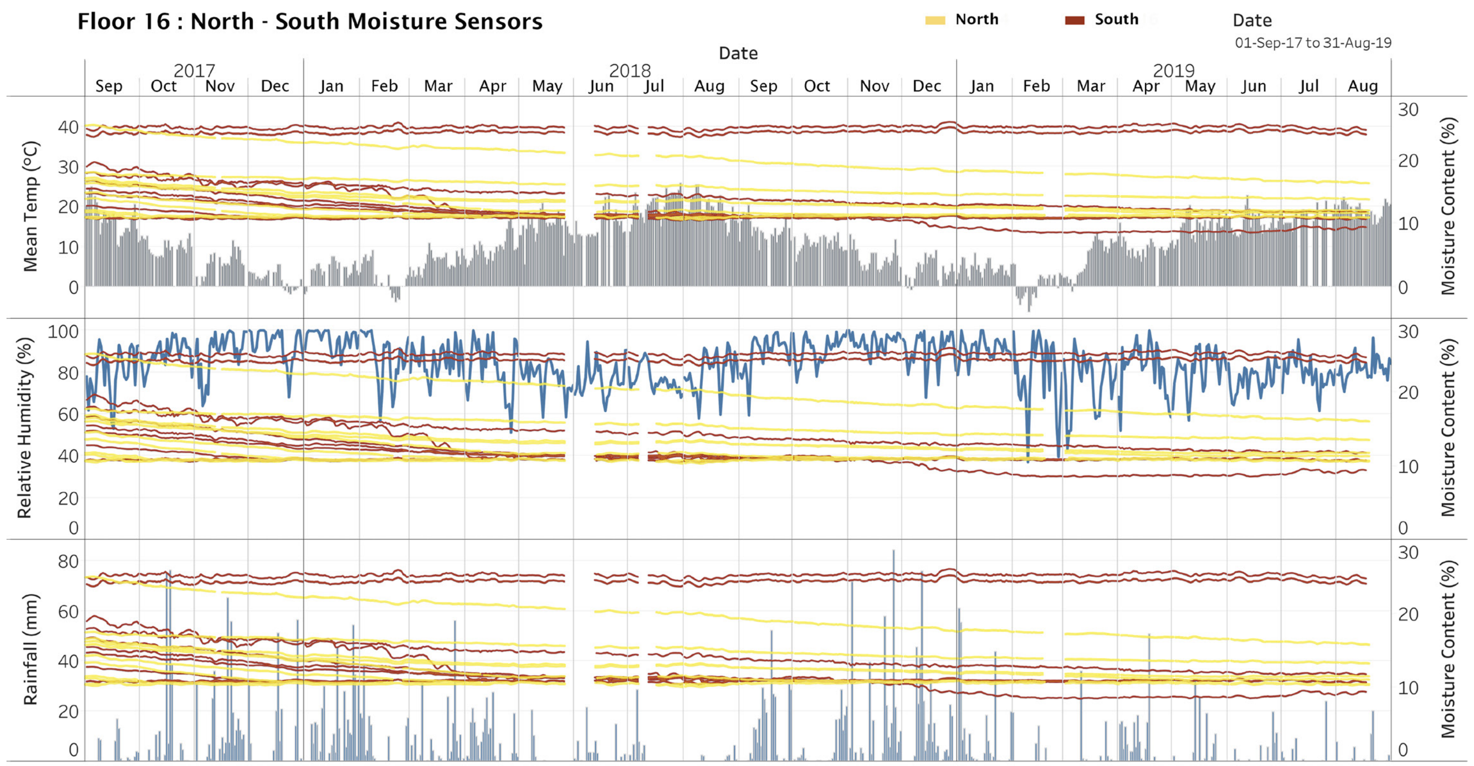


Figure 15: Floor 16: North-South Moisture Sensors. The moisture content of the CLT panels and its relation to the orientation, by comparing the data from the North and the South sensors at Floor 16.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Moisture content values in %)

INTERNAL TEMPERATURE:
RELATION WITH FLOOR HEIGHT

The four graphs on pages 9 and 10 compared the internal temperature of the CLT panels at different floor heights, against the local climate conditions (mean daily temperature, relative humidity, and rainfall). The graphs on page 9 compare the measurements from sensors on Floor 3 and Floor 14 located in East and West sides of the building. The graphs on page 10 compare the measurements from sensors on Floor 4 and Floor 16 located in North and South. Similar to the previous moisture content analysis, the comparisons assessed variations in internal panel temperature due to floor altitude or correlations to local climate conditions.

This study showed that the internal temperature of the CLT panels varied with the external mean daily temperature for both the East and West oriented sensors on both Floor 3 and Floor 14. Specifically the internal temperature of the CLT panels increased when the external temperatures was high in the summer months. On both floors, there were also some spikes of internal temperature that seems to be connected to days of high rainfall, but the correlation is not consistent. The internal temperatures of the CLT panels in the East and West locations, were very similar between the lower and upper floors throughout the year.

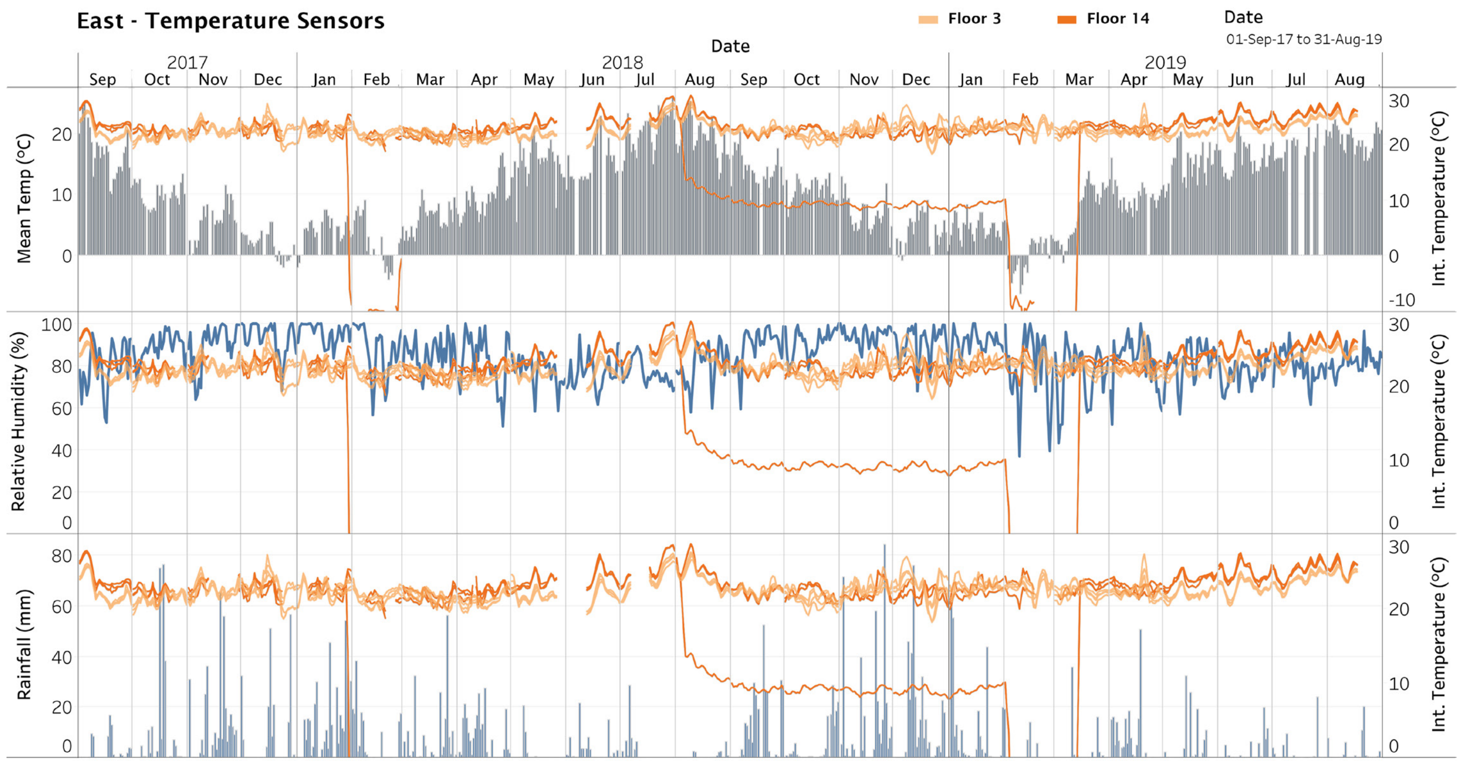


Figure 16: East - Temperature Sensors.
The internal temperature of the CLT panels and its relation to the floor height, by comparing the data from the sensors at Floor 3 and Floor 14 in the East.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Internal Temperature values in °C)

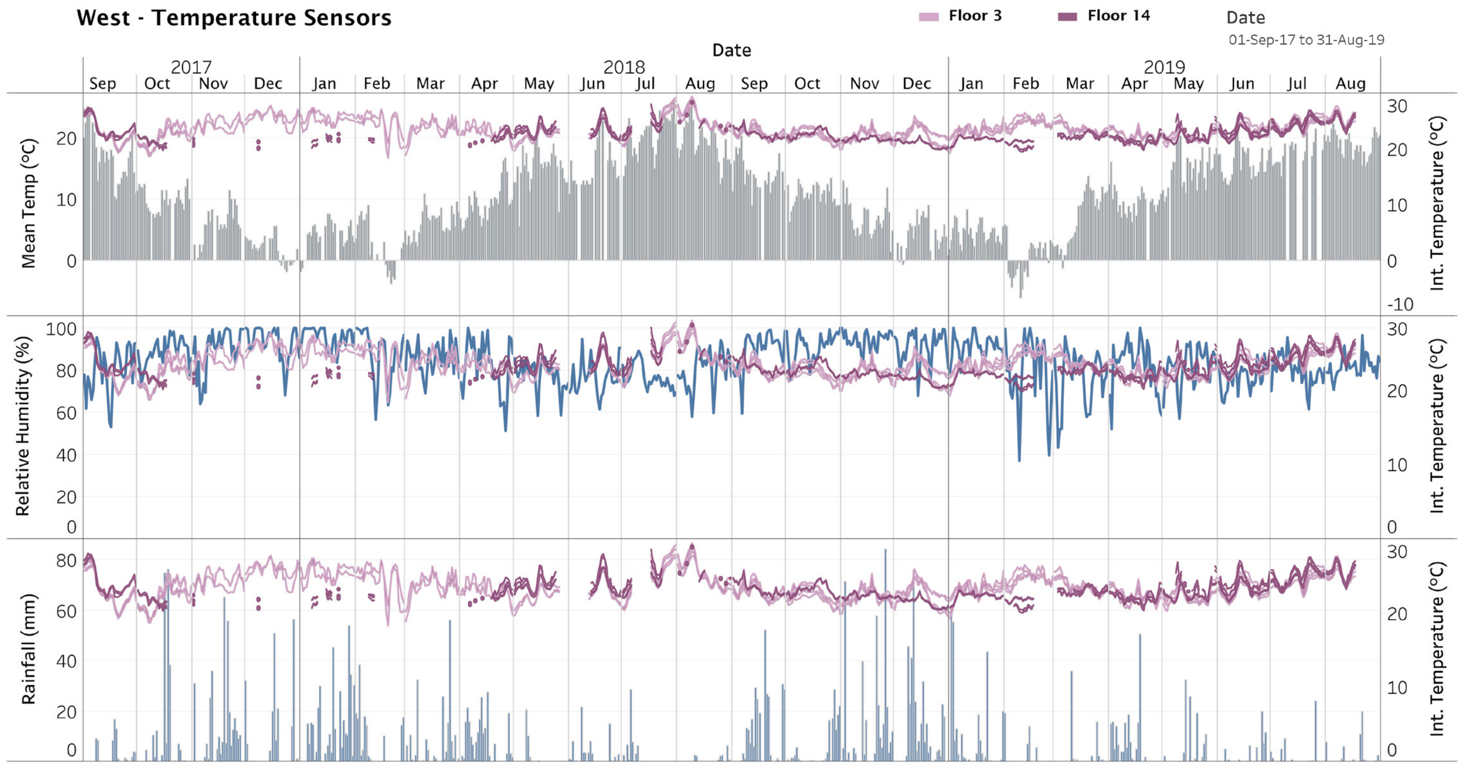


Figure 17: West - Temperature Sensors.
The internal temperature of the CLT panels and its relation to the floor height, by comparing the data from the sensors at Floor 3 and Floor 14 in the West.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Internal Temperature values in °C)

INTERNAL TEMPERATURE:
RELATION WITH FLOOR HEIGHT

Similarly to the graphs on the previous page, the internal temperature of the CLT panels varied with the external mean daily temperature for the North and South oriented sensors on Floor 4 and Floor 16, with an increase in temperature correlating to higher external temperature in the summer. However, in both North and South locations, there was a distinct although small difference between internal temperatures on Floor 4 and Floor 16, with the sensors on Floor 16 measuring a consistently higher temperature through the years. Floor 4 also had a greater fluctuations and notably lower internal temperature than Floor 16 during the winter months.

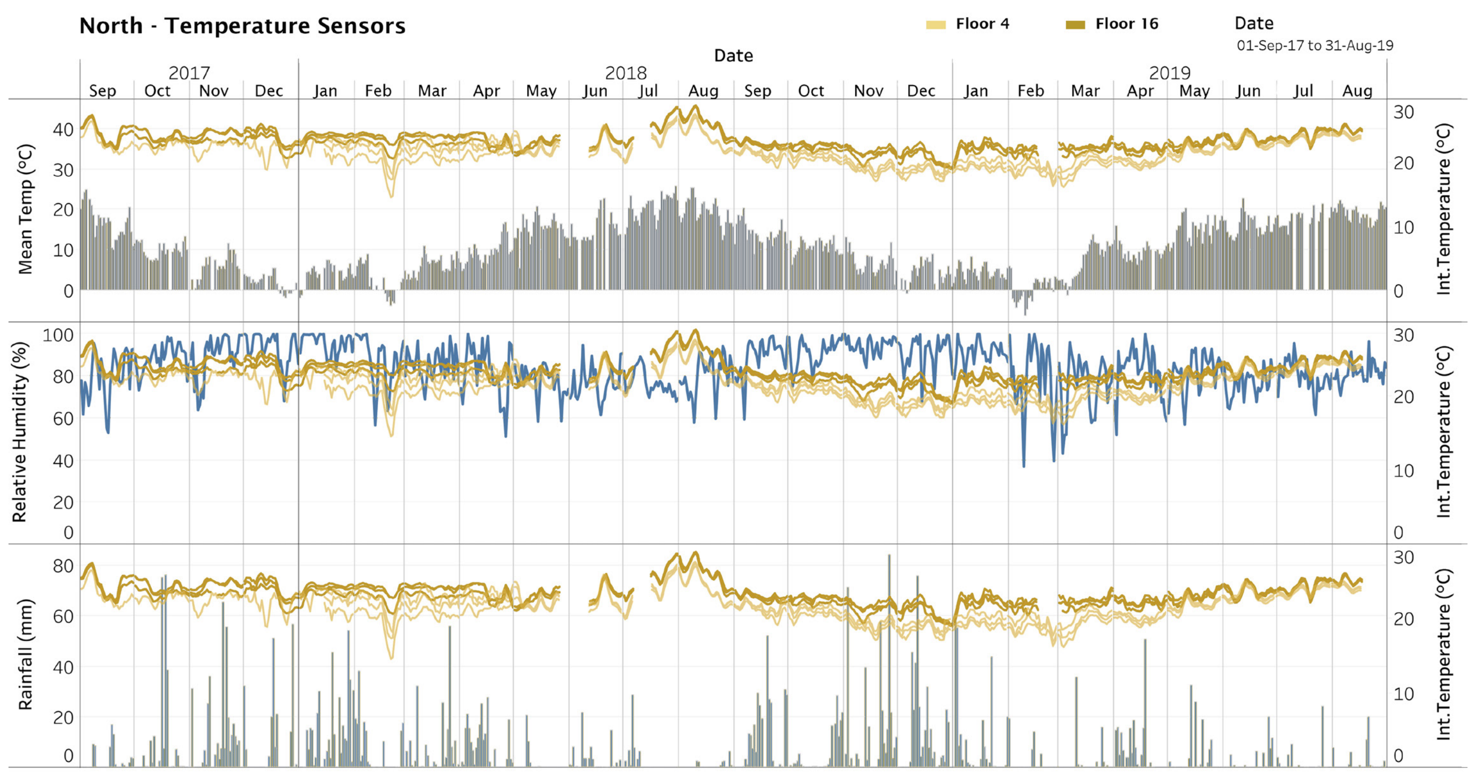


Figure 18: North - Temperature Sensors.
The internal temperature of the CLT panels and its relation to the floor height, by comparing the data from the sensors at Floor 4 and Floor 16 in the North.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Internal Temperature values in °C)

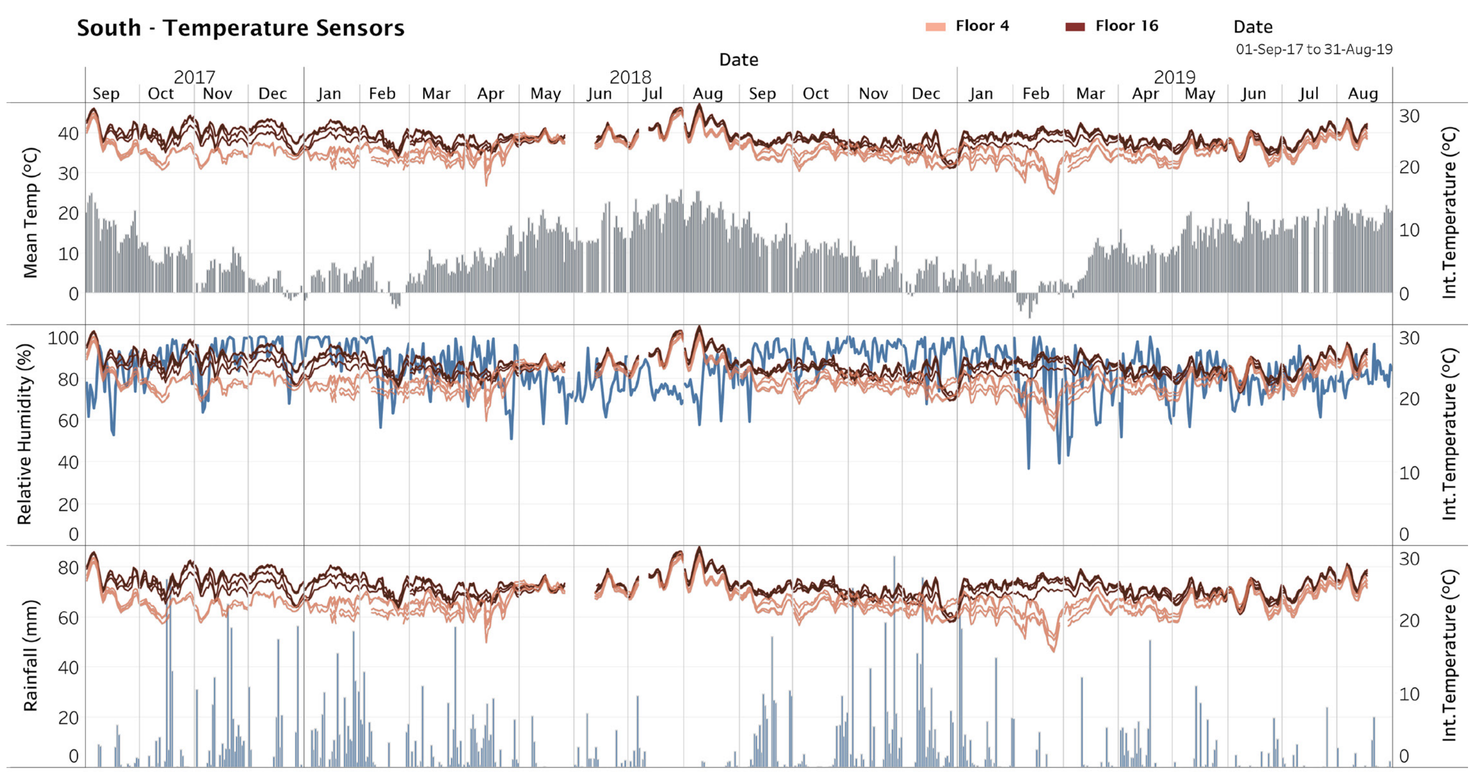


Figure 19: South - Temperature Sensors.
The internal temperature of the CLT panels and its relation to the floor height, by comparing the data from the sensors at Floor 4 and Floor 16 in the South.
(X-axis - Days from September 1, 2017, to August 31, 2019;
Dual Y-axis- Left: Climate conditions and Right: Internal Temperature values in °C)

INTERNAL TEMPERATURE:
RELATION WITH ORIENTATION

The graphs on pages 11 and 12 compare the internal temperature of the CLT panels and the mean average daily outside temperature for the period between June 1, 2018, and December 31, 2018. The graphs on page 11 compare the measurements from the East and West sensor locations in Floor 3 and Floor 14. The graphs on page 812 compared the North and South sensor locations in Floor 4 and 16. The comparison over 6 month period assessed the correlations between internal temperature of the CLT panels and the external temperature, as well as variations due to higher altitude, and orientation.

On both Floor 3 and Floor 14, the higher internal temperature measurements of the CLT panels correlated to higher outside air temperature in June, July and August, although the internal temperature generally remained steady when the external temperatures dropped in November and December. During the summer months, the West-oriented sensors on Floor 3 measured slightly higher temperatures than the East-oriented sensors. No similar variation was measured on Floor 14, however, there were greater fluctuations in the data from the East-oriented sensor than the West-oriented sensors on Floor 14.

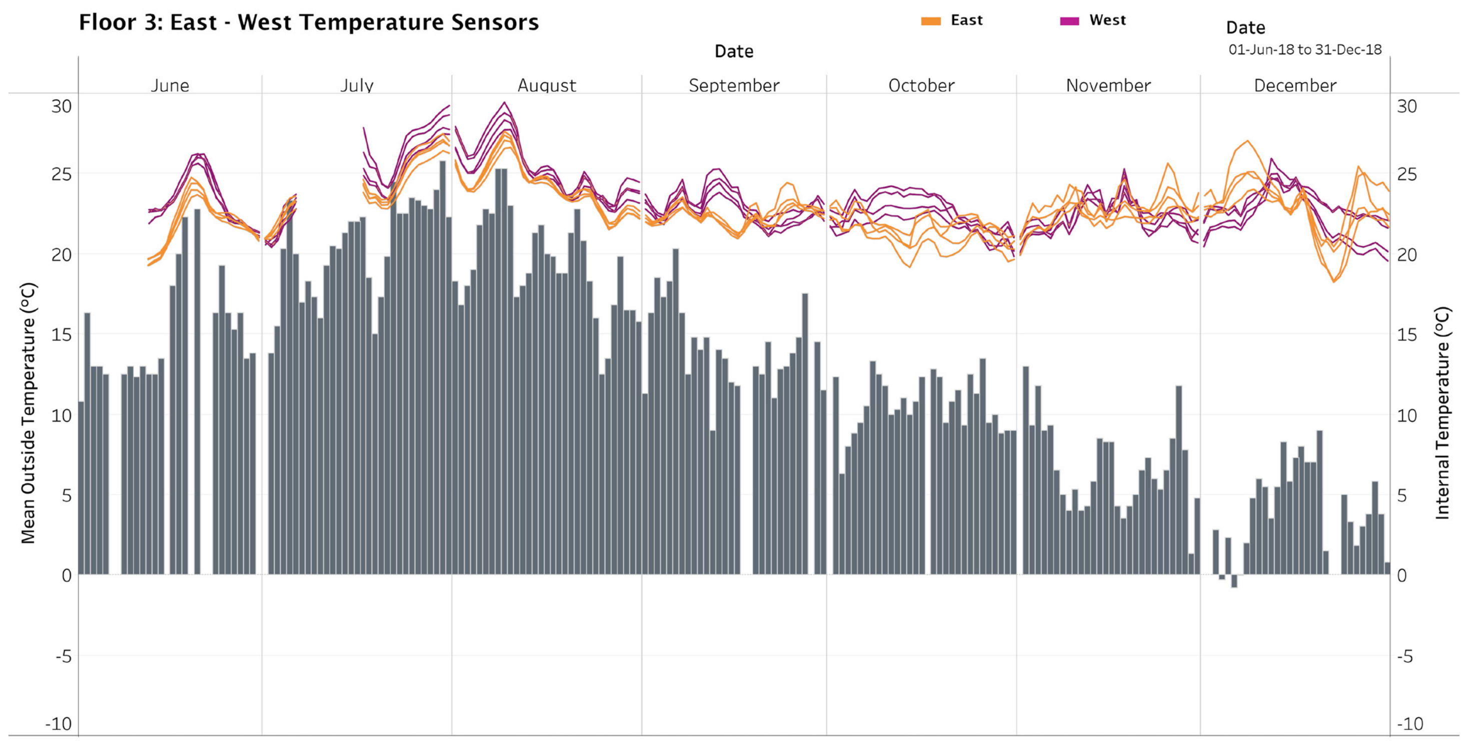


Figure 20 : Floor 3: East - West Temperature Sensors. The internal temperature of the CLT panels against the average outside temperature, comparing the measured values in Floor 3 in East-West locations.
(X-axis - Days from June 1, 2018, to December 31, 2018;
Dual Y-axis- Left: Outside temperature in °C and Right: Internal temperature in °C)

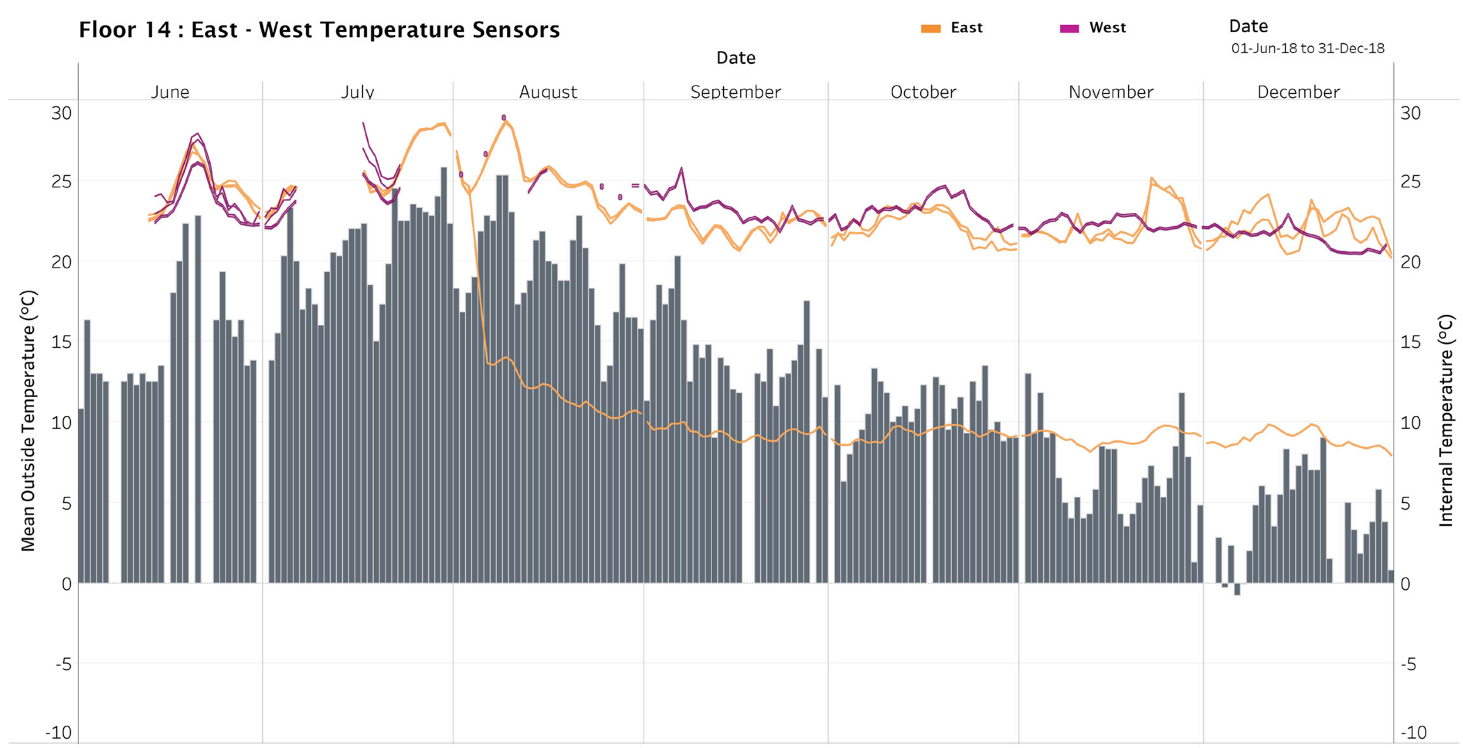


Figure 21 : Floor 14: East - West Temperature Sensors. The internal temperature of the CLT panels against the average outside temperature, comparing the measured values in Floor 14 in East-West locations
(X-axis - Days from June 1, 2018, to December 31, 2018;
Dual Y-axis- Left: Outside temperature in °C and Right: Internal temperature in °C)

INTERNAL TEMPERATURE:
RELATION WITH ORIENTATION

Similar to the pervious graphs, higher internal temperature measurements of the CLT panels on both Floor 4 and Floor 16 correlated to higher outside air temperature in June, July and August. Generally, the internal temperature of the South-oriented sensors on both floors remain steady into the winter month, although there was a drop in internal temperatures on Floor 16 at eh end of December correlating to the lowest external temperatures. The North-oriented sensors on both floors measure a small but consistent trend of decreasing in internal temperature from the summer to winter months. Throughout the year, the internal temperatures on the South side of the building were consistently higher than those on the North side, for both Floors, and the difference increased during October, November and December.

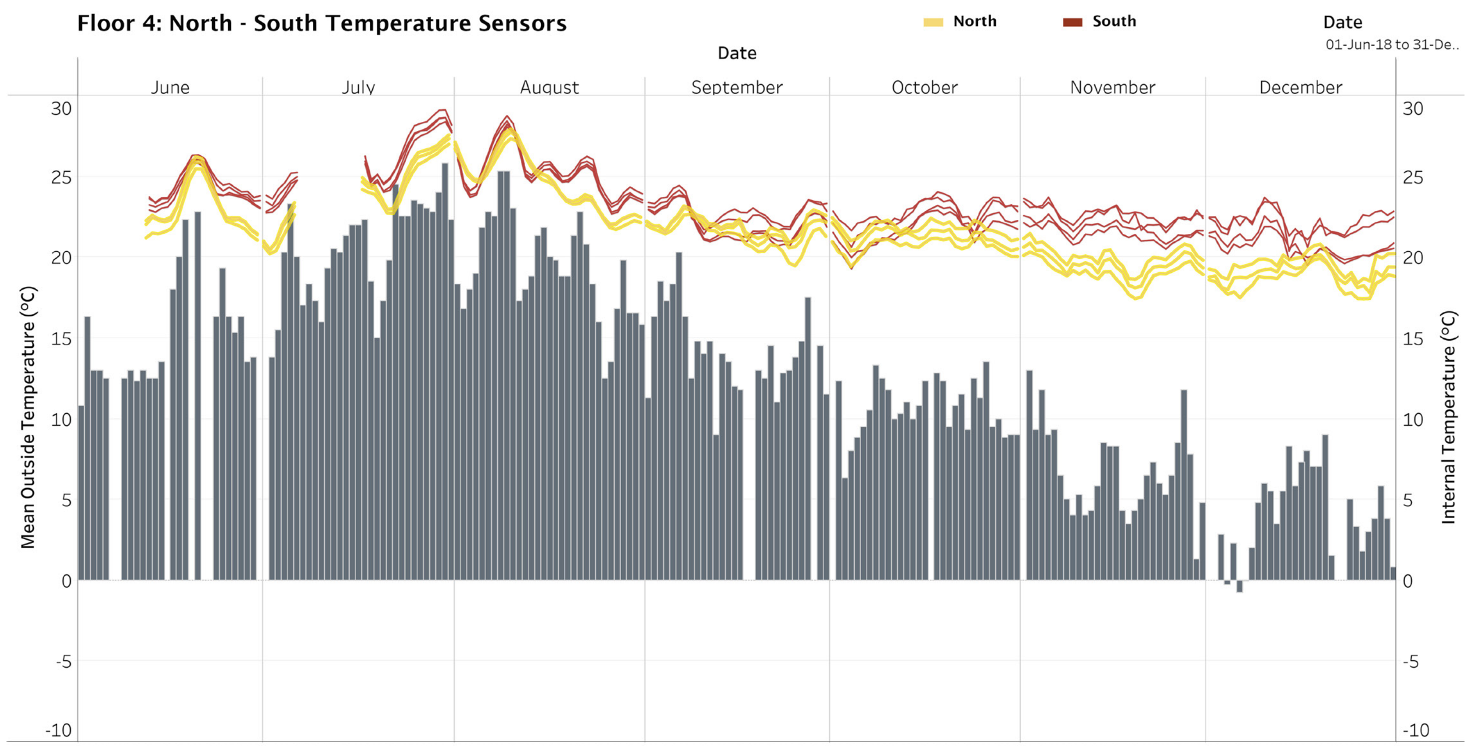


Figure 22 : Floor 4: North - South Temperature Sensors. The internal temperature of the CLT panels against the average outside temperature, comparing the measured values in Floor 4 in North-South locations.
(X-axis - Days from June 1, 2018, to December 31, 2018;
Dual Y-axis- Left: Outside temperature in °C and Right: Internal temperature in °C)

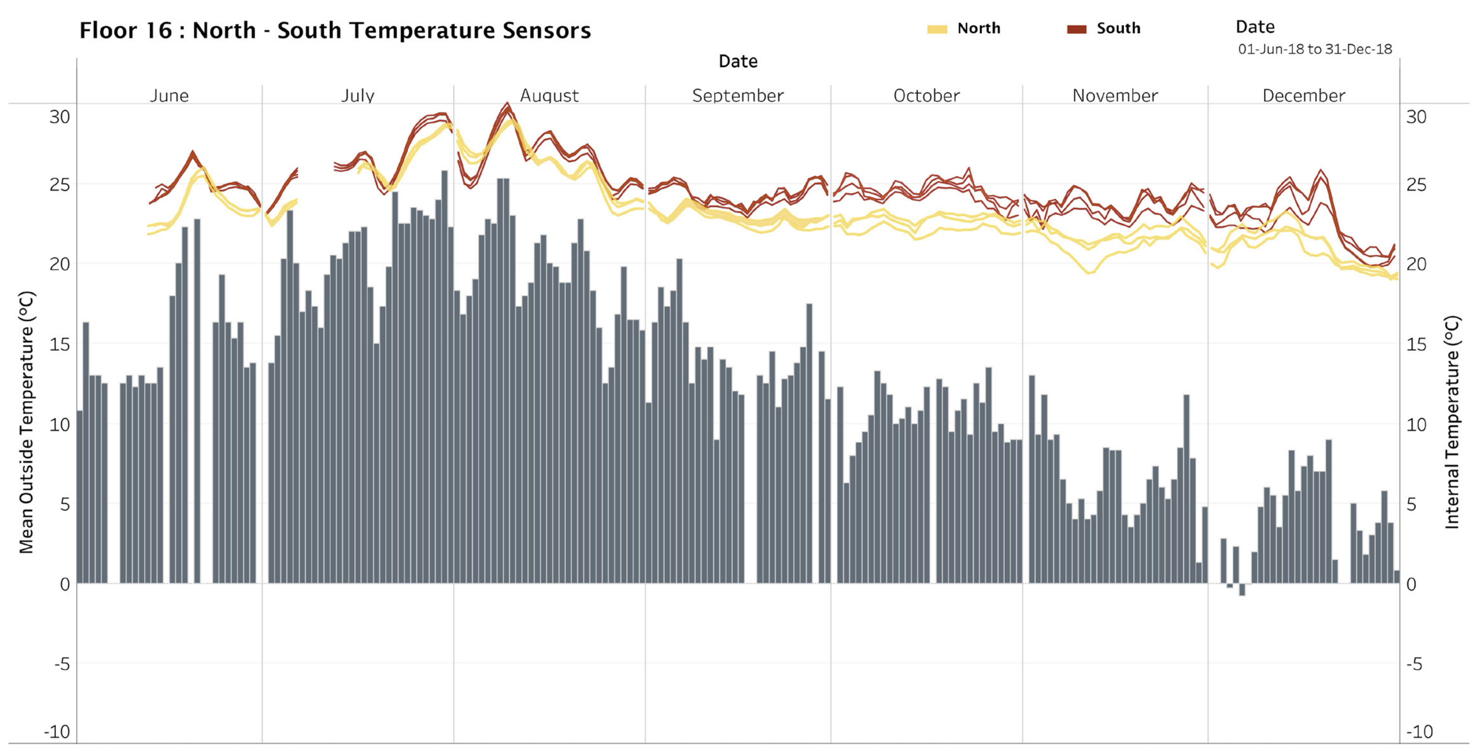


Figure 23 : Floor 16: North - South Temperature Sensors. The internal temperature of the CLT panels against the average outside temperature, comparing the measured values in Floor 16 in North-South locations.
(X-axis - Days from June 1, 2018, to December 31, 2018;
Dual Y-axis- Left: Outside temperature in °C and Right: Internal temperature in °C)

VERTICAL MOVEMENT

The performance analysis also included readings from the vertical movement string pot sensors. The readings from the sensors for all the floors were plotted over the period between September 2017 and August 2019. The days were used as the x-axis and the corresponding vertical displacement values were marked against the y-axis. The data was almost continually recorded on the upper floors, however, the sensor data the lower floors was temporarily unavailable for the period between August 20, 2018, and February 4, 2019.

The study showed a vertical compression of about 0.25-1mm over the two year period on all floors above Floor 7. The vertical compression in the bottom floors was significantly greater: about 2 to 4 mm over the same period.. The highest displacement was recorded on Floor 4-5: about 4mm over two years.

Overall, there was an average shortening of about 0.8-1 mm over the total height of the building over the two year period. There seems to be a slight upward trend in the 2019 data, with the most significant displacement occurring by March 2019, and then reducing afterwards.

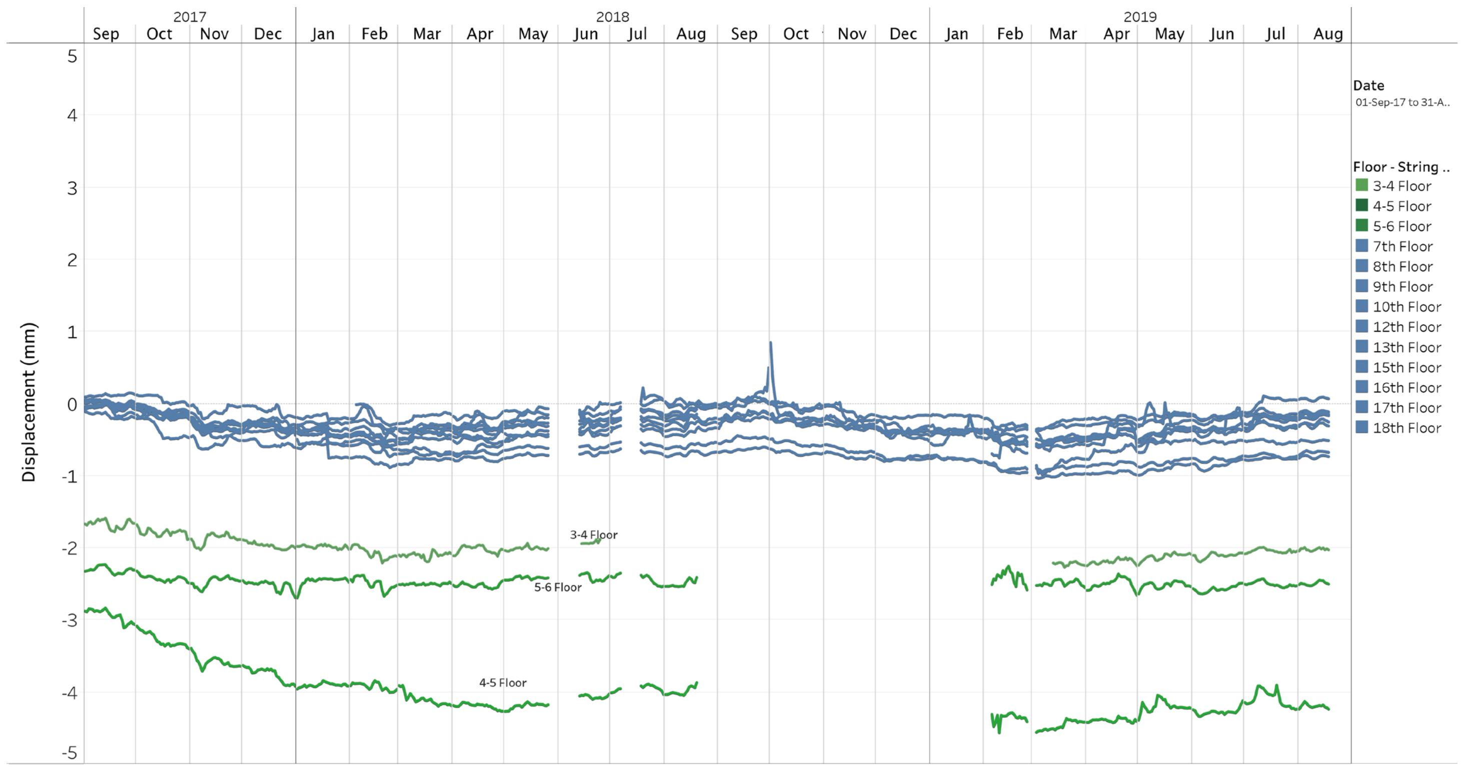


Figure 24 : Vertical movement recorded by the string pot sensors installed on each floor for the days between September 1, 2017, and August 31, 2019.
(Note : the negative values mean shortening of the panel and the positive values mean expansion of the panel.)

4. CONCLUSION

In conclusion, the brief study of the sensor data monitoring the moisture content of the CLT panels and the vertical movement of the mass timber structure in Tallwood House for the first two years revealed that:

- The moisture mitigation measures taken by the CLT panels during construction have been working well and continuing to provide good performance during the first two years of building occupancy.
- Though the internal temperature of the CLT panels varied with time of the year, the temperature variation inside the panels did not seem to affect its internal moisture content.
- The moisture content of the CLT panels was influenced more by the higher altitude and orientation than the amount of rainfall or relative humidity.
- Vertical compression varied above and below the seventh floor, with the greatest compression recorded on the mid-level floors (4-5).

This study was intended as a report of the sensor data in Tallwood House, with some preliminary correlation analysis, not a comprehensive assessment. Additional research should be pursued to fully explore the specific factors and conditions that impact the moisture and compression in the mass timber structure. The building's internal environment conditions, as well as the influence of individual occupant behavior (e.g. opening windows, use of space heating or humidifiers, or longer showers), could be worth exploring and may have stronger correlation on the structural conditions than external factors.

Photo Credit: naturallywood.com. Photographer: KK Law

UBC Sustainability Initiative

2260 West Mall
Vancouver BC, V6T 1Z4

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