TIMBER DEVELOPMENT ASSOCIATION

Six Storey Timber Framed Building's Movement and Moisture Content

Document Revision Status

Issued	Issue No	Description
11 June 2019	1	Submitted version
November 2020	2	Revised report issued

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Date: November 2020
Status: Updated

ACKNOWLEDGEMENT

The Timber Development Association wishes to acknowledge the assistance from the contractors on the project; Strongbuild and Westbourne Projects. We also wish to acknowledge Structural Monitoring Technology for their assistance in the selection and set up of the sensors.

EXECUTIVE SUMMARY

The objective of this research was to obtain real data on the temperature, relative humidity, moisture content of timber and vertical displacement of a real, six-storey timber-framed building, during its construction and initial occupation.

The research was successful in obtaining fourteen months of data, being the construction, handover and the early occupation of the building. Thankfully, twelve months of data were obtained, representing the period the building was enclosed, representing the annual seasonal weather variations.

The building experienced extreme temperatures variation from minus 0.9 to 47°C, also experienced a very wet period, receiving 87 mm of rain, following six months of very dry conditions. Surprisingly with this variation of weather conditions, the movement recorded within the building was much less than the expected 6.0 mm per storey, suggested in the WoodSolutions Guide #50.

Much of this reduced movement can be attributed to the use of engineered wood floors – Cross-laminated timber and Laminated Veneer Lumber load-bearing studs. The use of these materials reduced movement from crushing and deflection.

Although beneficial information was found from this research, Western Sydney represents only one climate zone in Australia. It is recommended that further monitoring of timber buildings occur in regions such as Melbourne and Brisbane is undertaken. Furthermore, the data on moisture content is representative of subsurface conditions and not the average of the entire timber element. Explanation or advice is needed to convert subsurface moisture content reading, as recorded in the above research, to the average moisture content of the timber element. This advice is particularly relevant to thick timber elements such as CLT.

Contents

INTRODUCTION

With the timber industry moving towards taller timber-framed buildings, there is a growing need to provide the designer and construction industry with a means to remove uncertainty in the design of tall lightweight timber-framed buildings. Evidence in the market place is that builders and contractors are risk-averse and require certainty before proceeding to newer building construction methods such as lightweight timber-framing for 4 to 8 storey buildings.

Movement within a building is not limited to timber as concrete can move up to 1.5 to 3.0 mm per meter of construction. Concrete is very slow to construct and is heavy, so most of the movement occurs before the building is fitted out whereas, for timber, it is quick to build and lightweight, so most of the movement related to timber occurs prior to occupation or shortly after that. This movement may results in call-back issues for cracked coverings or hung-up façades or breakage of plumbing and other services if this movement is not accounted for in the design.

Accurate estimates of movement within a timber-framed building are needed to minimise the effects of axial shortening or differential movement. Methods used in North America are based on moisture content change, but they are for different climate conditions, and their timber is often supplied partially seasoned, i.e. 18 to 19 % moisture content (MC). While in Australia, experience in movement and moisture content change, in these types of buildings, is relatively unknown.

This research project is about obtaining data on the building interior environment (temperature and relative humidity), moisture change and movement of a real, six-storey timber-framed building and from this information validation that the assumptions used to calculate movement are accurate. The primary aim of this research is to monitor temperature, relative humidity, moisture and the vertical displacement of a six-storey timber frame building in four locations within the building; exterior wall (south and east-facing), internal apartment wall and the building's central corridor wall.

Building Description

The building used for this research is a six-storey platform timber-frame building with 160 mm thick cross-laminated timber (CLT) floors. It is situated at the corner Rouse Road and Cudgegong Road in Rouse Hill, NSW Australia. The building is U shaped, and the dimensions of the building are: 18-metre height (3 metres per level), 60-metre length and 84-metre width, refer to Figure 1. The timber frame commences at level one, above a concrete car parking basement.

Figure 1: Aerial image of Phoenix, Image Credit: Strongbuild

The load-bearing walls are timber framed, predominately LVL from North America and Western Australia. They were manufactured as a closed panel at Strongbuild's factory in Bella Vista, Sydney, refer to Figures 2 and 3.

Figure 2: LVL wall frame on Strongbuild's wall line, Image Credit: Strongbuild

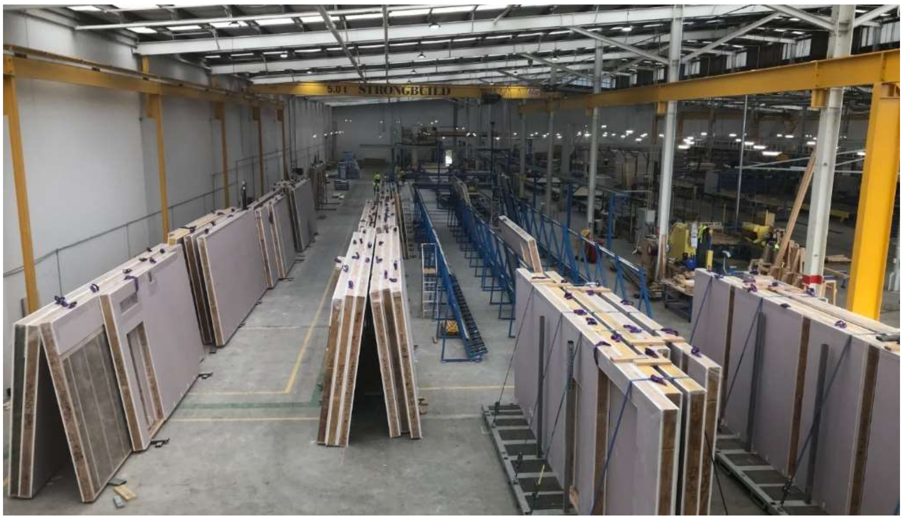


Figure 3: Finished wall frames waiting for delivery to site, Image Credit: Strongbuild

The floors and the core walls are made from 160 mm thick spruce CLT from Binderholz, Austria, refer to Figure 4.

Figure 4: CLT floor and lift core at Phoenix, Image Credit: TDA

The internal partition walls and exterior walls are made from steel studs, refer to Figure 5.

Figure 5: Exterior Steel Frame Walls, Image Credit: TDA

MATERIAL AND METHOD

The sensors and the software used for measuring were purchased from Structure Monitoring Technology (SMT) (www.smtresearch.ca) from Canada. The company has off the shelf solutions and software for monitoring moisture and vertical movement. The company has also supplied equipment to FPInnovation, a wood industry research company in Canada. FPInnovations has conducted similar monitoring research on four mid-rise timber buildings in Canada.

Sensors

Displacement Sensor (String Pot, SPOT)

A String Pot or Draw Wire sensor is a device used to measure vertical displacement from storey to storey. The sensor has a non-extendable thin wire that is attached to the storey above or below. A series of these sensors were placed above each other, and the displacement for each storey can be measured, added together to represent the movement of timber part of the building, refer to Figure 6.

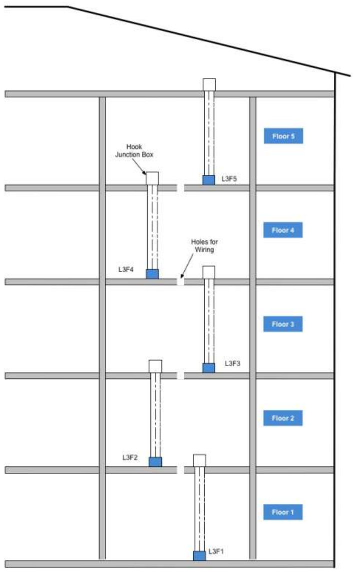


Figure 6: Typical String Pot deployment for monitoring compression in a multi-storey building, Image credit: SMT Research

The String Pot sensor is a rotary potentiometer that measures electrical resistance. The rotary potentiometer is located typically on a floor of one storey within the building, connected to the next storey by a thin non-extendable stainless steel wire. When the building moves vertically, the cable moves, rotating the potentiometer. This movement is registered by the potentiometer and in turn, is calibrated to provide displacement measurement. The potentiometer is positioned so it can read expansion or settlement of each storey. The sensor is then hardwired to a data logger that collects the recorded information.

The String Pot model used in this research is SPOT-00-50 mm, with a measuring range of 50 mm, refer to Figure 7.

Figure 7: String Pot sensor Image, Credit: TDA

Displacement Configuration

Figure 8 illustrates how the String Pot box is connected to the floor.

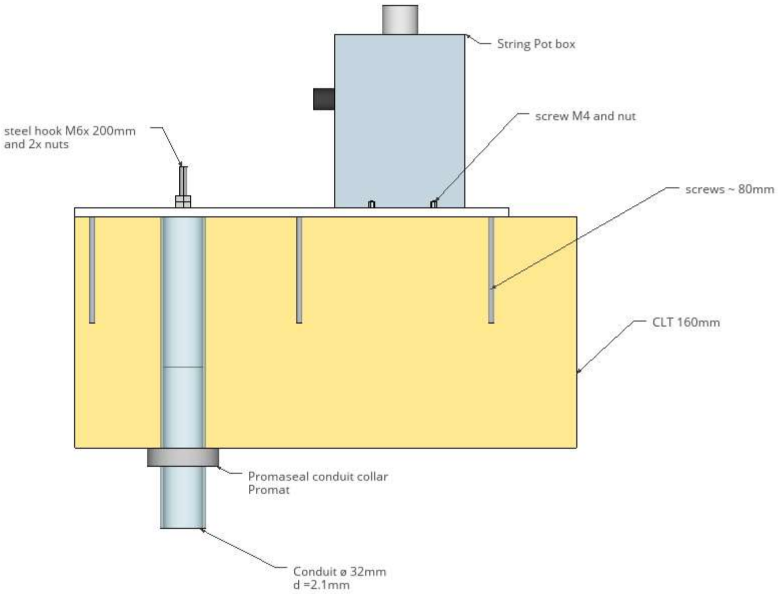


Figure 8: Connection of the String Pot Box to the floor

Figure 9 illustrates the location of the installed sensors in the south-east corner of the building.

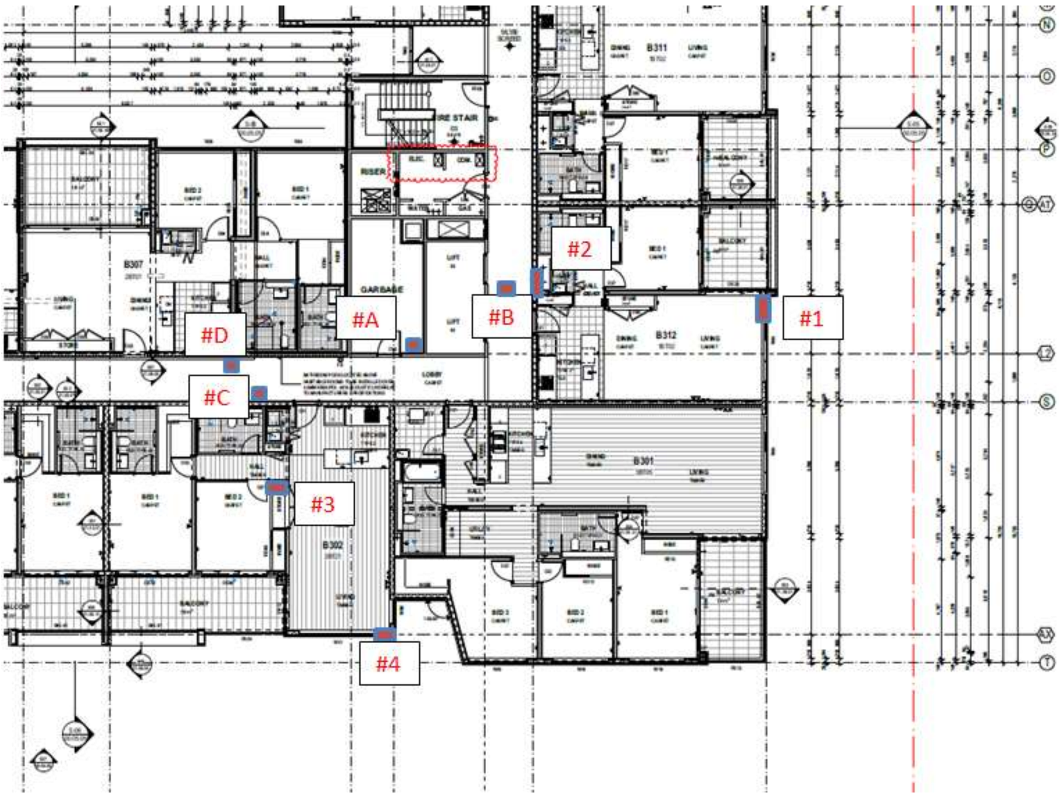


Figure 9: Floor plan with sensor position marked up, Image Credit: Floor plan Strongbuild and TDA

To anchor the non-extendable thin stainless steel wire to the floor above, a galvanised hook bolt (Eye Bolt) is connected to the floor above by an aluminium angle that is also used to secure the String Pot box to the next level, refer to Figure 10.

Figure 10: Connection Eye-bolt and stainless steel wire, Image Credit: TDA

The hook bolt runs through a hole in the CLT floor and is anchored to an aluminium angle used to fix the next floor's String Box, refer to Figure 11. To ensure the fire rating of the ceiling is not compromised, the hole the hook bolt is contained in is protected by a 32 mm HPDM conduit, refer to Figure 12.

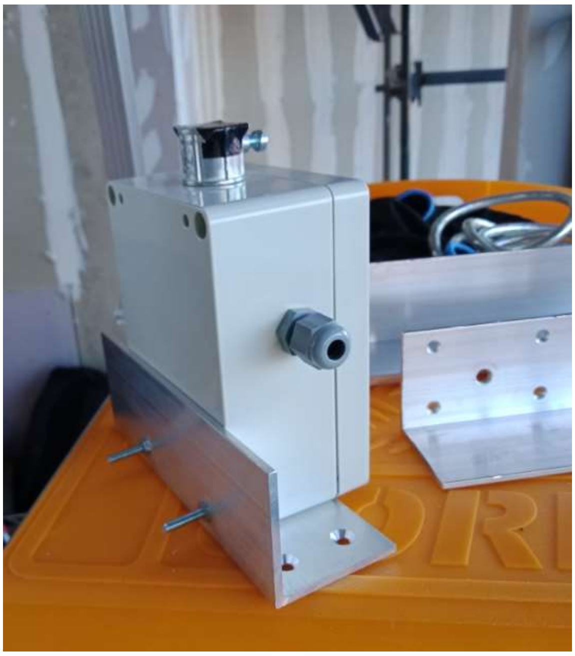


Figure 11: Aluminium Angle used to secure eye bolt and String Pot Box, Image Credit: TDA

Figure 12: 32 mm conduit penetrating the floor, Image Credit: TDA

At the underside of the fire-rated plasterboard directly fixed to the CLT floor, is a fire-rated collar from Promaseal® which is installed around the conduit, refer to Figure 13.

Figure 13: Fire Rated collar around the conduit, Image Credit: TDA

Figures 14 and 15 show the connection of the stainless steel wire to the rotary potentiometer by a fishing hook and tracer line.

Figure 14: Connection of a fishing hook and the displacement sensor, Image Credit: TDA

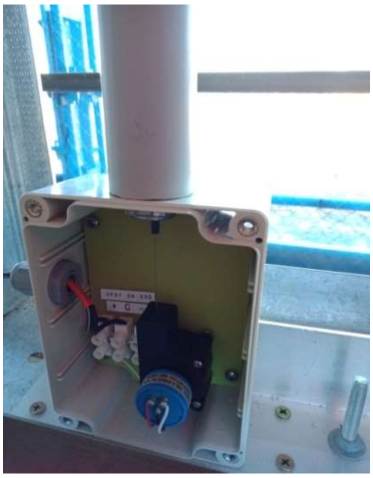


Figure 15: String Pot Sensor prior to being enclosed, Image Credit: TDA

Figure 16 shows the fishing hook tracer connected to the non-extendable stainless steel wire inside the 25 mm HPDM conduit.

Figure 16: Connection of the stainless steel wire to fishing hook tracer, Image Credit: TDA

The non-extendable stainless steel wire runs through a 25 mm diameter conduit, to prevent the wire elements within the wall cavity from getting caught on any insulation or services, refer to Figure 17. At the top of the wall, the 25 mm diameter conduit is cut short off the floor and placed inside a larger 32 mm diameter conduit. This arrangement forms a slip joint, preventing the conduit from getting caught between the floors, as the floor to floor height changes.

Figure 17: 25 and 32 mm conduit in a wall cavity with fire-rated collar, Image Credit: TDA

Figure 18 shows the installed String Pot sensor and conduit with the wall insulation installed within the cavity and prior to the wall being sealed with plasterboard.

Figure 18: Wall cavity before the wall gets closed, Image Credit: TDA

String Pot's Position

The String Pot displacement sensor measures the vertical movement of every level of the building in four different positions. The positions are marked as follows #1, #2, #3 and #4 on a typical floor plan, refer to Figure 19.

The position of the sensors is chosen to represent different possible environments within the building. Position #1 and #4 are placed in the outside walls. Position #1 has the sun in the morning, and Position #4 has the sun in the afternoon. Position #2 is placed next to the hallway, and Position #3 is placed within an apartment unit itself. It is conjectured that the timber-framed elements on the exterior wall may have a moisture content higher than the studs near the building's corridor, i.e. buildings centre.

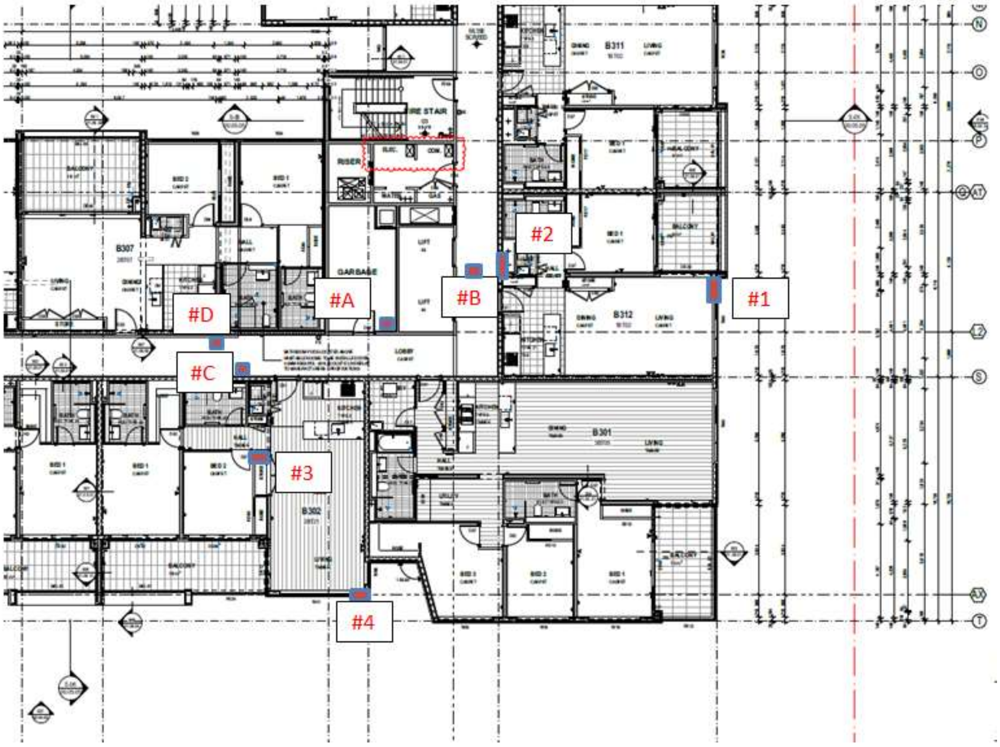


Figure 19: String Pot location, Image Credit: Strongbuild and TDA

Each String Pot is connected to a data logger by running a fixed wire from each displacement sensor to the resistance channels (17 to 20) on the A3 4R4V Data Acquisition Unit located in the garbage room on each floor of the apartment building.

Point Moisture Measurement Sensor (PMM)

The Point Moisture Measurement (PMM) Sensor is used to perform a direct contact measurement of moisture content in timber used within the building. The design of the PMM ensures moisture probes are spaced consistently apart and contain an integrated temperature sensor that allows temperature correction of moisture content readings, refer to Figure 20.


Figure 20: Point Moisture Measurement (PMM) Sensor, Image Credit: SMT Research

The sensor measures the moisture content of the timber by gauging the electrical resistance of the timber between the screws. The resistance is higher if the moisture content in the timber is low because the timber does not act as a conductor of electricity. The water in the walls of the timber fibres conducts electricity applied by the sensor through the timber. The electrical resistance is calibrated by the Building Intelligence Gateway software, which is discussed later.

Installation

Since the timber-framed walls used predominately throughout the building were made from enclosed panels, access to the timber framing was not possible to insert the sensors, on the building site. Furthermore, the walls used for the apartment partitions and exterior walls were constructed from steel framing. Consequently, this led to the need to place sensors into dummy studs within the steel-framed partition and exterior walls.

The PMM sensors were installed into dummy studs positioned in the cavities of the non-load-bearing walls and behind bathroom pods next to the String Pot displacement sensors illustrated in Figure 19. The Timber species used for the dummy studs were predominately a 70 x 35 mm Radiata Pine (Pinus Radiata). Spruce (Picea Abies) was also used in some location to ascertain if there is a species variance. The sensors were installed at a height of 1.5 m to 2.0 m above the floor. The PMM probes are inserted 20 mm into the timber.

Figure 21: Radiata Pine stud with PMM sensor, Image Credit: TDA

Figure 22: Spruce stud with PMM sensor, Image Credit: TDA

To ensure that the studs measure the moisture content is equivalent to a long length stud, each dummy stud was at least 1,000 mm long, and the end of the studs was sealed with a moisture-proofing compound, refer Figure 23.

To account for the density of the different species used, the Building Intelligence Gateway (BiG), discussed later, has a correction factor incorporated within the software. The sensor also includes a temperature sensor to allow temperature compensation.

Figure 23: Dummy stud showing moisture-proof compound attached, Image Credit: TDA

PMM sensors were also placed into the CLT floor in the hallway and at a load-bearing CLT wall in the garbage room for every level of the timber component of the building. The timber species used for the CLT walls and floors was Spruce (Picea Abies). The PMM sensors are inserted 20 mm into the CLT.

All PMM sensors are hardwired to an A3 Data Acquisition Units. Wires from the PMM sensors run along with the ceiling of each level of the building to the A3 Data Acquisition Units located in the garbage rooms, refer Figure 24.

Figure 24: PMM wires penetrating wall in the garbage room and connected to A3 Data Acquisition Units, Image Credit, TDA

Sensor Positions

The PMM sensors are installed into dummy studs positioned within the cavities of the non-load bearing partition and external walls. The location of the sensors is nearby to the String Pot displacement sensors illustrated in Figure 19. Some sensors are located in the void near the bathroom pods.

Additional PMM sensors are installed to the underside of the CLT floor, located in the hallway of every floor and marked as positions #B, #C and #D in Figure 19. Furthermore, PMMS sensors and marked as positions #A, are installed into the CLT walls in the garbage room of all floors nearby the location of the data loggers.

The PMM sensors are interfaces to SMT's A3 Data Acquisition Unit. The A3 Data Acquisition Unit transmits readings to the Building Intelligence Gateway (BiG) where temperature compensation and wood species correction factors are applied.

Relative Humidity and Temperature Sensor HTM2500 (RH/T)

Humirel HTS2010 humidity sensors were installed throughout the building. The relative humidity (RH) sensor is a voltage based sensor and needs to be connected to A3 Data Acquisition Units voltage ports (input 21 to 24). The temperature sensors in the HTM2500 RH units were not used as the resistance channels of the A3 Data Acquisition Units are required for the displacement sensors (string pots). However, the moisture PMM has temperature measuring capability, and these were used in several locations. Figure 25 shows the Relative Humidity and Temperature sensor HTM2500 (RH/T).

Figure 25: Relative humidity and Temperature sensor HTM2500, Image Credit: SMT Research

Installation

The Relative Humidity and Temperature sensors were installed in the non-load-bearing wall cavities and behind bathroom pods next to the PMM sensors. Figure 26 shows a Relative Humidity and Temperature sensor installed behind a bathroom pod.

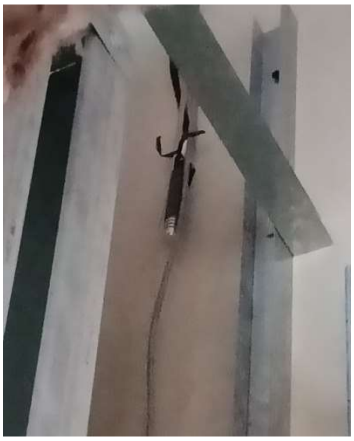


Figure 26: Relative Humidity and Temperature sensor behind a bathroom pod, Image Credit: TDA

DATA COLLECTION AND ANALYSIS

A3 Data Acquisition Unit

The A3 Data Acquisition unit is a multichannel measurement device designed to interface with a variety of different building sensors. On this project, two types of A3 Data Acquisition units were used, and each is described below. All A3 Data Acquisition units are hardwired to their sensors. The A3 Data Acquisition unit communicates wirelessly to the Building Intelligence Gateway, which is discussed later. The A3 Data Acquisition unit is powered by batteries which have a life of over one year.

A3 – 8 Channel Wireless Data Acquisition Unit (A3 8CH 8)

An eight resistance channel data acquisition unit is used to collect the data from the Point Moisture Measurement (PMM) sensor. Figure 27 shows an A3 8R Data Acquisition Unit. The wires from the PMM sensors are connected at the inputs numbered 17 - 24.

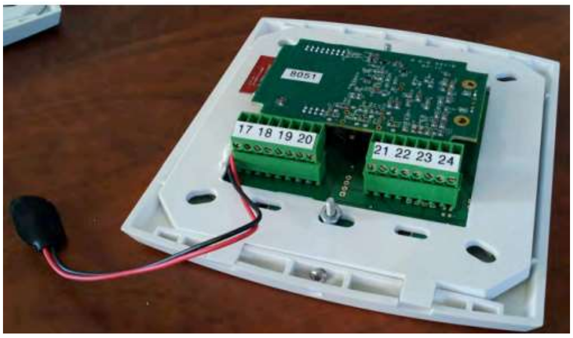


Figure 27: A3 8R Data Acquisition Unit, Image Credit: TDA

A3 – 4 Resistance 4 Voltage Wireless Data Acquisition Unit (A3 4R4V)

A four resistance 4 Volt channel data acquisition unit is used to collect the data from the Relative Humidity and Temperature (RH/T0) and the displacement (string Pot, SPOT) sensor. Figure 28 shows an A3 4R 4V Data Acquisition Unit. The wires from the RH/T and the SPOT sensors are connected to the inputs numbered 17 - 24.

Figure 28: A3 4R 4V Data Acquisition Unit, Image Credit: TDA

Figure 29 shows the A3 Data Acquisition unit in the garbage room and similar units are located in the garbage room at every level within the timber part of the building. There are typically three A3 Data Acquisition units per level that were later covered by a cabinet to secure them.

Figure 29: A3 Resistance unit in the garbage room, Image Credit: TDA

Building Intelligence Gateway (BIG)

The Building Intelligence Gateway is a program used to provide continuous monitoring and data collection of the sensor's information used for the structure's monitoring.

The BIG system collects real-time data from the variety of sensors used within the building. It also provides a local analysis of data such as moisture correction for timber species and temperature, as well as distribution to a central monitoring database and reporting system. The BIG also forwards the collected data to the web-based Building Analytics monitoring centre that can be accessed via the internet, refer to Figure 30 for an image of the installed BIG.

Figure 30: Locked box with the BIG installed, Image Credit: TDA

Sensor Communication to BIG

All sensors are hardwired to an A3 Data Acquisition Unit located in the garbage room on each floor of the building. Each A3 Data Acquisition Unit is then connected to a Building Intelligence Gateway (BIG) via wifi.

The Building Intelligence Gateway is located on level three of the building. To ensure adequate wifi connection is maintained, wifi aerials (I3) are located on each floor nearby to the A3 Data Acquisition Units. USB extensions and Cat 5 wires are employed to extend the reach of the wifi aerial. The Cat 5 wires are placed in a 25 mm conduit which runs from level 5 to the upper ground. Figure 31 shows an I3 (USB - Wireless Interface) connected to the BIG.

Figure 31: I3 USB - Wireless Interface, Image Credit: TDA

Figure 32 provides a schematic illustration of the setup used.

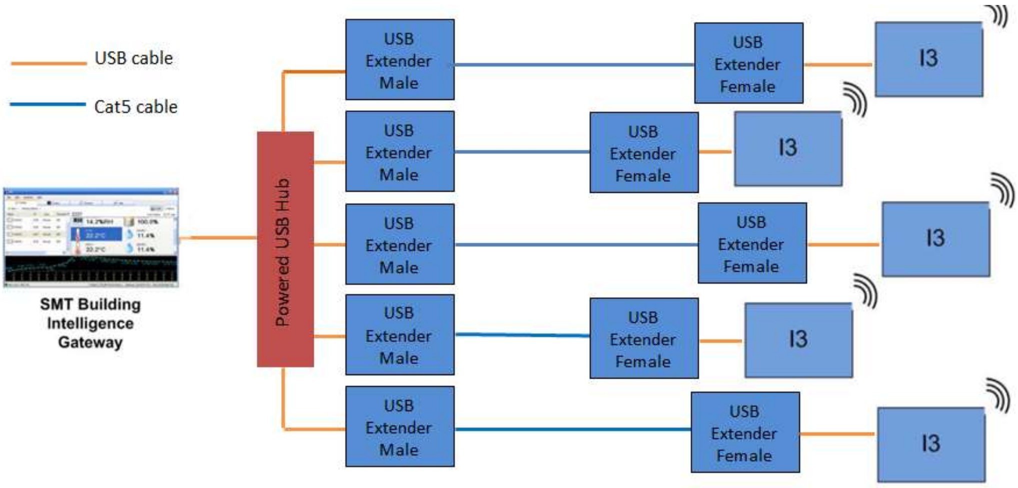


Figure 32: Connection between BIG and Resistant Units, Image Credit: TDA

Figure 33 shows the garbage room on level 3. The Cat 5 wires are placed in the conduit in the corner. The BIG is placed in the locked box to the left. The A3 Data Acquisition Units at the right was covered in by a locked box at a later date.

Figure 33: Garbage room level 3, Image Credit: TDA

Hard Wiring between the sensors and the A3 (Data Acquisition Units)

Figure 34 illustrates the position of the wires connecting the sensors and the A3 Data Acquisition Units. The wires run from the sensors to the door taking the shortest way. The wires between the Units and the hallway go through a fire-rated penetration above the apartment's entry door. In the hallway, the wires from the different sensors are bundled together. The wires then run parallel to the walls next to the installation of the other trades.

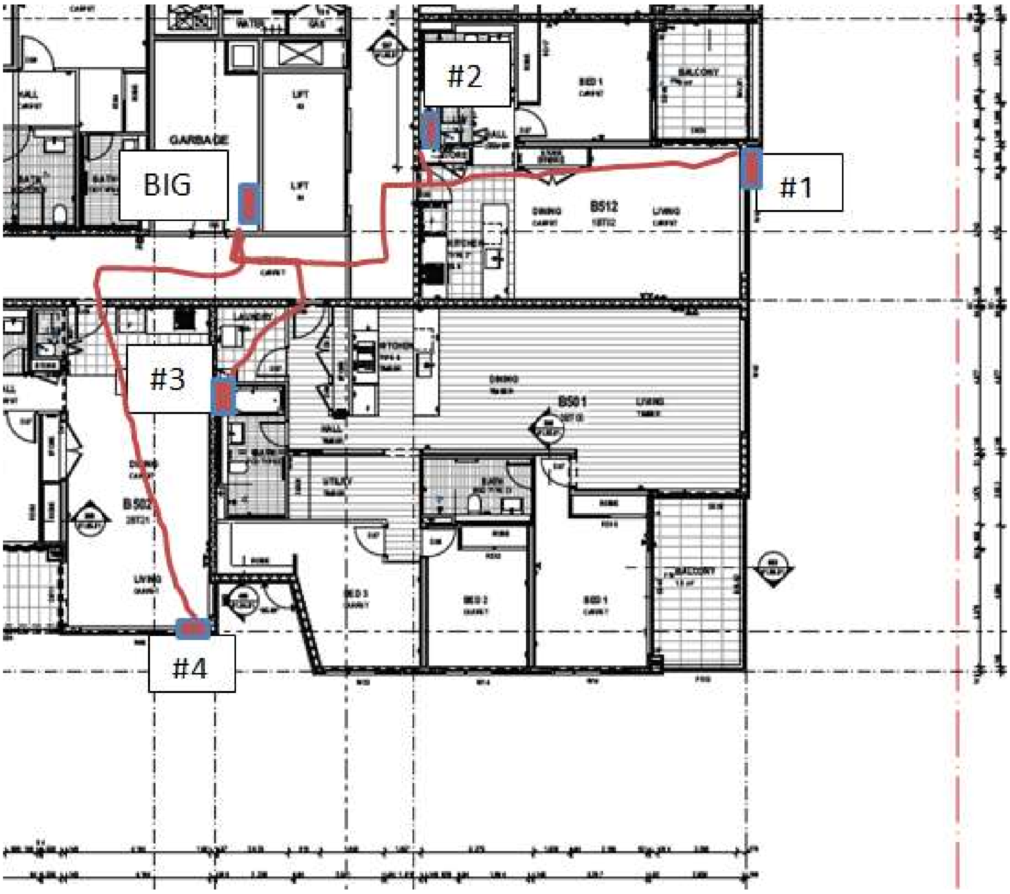


Figure 24: Position of wires connecting sensors and A3's, Image credit: Strongbuild

Figure 35 shows the penetrations between the hallway and the garbage room. Each cable runs through a 10 mm hole which is sealed with fire-rated sealant. The holes are positioned 50 mm apart, a requirement for maintaining fire resistance to the wall.

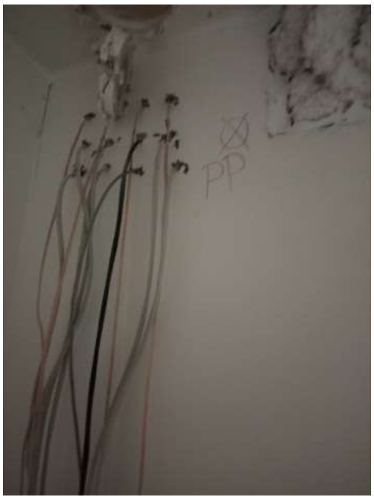


Figure 35: Penetration of the wall between the hallway and the garbage room, Image Credit: TDA

RESULTS

Temperature

A Point Moisture Measurement sensor (PMM) measures the temperature to make corrections to the moisture content of the timber. These PMM sensors are also used to find the maximum and minimum temperature for each day, for various locations within the building. Refer to Figure 9 for the exact position of each sensor.

Figure 36 displays the temperature measured in the building's exterior wall facing North/East – Position #1 for all levels of the building at that location. Figure 37 is for the temperature measured in the wall next to the hallway – Position #2, Figure 38 is the temperature measured in a wall positioned within an apartment – Position #3 and, Figure 39 is for the temperature measured in the exterior wall facing South/West – Position #4.

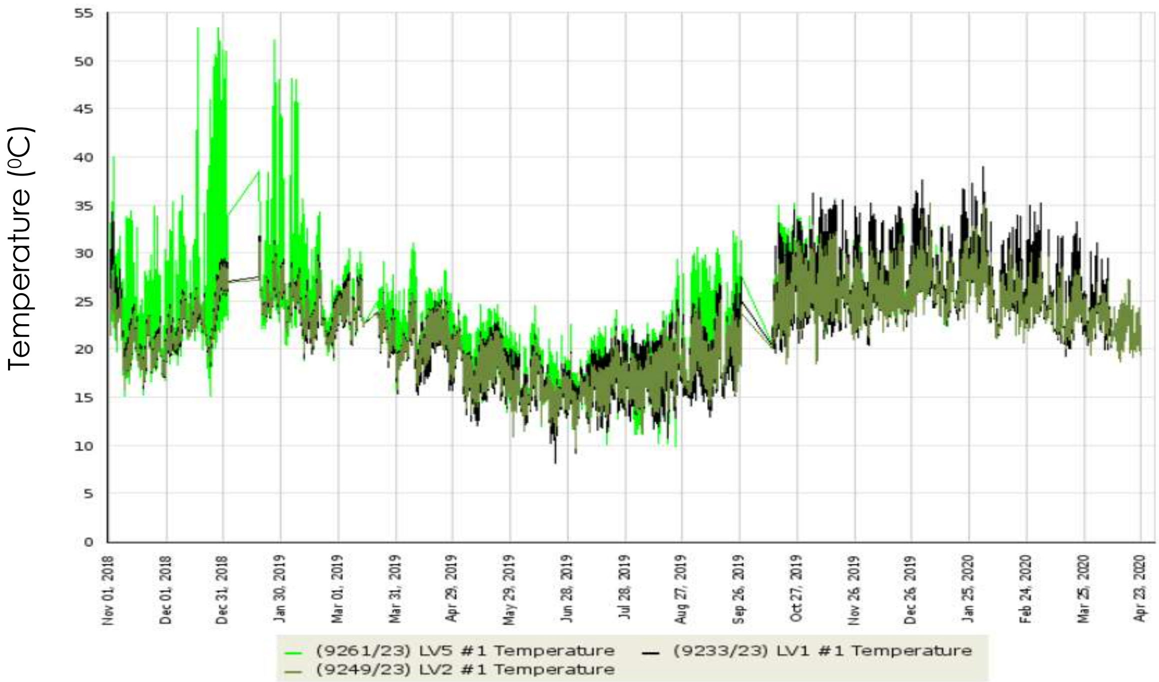


Figure 36: Temperature measured in the exterior wall facing North/East – Position #1, Levels 1, 2 and 5

Notes

1. "LV_" means the level of the building.
2. "#1" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Level 3 and 4 sensors were malfunctioning and removed from the data.
5. Graphs of each Individual sensors per floor can be found in Appendix B.

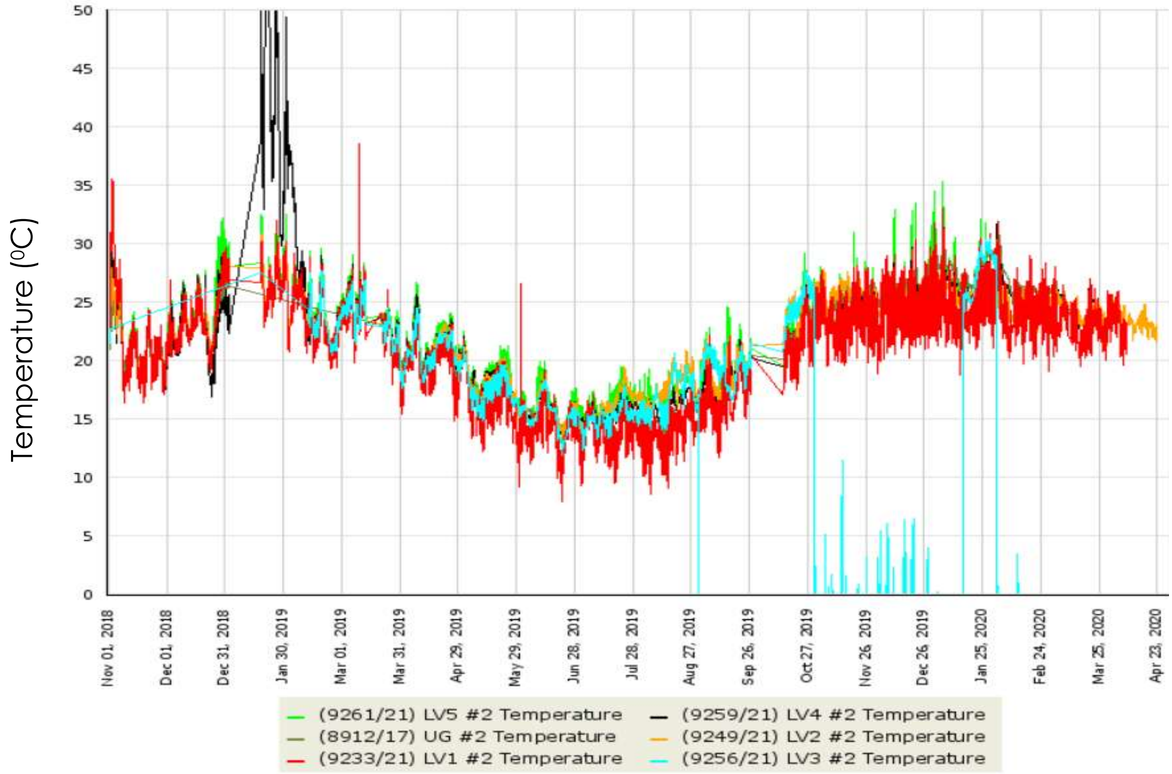


Figure 37: Temperature measured in the wall next to the hallway – Position # 2 Levels, UG, 1, 2, 3, 4 and 5

Notes

1. "LV_" means the level of the building.
2. "#2" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

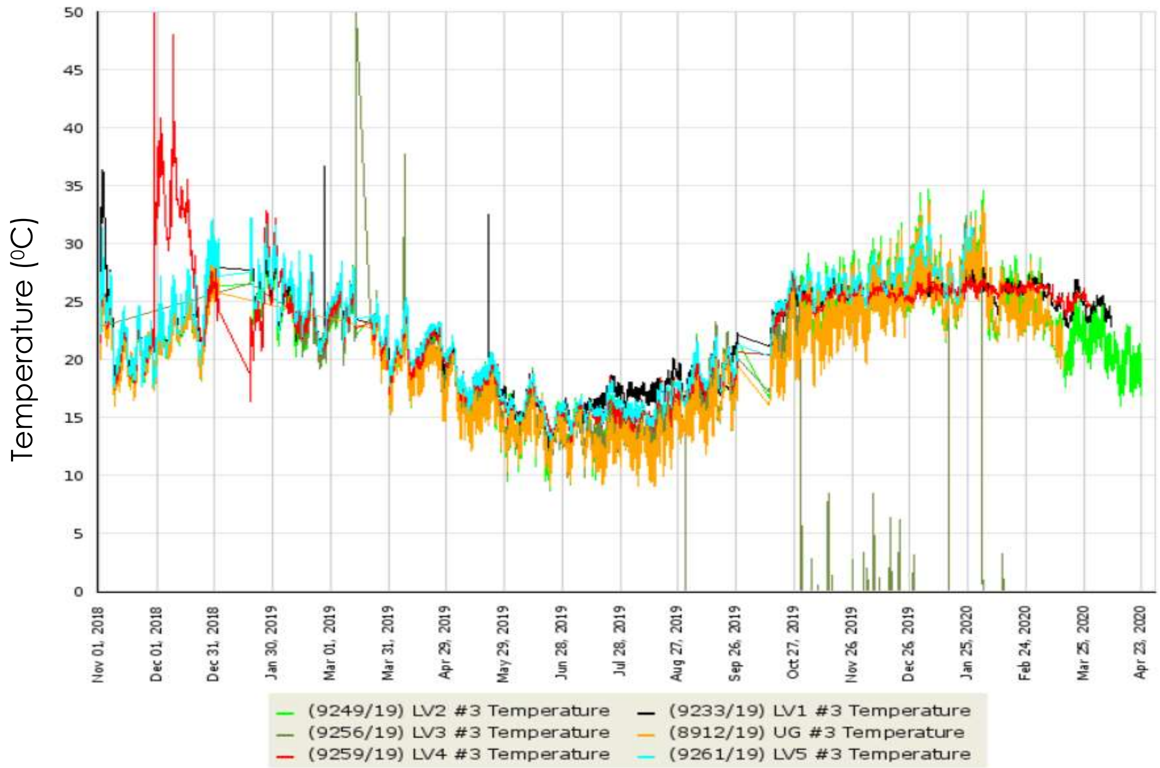


Figure 38: Temperature measured in a wall positioned within an apartment unit – Position #3

Notes

1. "LV_" means the level of the building.
2. "#3" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

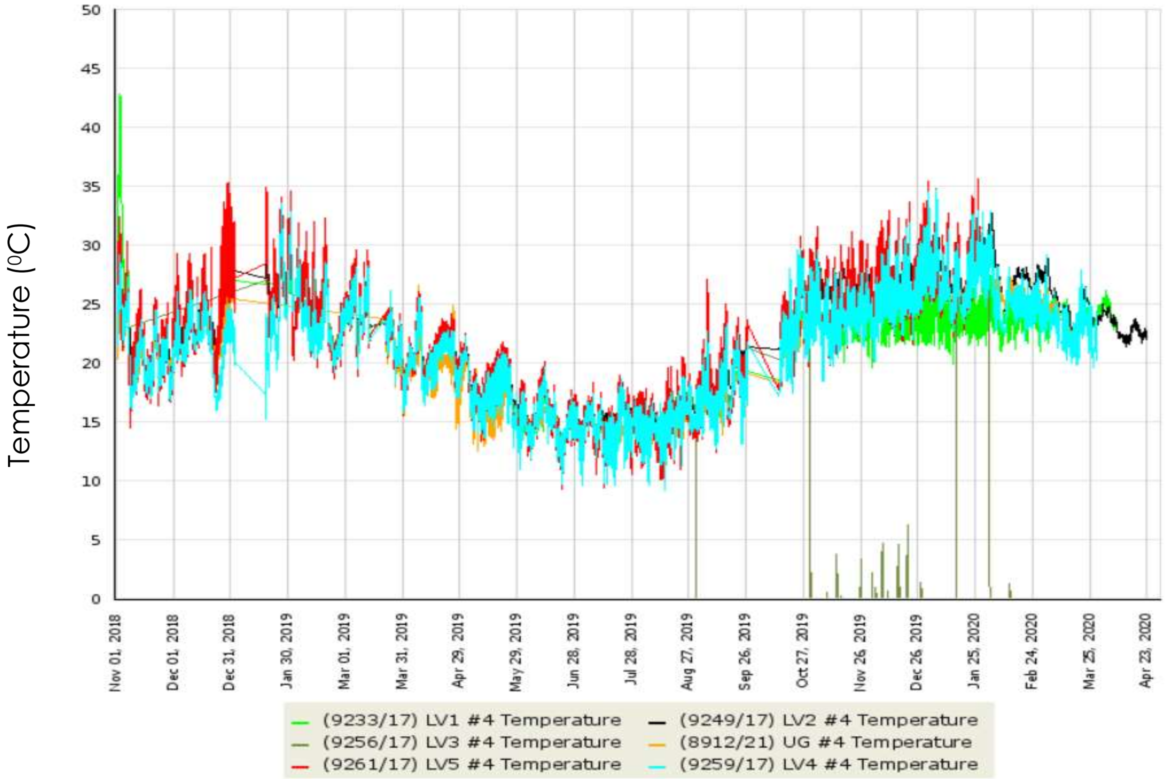


Figure 39: Temperature measured in an exterior wall facing South/East – Position #4

Notes

1. "LV_" means the level of the building.
2. "#4" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

Figure 40 represents the temperature data from the sensors "B" located in the building's corridor and measuring the moisture content of the underside of the CLT floor.

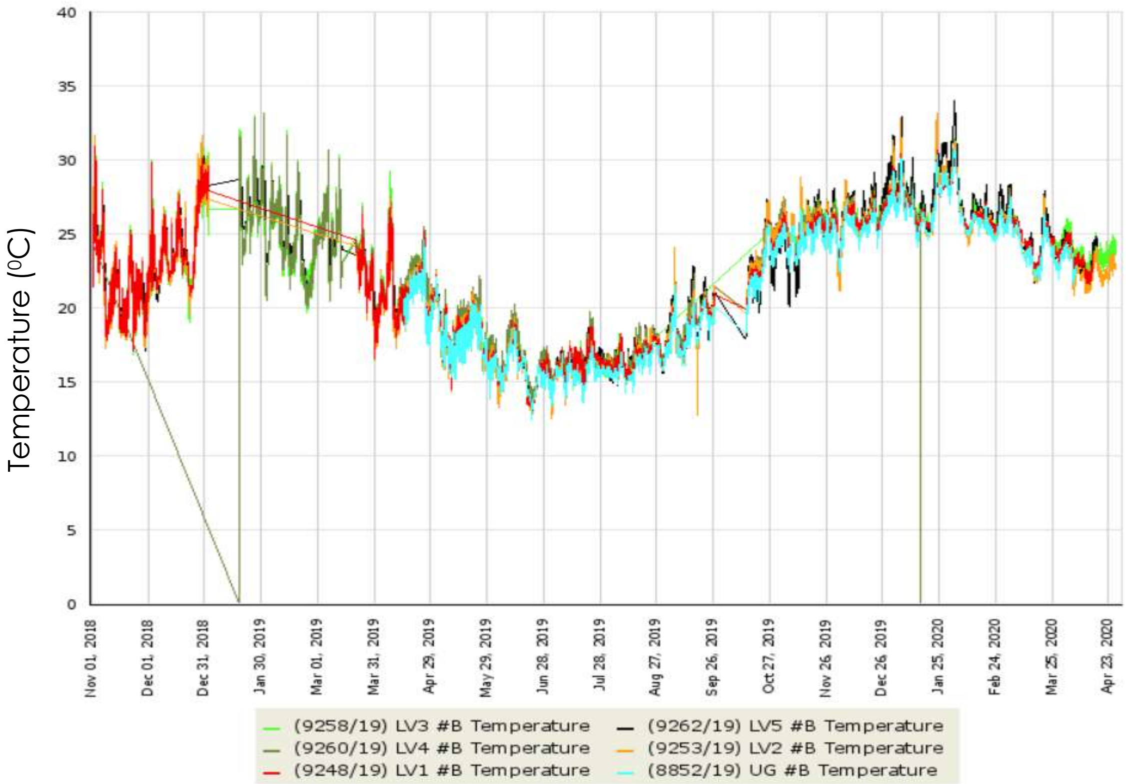


Figure 40: Temperature measured in the hallways Position #B

Notes
1. "LV_" means the level of the building.
2. "#A" means position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

Moisture

Moisture Content of the Wall Framing

The same PMM sensors used to measure the temperature were used to monitor the moisture content of dummy radiata pine studs inside selected wall cavities. Figures 41 to 44 are the moisture content for all levels in the building at Position 1 to 4.

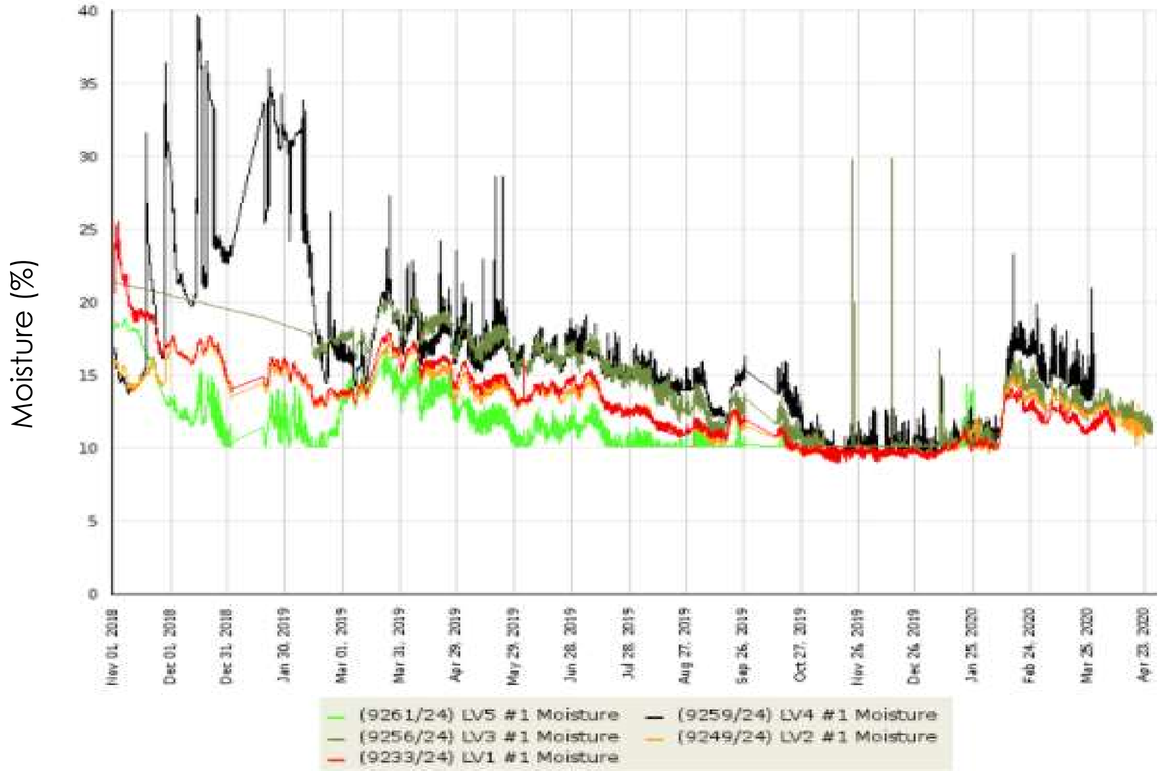


Figure 31: Moisture content of a radiata pine stud measured in an Exterior wall facing North/East - Position #1

Notes:

1. "LV_" means the level of the building.
2. "#1" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

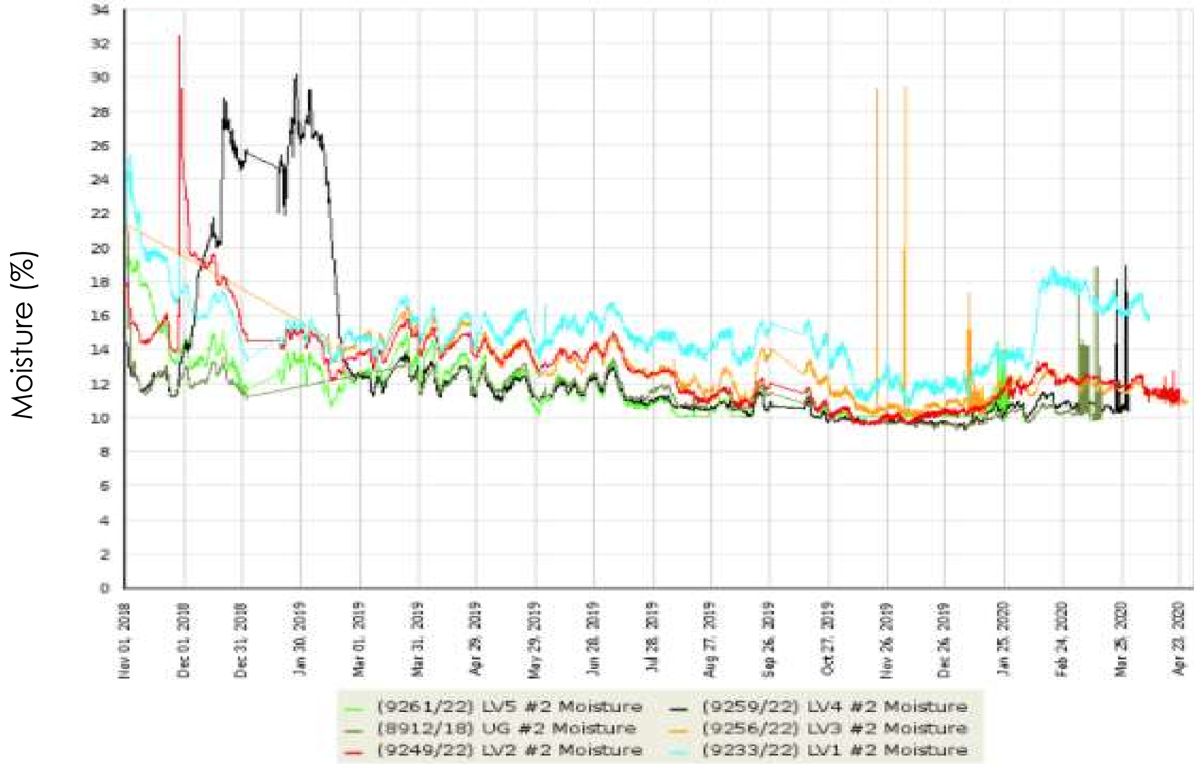


Figure 42: Moisture content measured in a radiata pine stud in a wall positioned close to the hallway - Position #2

Notes:

1. "LV_" means the level of the building.
2. "#2" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

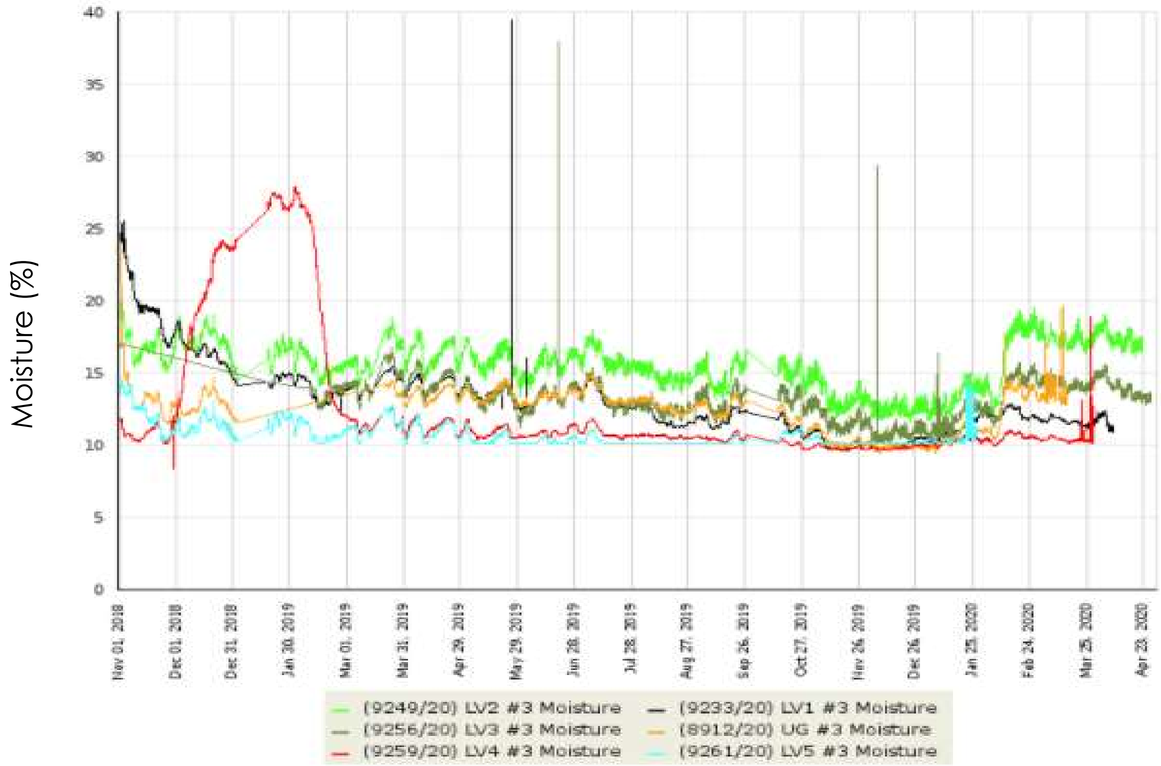


Figure 43: Moisture content measured in a radiata pine stud positioned in a wall within the apartment - Position #3

Notes:

1. "LV_" means the level of the building.
2. "#3" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

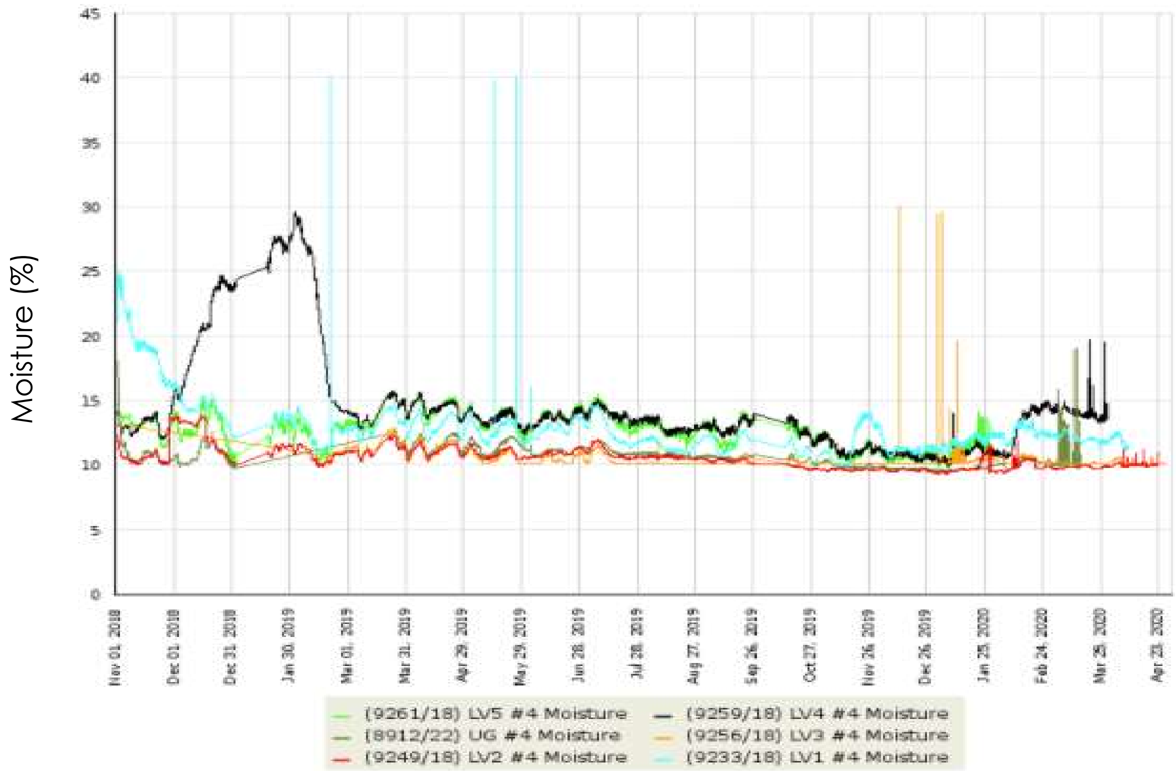


Figure 44: Moisture content measured in a radiata pine stud positioned in the exterior wall facing South/East - Position #4

Notes:

1. "LV_" means the level of the building.
2. "#4" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

Moisture Content of the CLT Floor

In addition to the timber-framed walls, the CLT floors were also measured for moisture content. Figure 45 illustrates Position B for all levels, Figure 46 for Position C for levels and Figure 47 for Position D for all levels.

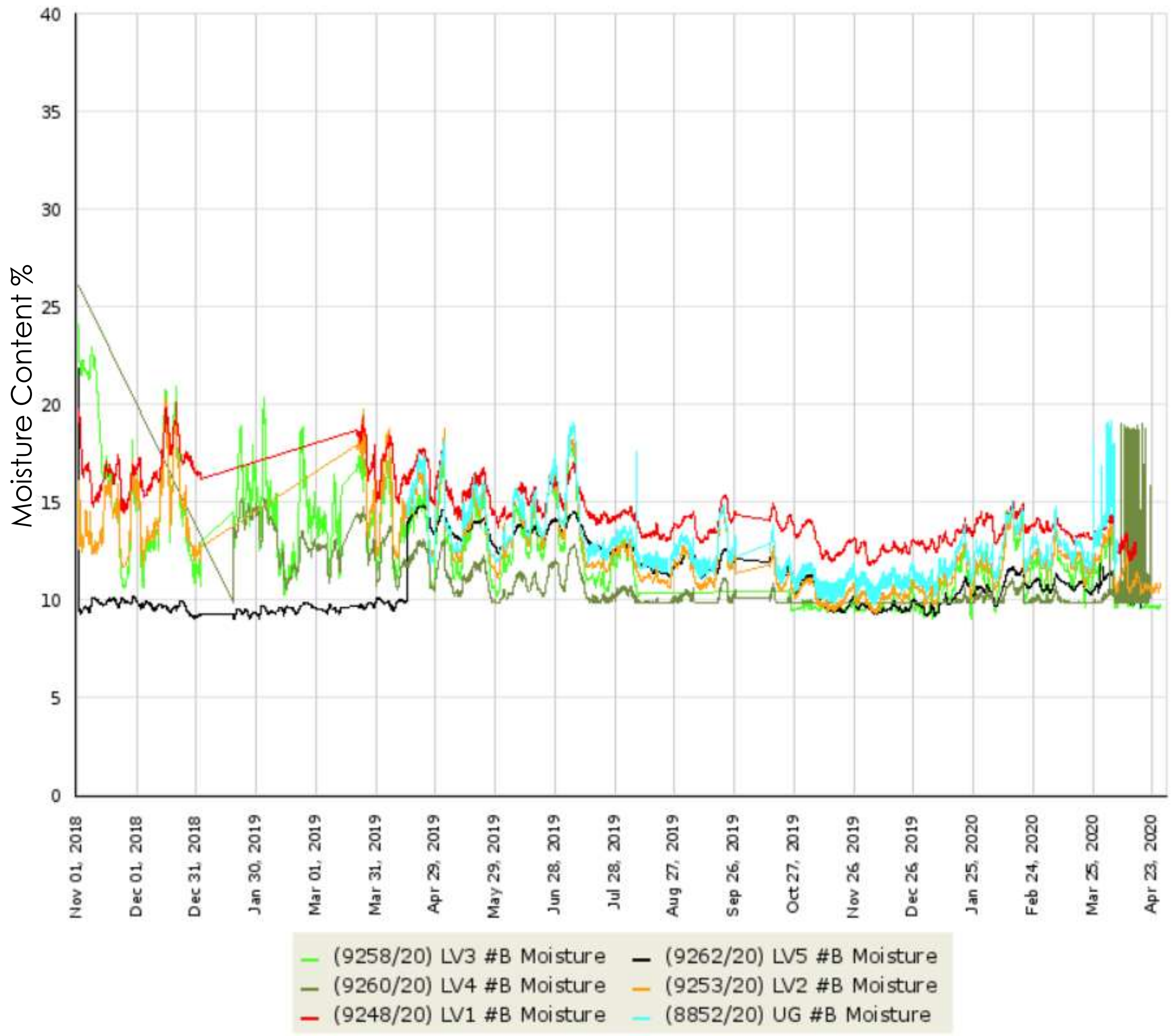


Figure 45: Moisture content of CLT floor for various levels, locations in Position #B

Notes:

1. "LV_" means the level of the building.
2. "#B" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

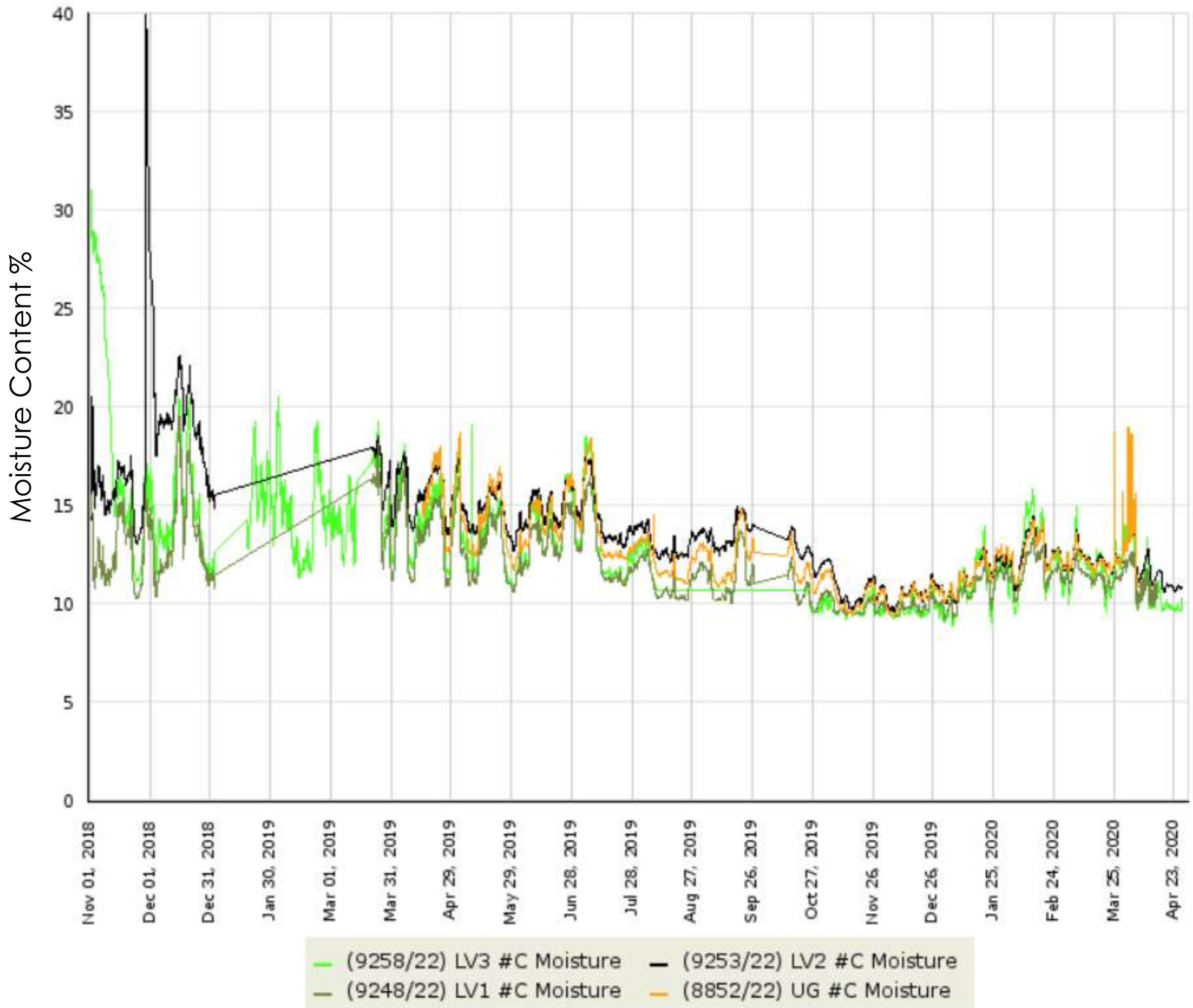


Figure 46: Moisture content of CLT floor for various levels, located in Position #C

Notes:

1. "LV_" means the level of the building.
2. "#C" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Level 3 and 4 sensors were malfunctioning and were removed from the data.
5. Graphs of each Individual sensors per floor can be found in Appendix B.

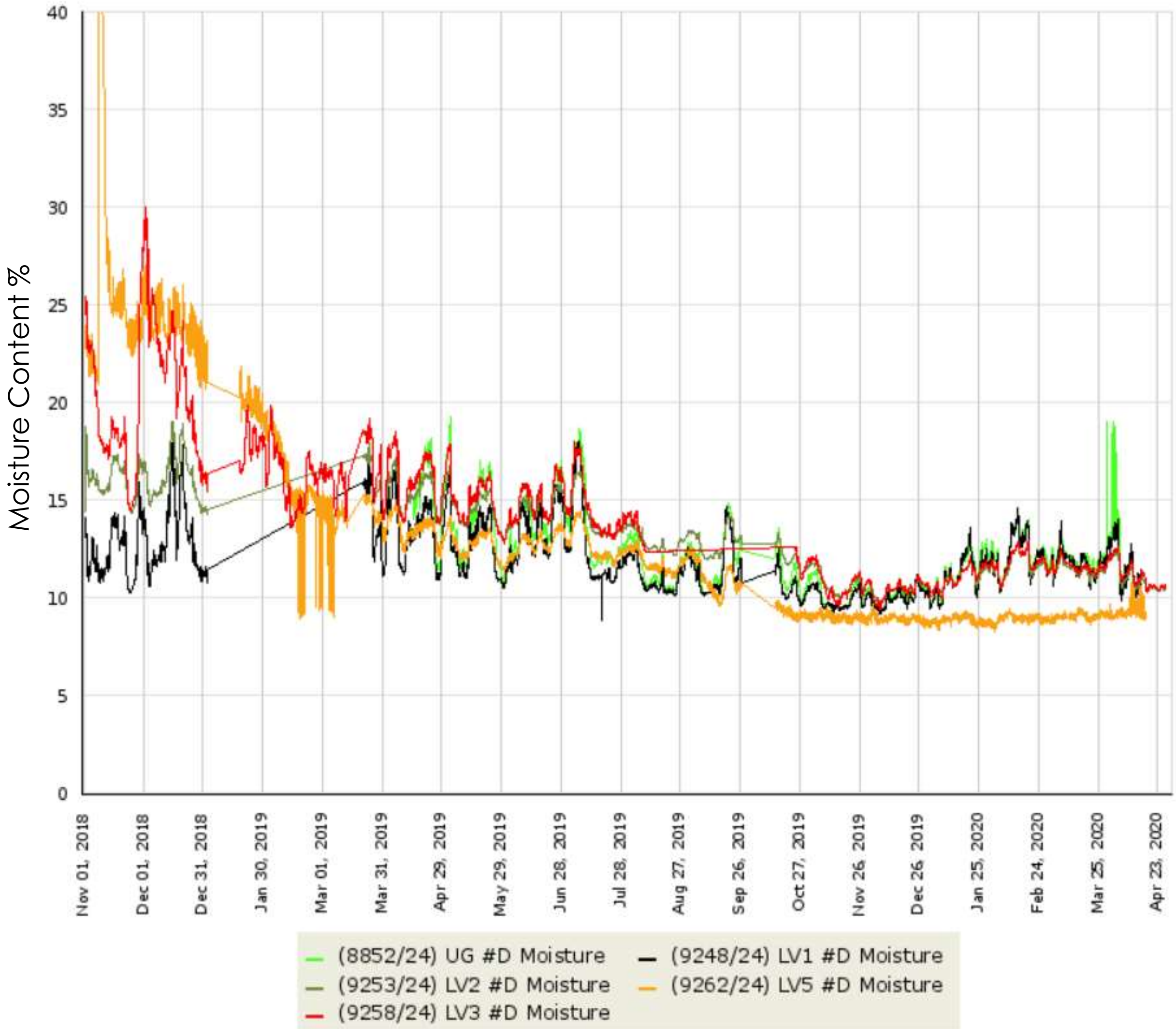


Figure 47: Moisture content of CLT floor for various levels, located in Position #D

Notes:

1. "LV_" means the level of the building.
2. "#D" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Level 4 sensor was malfunctioning and was removed from the data.
5. Graphs of each Individual sensors per floor can be found in Appendix B.

Moisture Content of the CLT Walls in the Garbage Room

In addition to the timber-framed walls, the CLT walls in the garbage room for each level were also measured for moisture content. Figure 48 illustrates Position A for all levels.

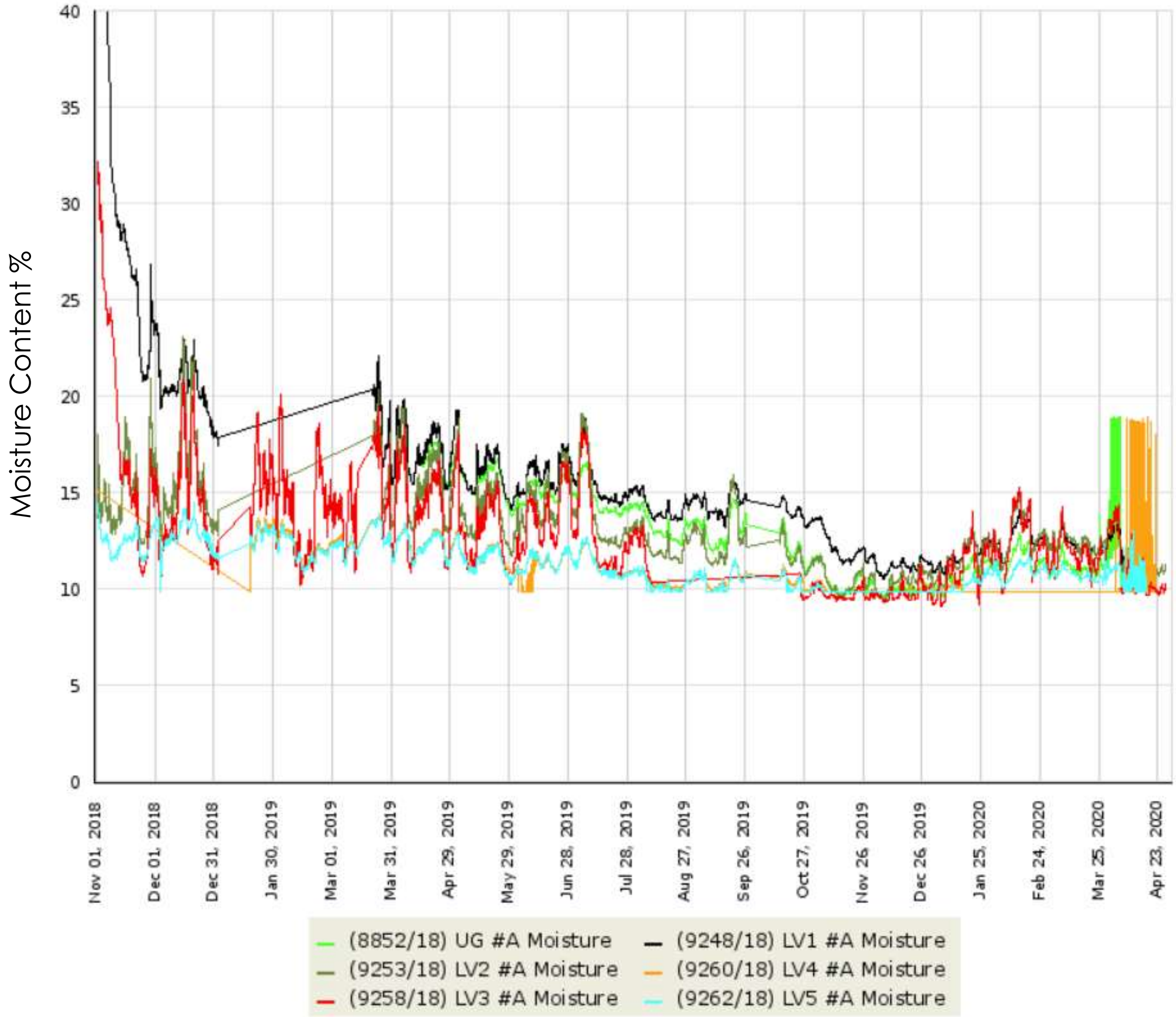


Figure 48: Moisture content of CLT wall for various levels, located in Position #A

Notes:
1. "LV_" means the level of the building.
2. "#A" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

Comparison Spruce and Radiata Pine Studs

Radiata pine is known to be a timber species that reacts to the change in moisture content quickly. An aside investigation was to examine if there is any difference between timber species, Radiata pine and Spruce, in regards to moisture content and speed in the change in moisture content.

Therefore, four dummy studs made of timber from both species were located throughout the building in the four levels. Each comparing timber species was placed close to each other.

Figure 49 illustrates the change in moisture content for Spruce, while Figure 50 shows a change for Radiata pine. Direct comparison between radiata pine and Spruce per level are in Figures 51 – Level 1, 52 - Level 4, and 53 – Level 5.

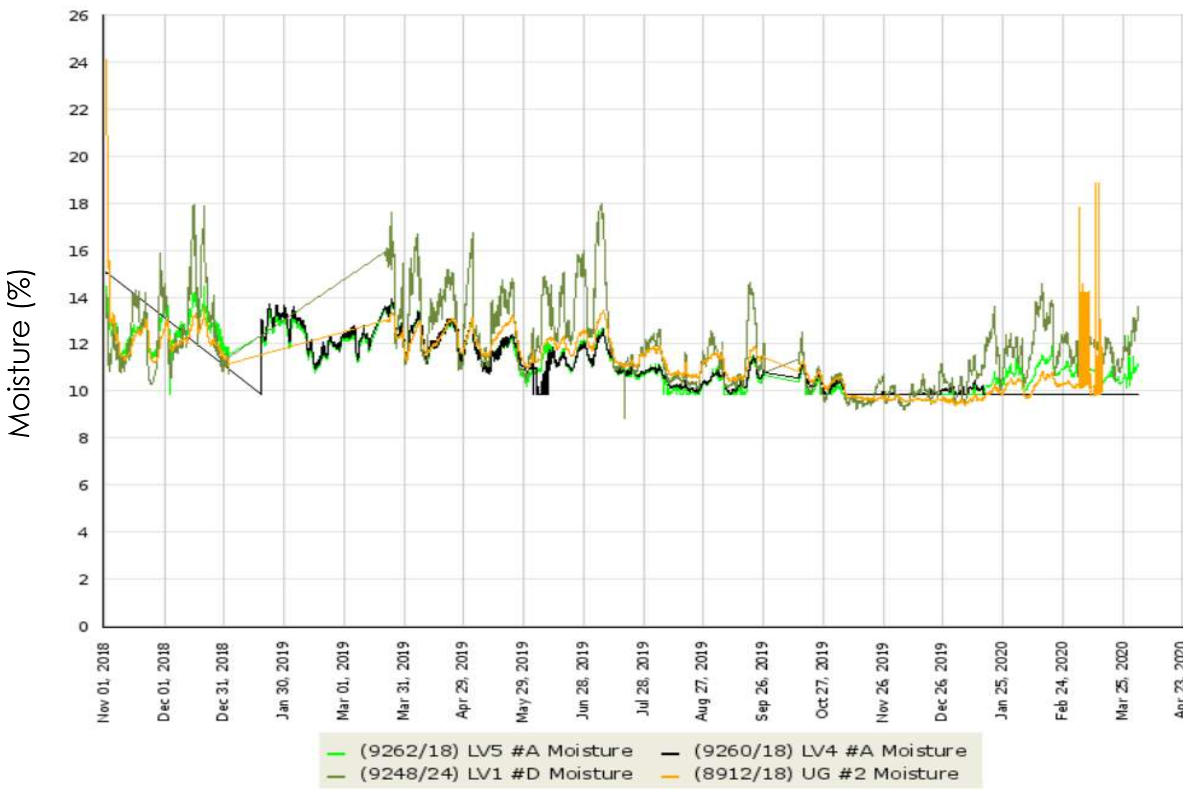


Figure 49: Moisture content within spruce studs

Notes:

1. "LV_" means the level of the building.
2. "#A, #B, #C, #D" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.

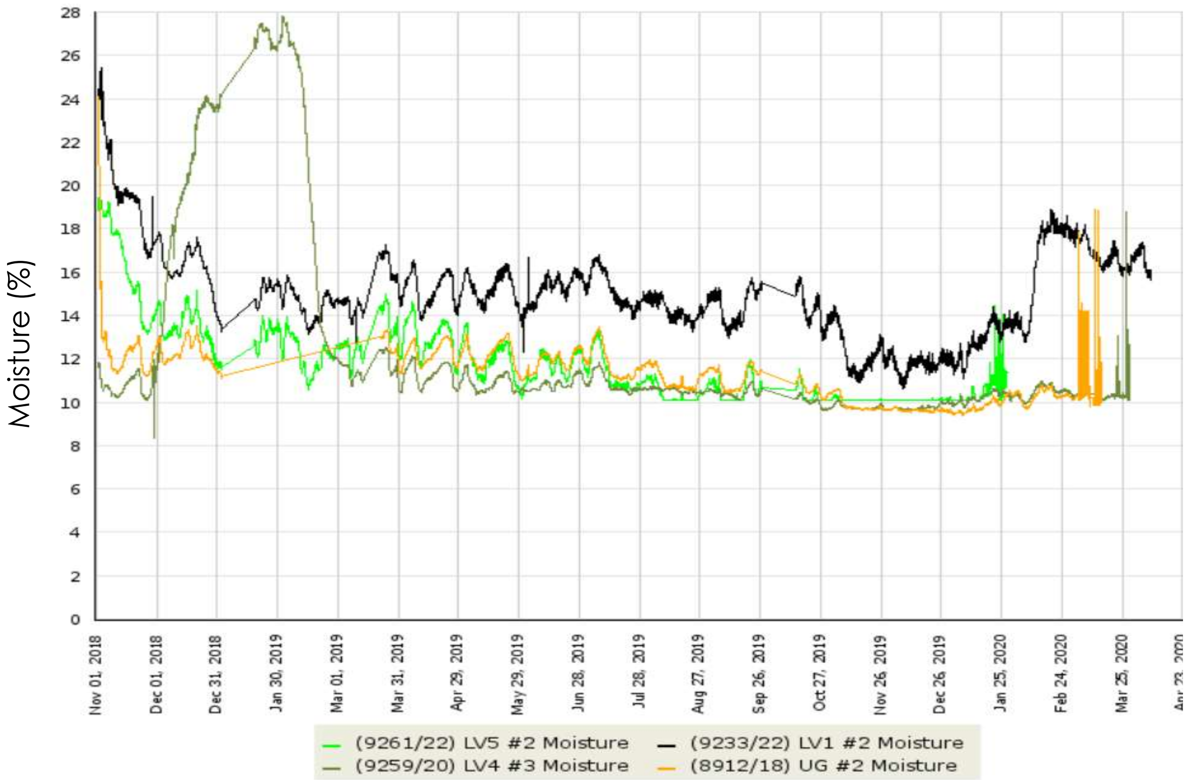


Figure 50: Moisture content within radiata pine studs located near spruce studs

Notes:

1. "LV_" means the level of the building.
2. "#1, #2, #3, #4" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.

Figures 51, 52 and 53 presented the moisture content of one radiata pine and Spruce stud from the same location within the building.

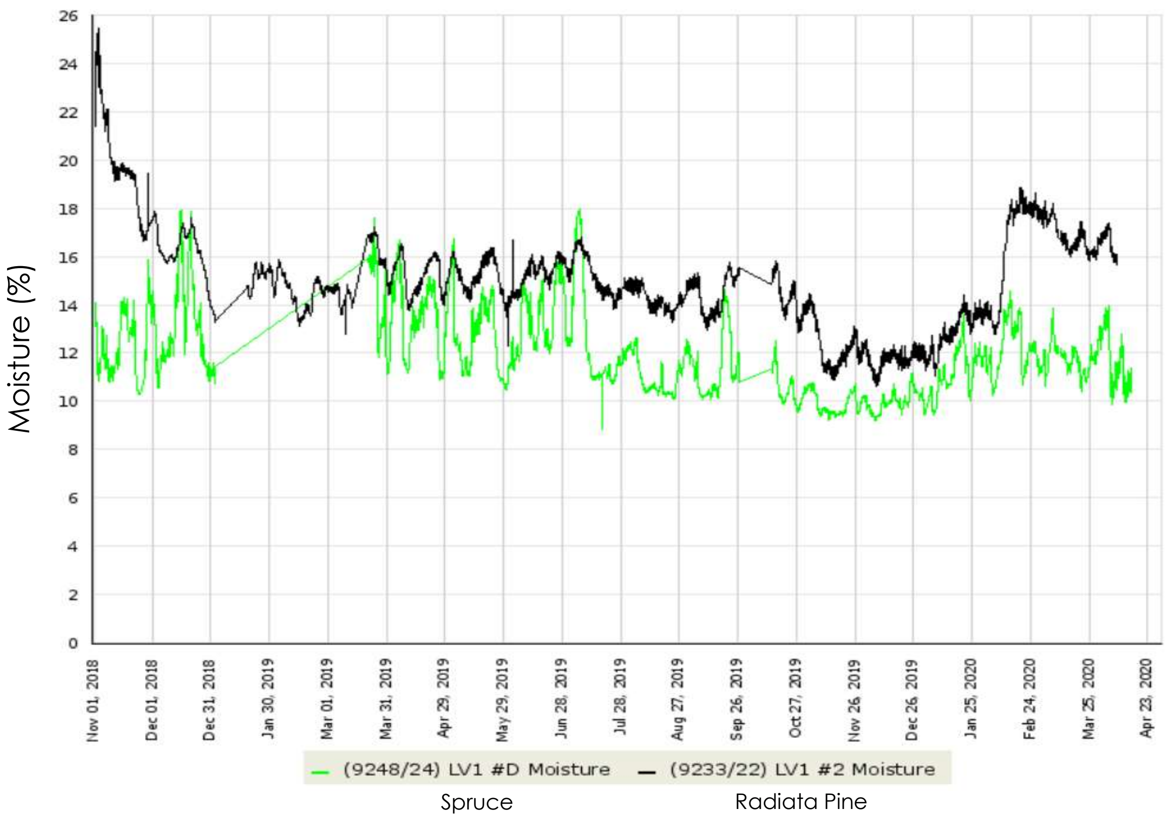


Figure 51: Level 1 Stud Moisture Content Radiata versus Spruce

Notes:

1. "LV_" means the level of the building.
2. "#D, #2" means the position of the sensor, refer to Figure 9.

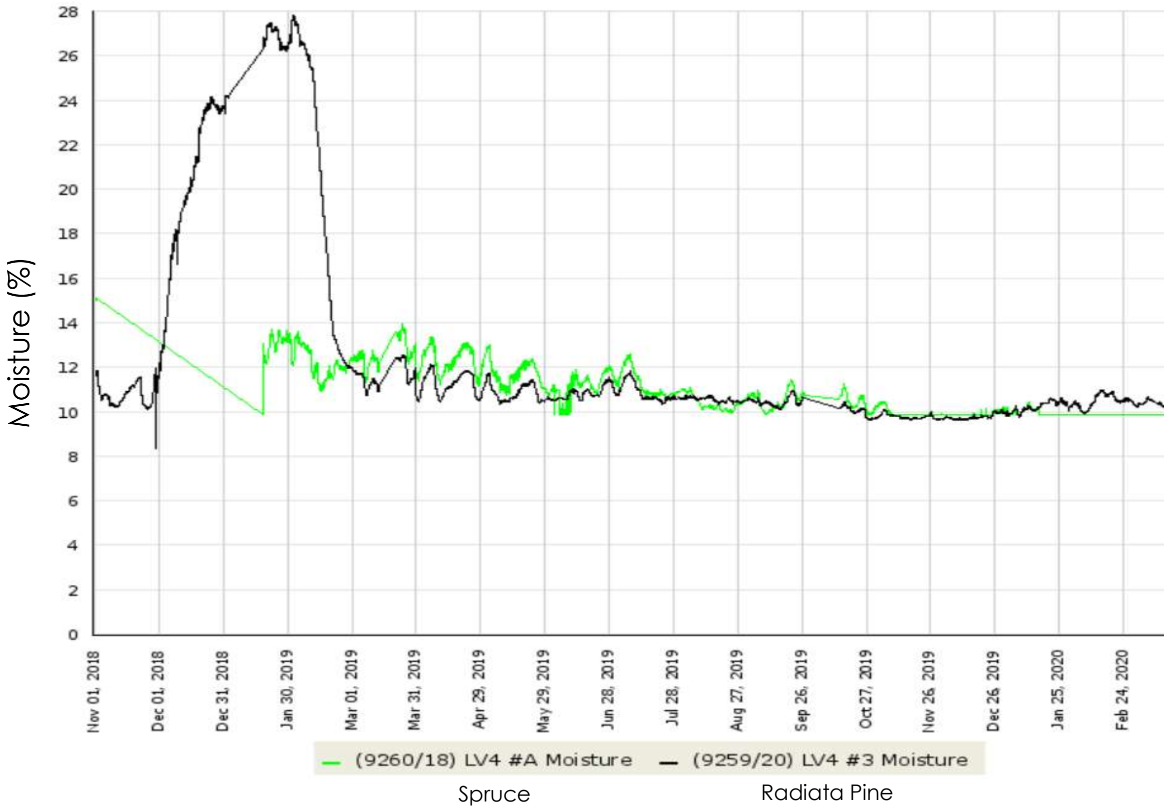


Figure 52: Level 4 Moisture content in radiata pine and Spruce studs

Notes:

1. "LV_" means the level of the building.
2. "#A, #3" means the position of the sensor, refer to Figure 9.

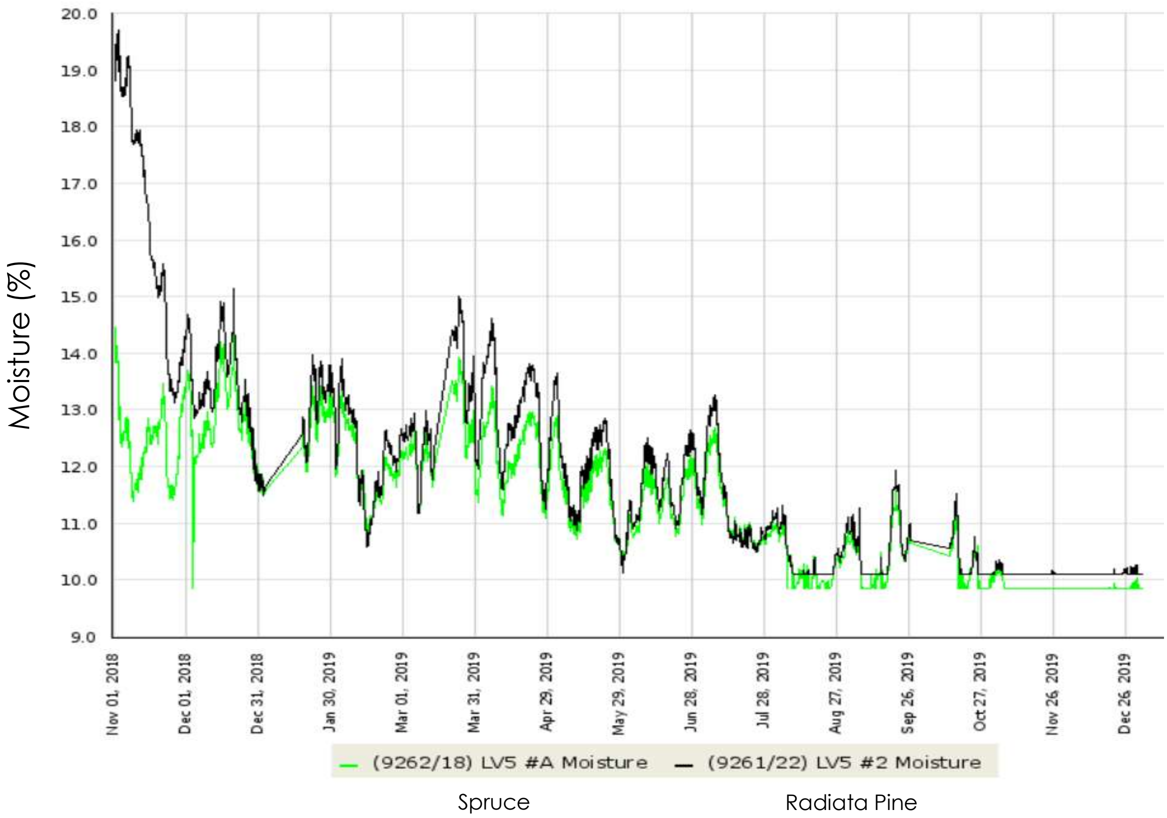


Figure 53: Level 5 Moisture content in radiata pine and Spruce studs Level 5

Notes:

1. "LV_" means the level of the building.
2. "#A, #2" means the position of the sensor, refer to Figure 9.

Relative Humidity

Relative Humidity was also recorded at each location. Figure 54 is for Location 1, Figure 55 is Location 2, Figure 56 is Location 3, and Figure 57 is Location 4.

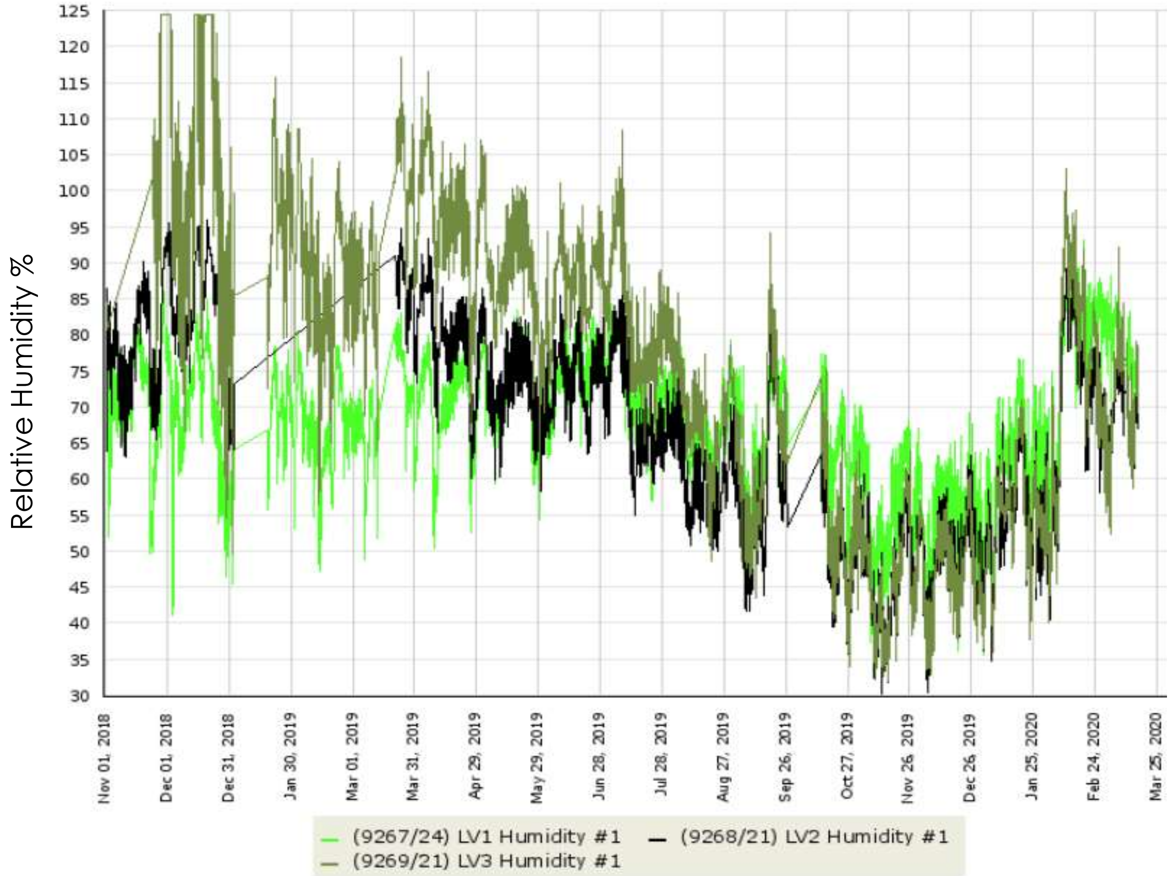


Figure 54: Location 1 Relative Humidity

Notes:

1. "LV_" means the level of the building.
2. "#1" means the position of the sensor, refer to Figure 9.
3. Levels UG, 4 and 5 sensors were malfunctioning and were not included.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

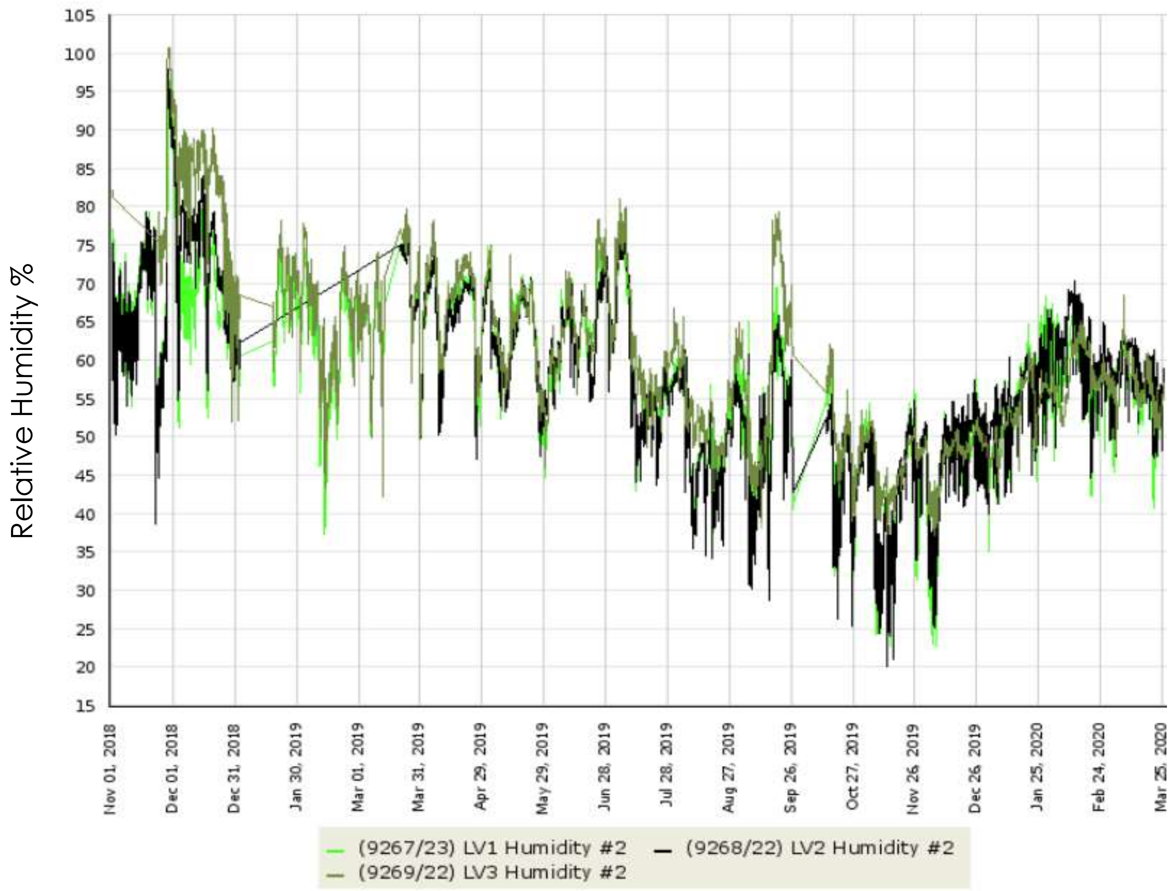


Figure 55: Location 2 Relative Humidity

Notes:

1. "LV_" means the level of the building.
2. "#2" means the position of the sensor, refer to Figure 9.
3. Levels UG, 4 and 5 sensors were malfunctioning and were not included.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

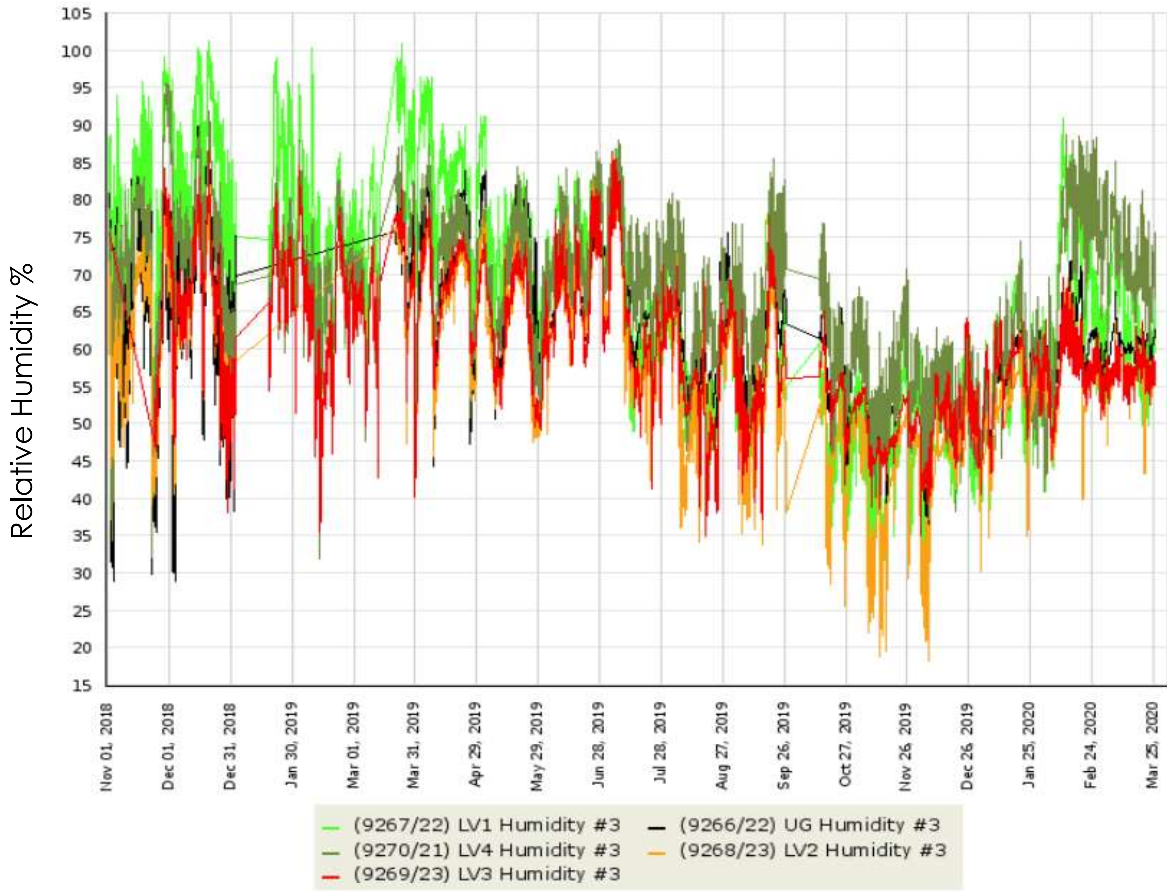


Figure 56: Location 3 Relative Humidity

Notes:

1. "LV_" means the level of the building.
2. "#3" means the position of the sensor, refer to Figure 9.
3. Graphs of each Individual sensors per floor can be found in Appendix B.

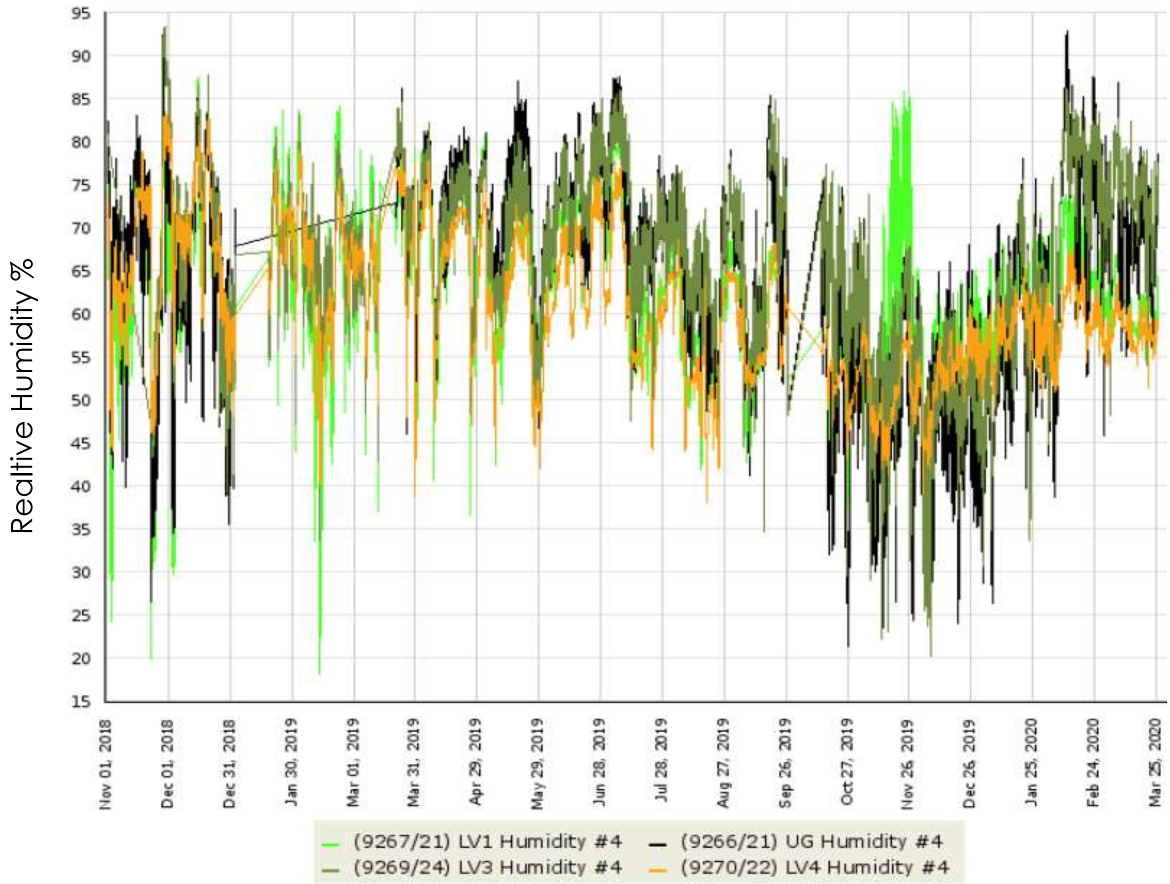


Figure 57: Location 4 Relative Humidity

Notes:
1. "LV_" means the level of the building.
2. "#4" means the position of the sensor, refer to Figure 9.
3. Levels 2 sensor was malfunctioning and was not included.
4. Level 5 was not included.
5. Graphs of each Individual sensors per floor can be found in Appendix B.

Movement

The vertical movement of each storey of the building was monitored in four positions within the building. Measurement was carried out by String Pot sensors. The sensors are installed so that each sensor monitors the vertical displacement of one storey. At each location, sensors are installed in each storey so that they measure the total displacement of the building. Only the timber portion of the building was measured. Figure 58 – Position #1, Figure 59 – Position #2, Figure 60 – Position #3 and Figure 61 – Position #4.

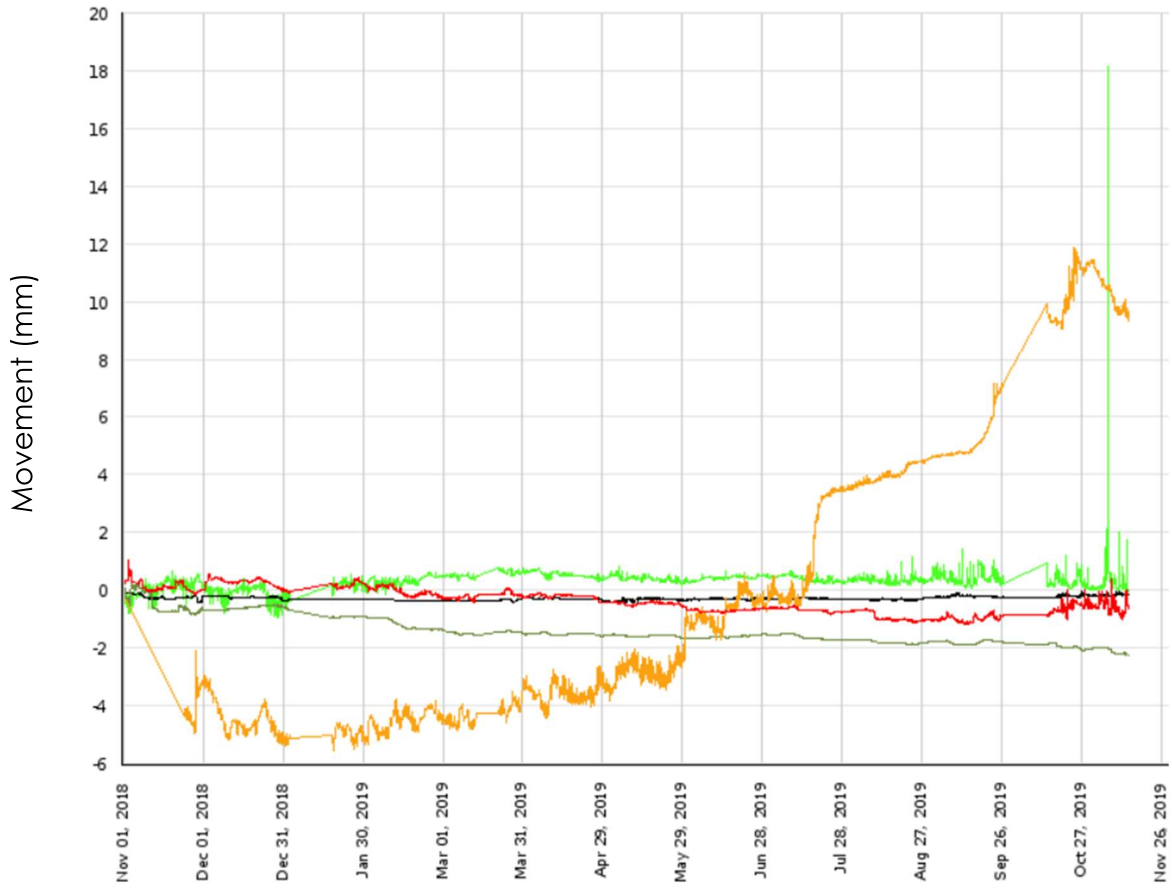


Figure 58: Vertical movement of each level measured in an external wall facing North/East – Position #1

Notes:

1. "LV_" means the level of the building.
2. "#1" means the position of the sensor, refer to Figure 9.
3. Graphs of each Individual sensors per floor can be found in Appendix B.

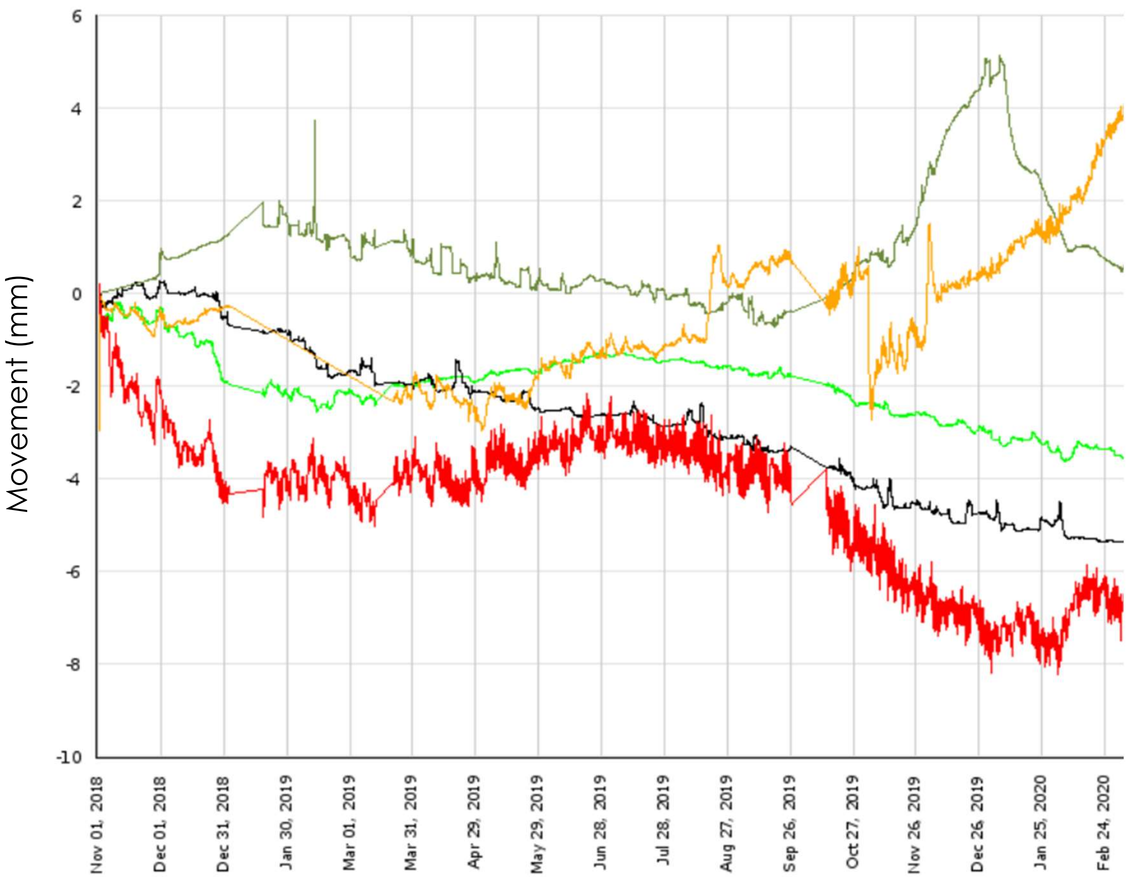


Figure 59: Vertical movement of each level measured in a wall close to the hallway – Position #2

Notes:

1. "LV_" means the level of the building.
2. "#2" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

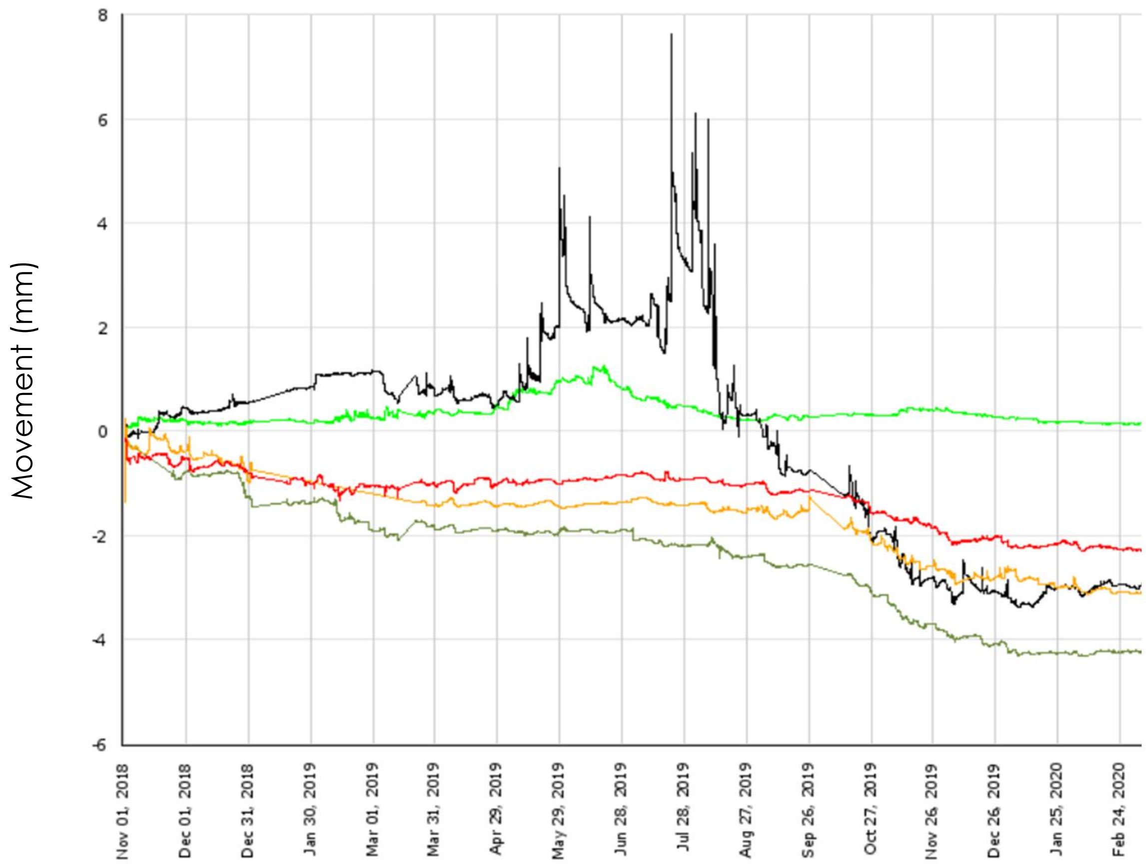


Figure 60: Vertical movement of each level measured in a wall positioned within an apartment unit – Position #3

Notes:

1. "LV_" means the level of the building.
2. "#3" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Graphs of each Individual sensors per floor can be found in Appendix B.

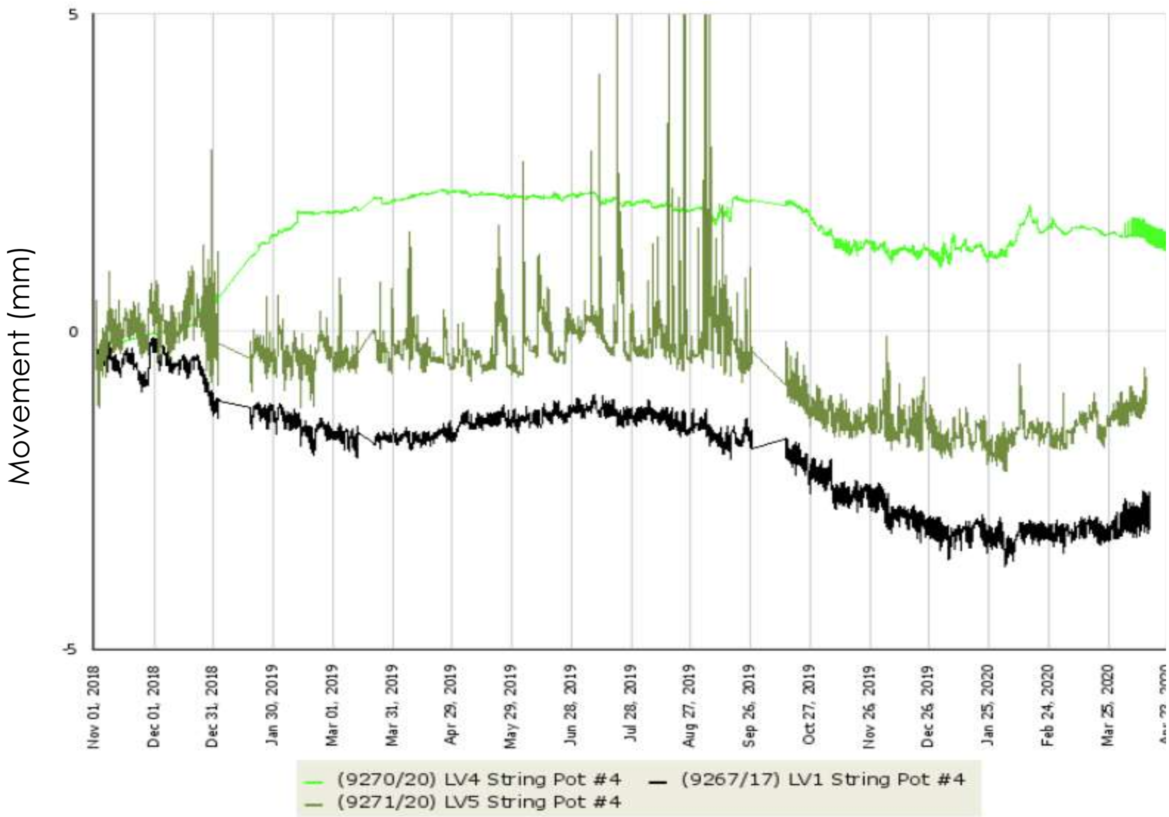


Figure 61: Vertical movement of each level measured in an external wall facing South/East – Position #4

Notes:

1. "LV_" means the level of the building.
2. "#4" means the position of the sensor, refer to Figure 9.
3. Gaps in data collection reflected the periods when data loggers were malfunctioning.
4. Levels UG, 2 and 3 sensors were malfunctioning and were not included.
5. Graphs of each Individual sensors per floor can be found in Appendix B.

Atmospheric Rainfall and Temperature Data

In addition to the collection of data from the building, the local temperature and rainfall data were also collected. This information was found from the nearby Bureau of Meteorology weather stations. Rainfall was collected from a weather station named Box Hill (McCall Gardens), located at 150°53'35"E and 33°39'15"S, being 3.9 km away from the building. As Box Hill only records rainfall, Richmond RAAF base is used to collect temperature information. Richmond RAAF is located at 150°46'34"E and 33°36'1"S and is 15 kilometres away.

Figure 62 illustrates the daily rainfall recorded at the nearby Bureau of Metrology Box Hill weather station.

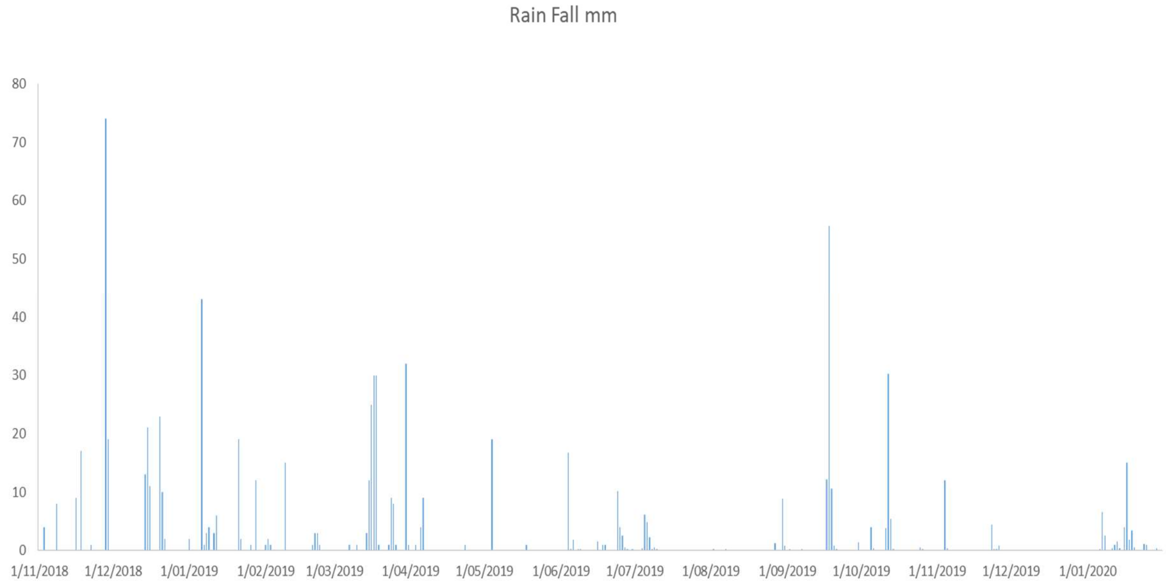


Figure 62: Box Hill Daily Rain Fall Data November 2018 to April 2020

Figure 63 illustrates the maximum and minimum outside temperature at Richmond RAAF base.

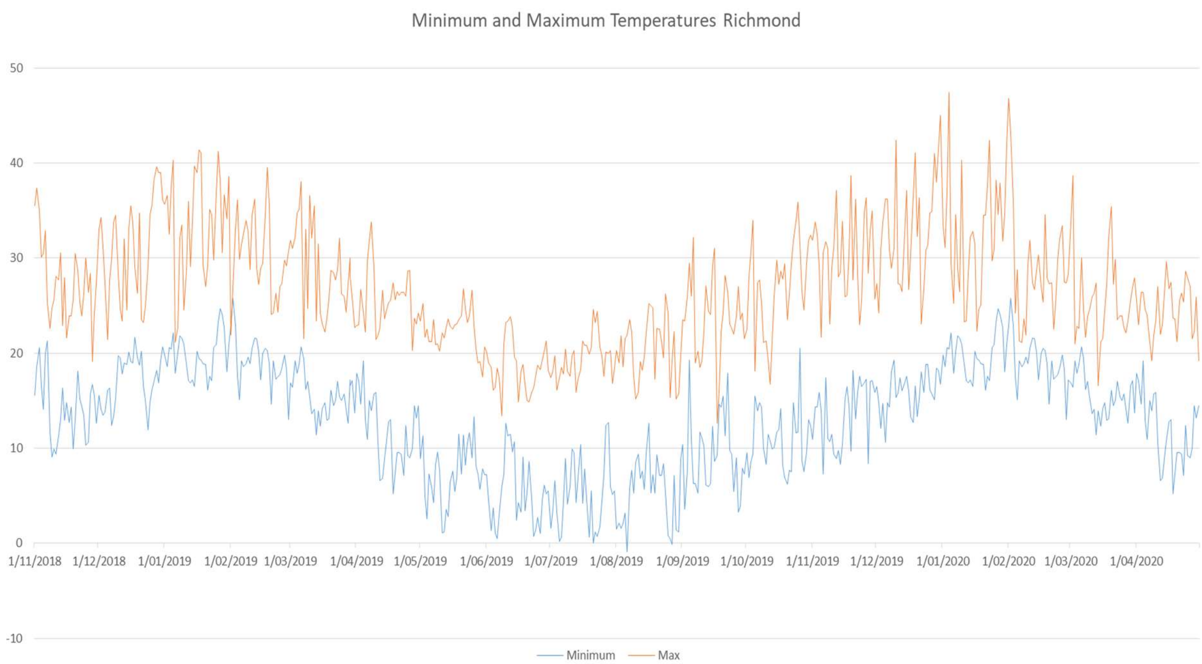


Figure 63: Maximum and Minimum Outdoor Temperature at Richmond RAAF Source: Bureau of Metrology

DISCUSSION

Data Collection

The data collection period was from 1 November 2018 until mid-April 2020, being eighteen months. 1 November 2018 was the date of the last sensor installation and also when the building was structurally complete, but not fully enclosed.

Around the commencement of the data collection, the contractor on the project ceased building, and the project was left in a partially completed state. During December 2018 the building was secured but not completely weather tight. February 2019 saw a new contractor appointed and the building was progressively made weather tight and completed, with handed over for occupation occurring in the third quarter of 2019. At this point, the building was being occupied, but due to privacy concerns, no record of the commencement of the apartment's occupation was made.

Temperature

The collection of the building's temperature data occurred during the building's construction, commissioning and occupational, and may contain heating or cooling if the nearby apartment was occupied. Figure 63 above contains the maximum and minimum daily temperature of the nearest Bureau of Metrology weather station at Richmond RAAF Base. The maximum temperature recorded was 47.4°C, and the minimum was - 0.9, a difference of 48.3°C.

It was found that the temperature readings on the exterior walls fluctuated more than the interior walls. Some of this fluctuation is attributed to the exterior wall cladding not being in place during the early period of data recording. However, it was expected and observed that there were higher temperatures within the building's façade, in comparison to the temperature within the interior of the building itself.

Generally, the interior walls were consistent, not experiencing the highs and lows of the exterior wall's temperatures. The exterior wall temperatures to the north/east side of the building were similar to the temperatures found for the exterior walls to the south/weas. Figure 64 illustrates the maximum and minimum temperature on the outside of the building compared with the temperature of the corridor within the building. Figure 65 is the illustrates the maximum and minimum temperature on the outside of the building compared with the temperature of the south/west external wall of the building included. In both cases, the peak maximum and minimum temperatures within the building were considerable less than observed at the nearby weather station.

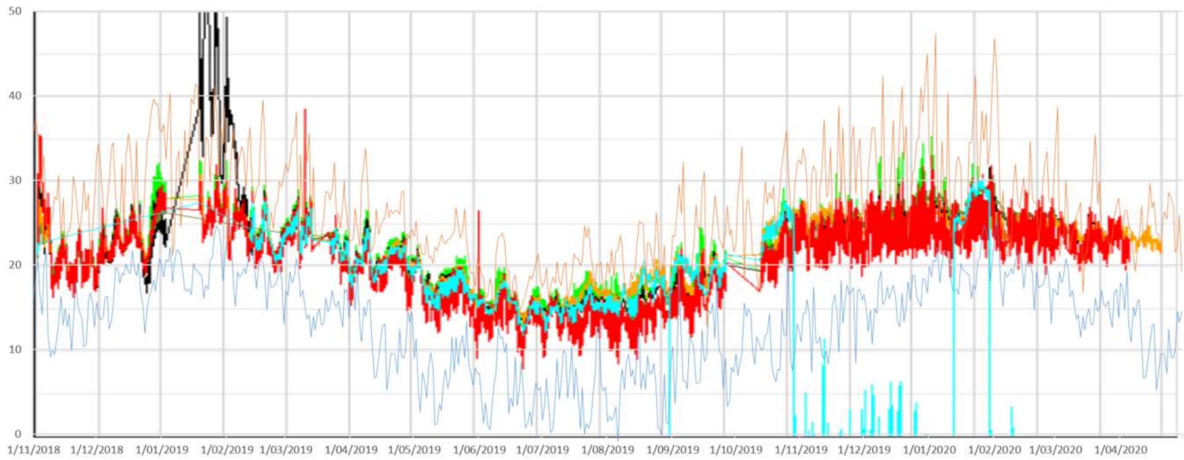


Figure 64: Maximum and minimum temperatures on the outside of the building compared to the temperatures of the corridor within the building

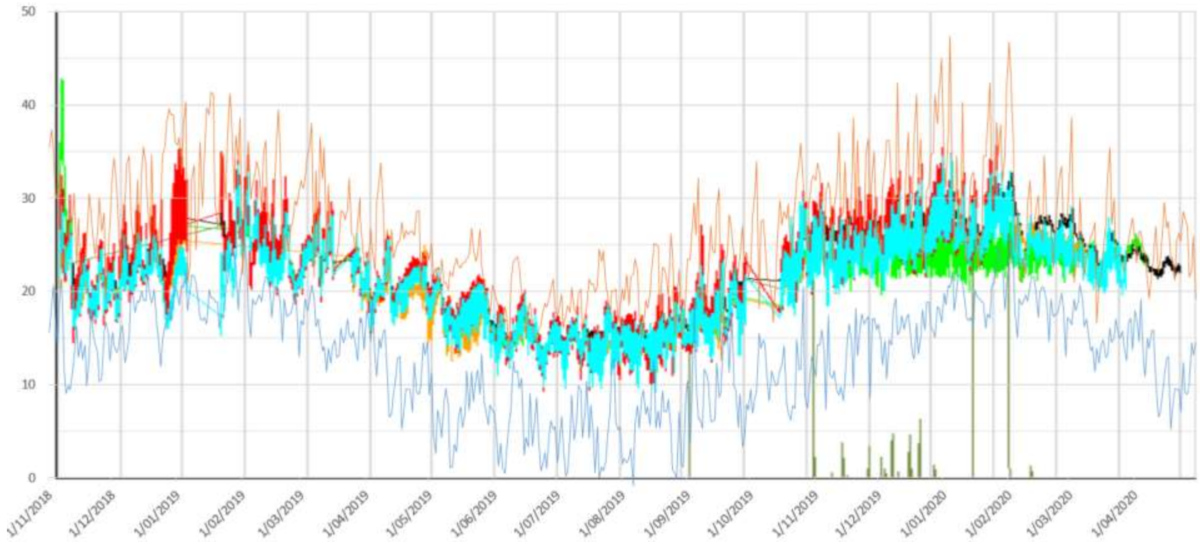


Figure 65: Maximum and minimum temperatures on the outside of the building compared to the temperatures of south/west external wall

Moisture Content Change in the timber

Figure 66 shows the rainfall data overlaying the moisture content of a radiata pine stud in the north/east exterior wall, found on Level 2. In contrast, Figure 67 shows rainfall data overlaying the moisture content of a radiata pine stud in the building's interiors corridor, found on Level 1. There is a noticeable increase in the moisture content of the stud with an increase in rainfall. This observation was particularly noted in a significant rainfall event that occurred in February 2020, where following this rain event, the moisture content of the stud was seen to increase by four per cent.

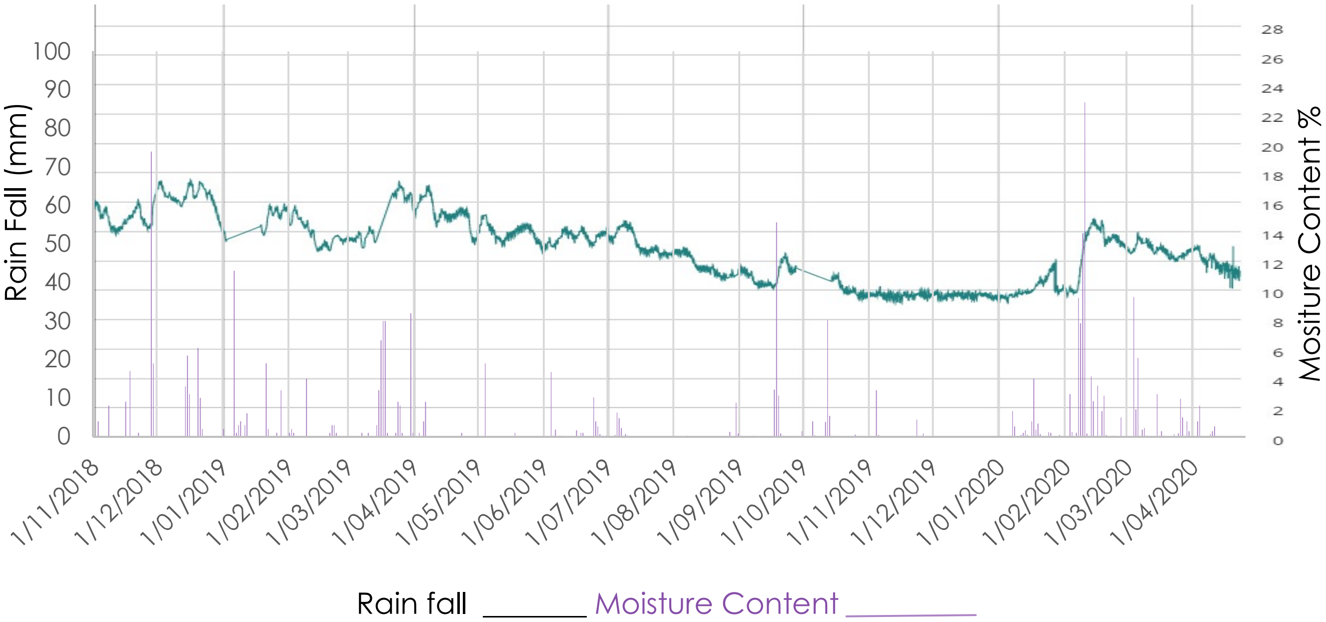


Figure 66: Rainfall data overlaid onto the moisture content of a wall stud in the North/East Wall – Position LV2 #1

Notes

1. "LV_" means the level of the building.
2. "#1" means the position of the sensor, refer Figure 9.

Figure 67: Rainfall data overlaid onto the moisture content of a wall stud in a corridor – Position LV1 #2

Relative Humidity

During the construction stage of the building, the Relative Humidity was comparatively high, and correspondingly there was higher than the expected moisture content of timber studs, in many locations. Since April 2019, the building has been enclosed, and the recorded Relative Humidity has fallen, with the moisture content of timber studs also being much less.

Figure 68 compares the relative humidity, temperature and moisture content of stud within an apartment at Level 2, Position 2. The moisture content of the stud varies as the Relative Humidity and Temperature fluctuates.

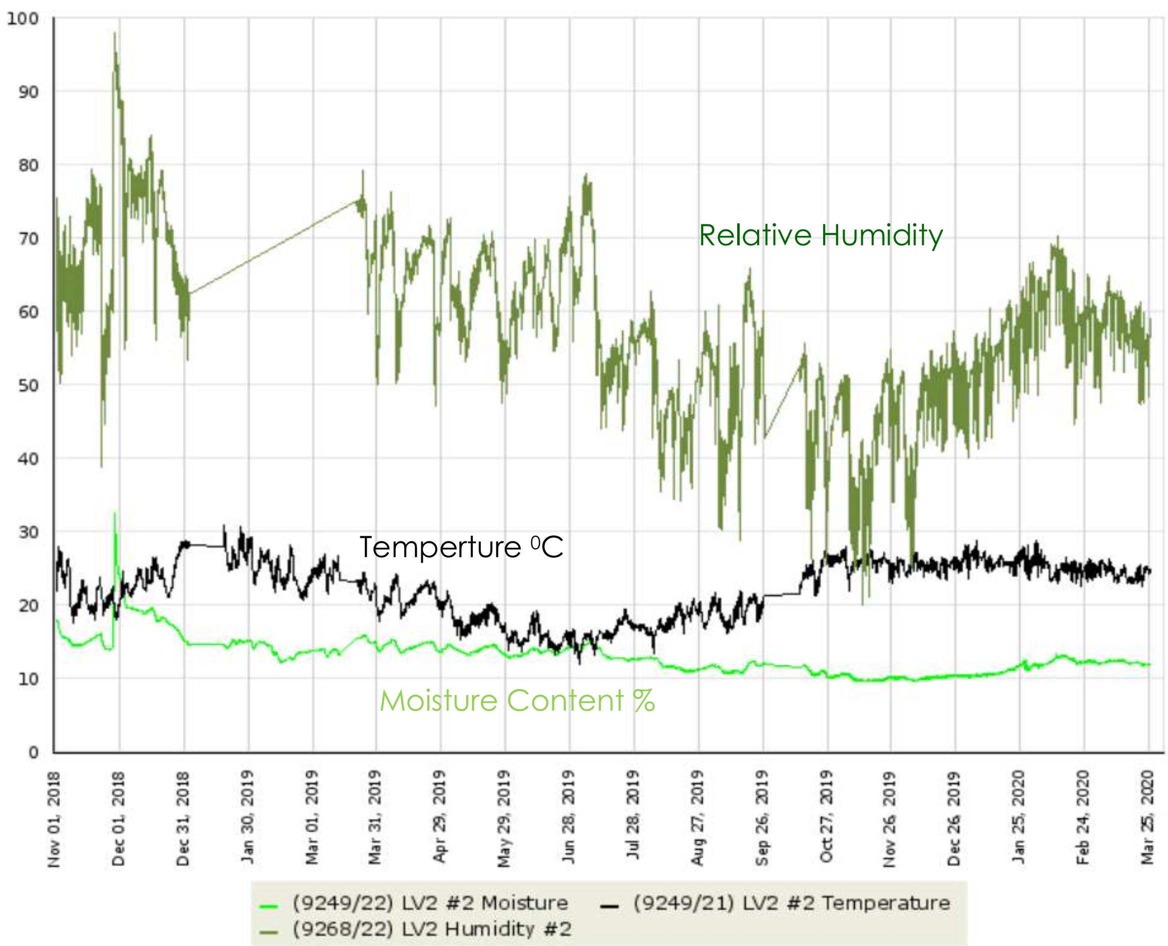


Figure 65: Relative Humidity, Temperature and Moisture Content of Stud in Level 2, Position #2

However, care is required in drawing direct conclusions from the moisture content data representing the change of moisture content of the entire timber element. The data collected was the moisture content of the timber at approximately 20 mm within the timber stud or CLT, representing the subsurface change in moisture content not for the entire element. It is expected that there is a moisture gradient through the timber element, with the thick timber element's centre remaining relatively unchanged, while the surface moisture content is varying with the changing atmospheric conditions.

In hindsight, the moisture content gradient, i.e. moisture content at different depths within the timber element, should have been measure in some locations, to be able to inform what the average moisture content of the timber element was.

Building's Movement

The maximum and total displacement of all string pot locations are contained in Table 1 – North/East Exterior Wall, Table 2 - Close to Corridor, Table 3 – Inside Apartment and Table 4 – South/East Exterior Wall.

Table 1: String Pot Location 1 – North/East Exterior Wall

	Maximum Displacement (mm)	Displacement at April 2020 (mm)
Level 5	+ 4.0	+ 0.5
Level 4	- 1.0	+ 0.7
Level 3	+ 21.0	+16.0
Level 2	-	-
Level 1	- 2.0	- 2.0
Upper Ground	-	-
Total	**+ 21.0**	**- 15.2**

Note: Level 3 movement does not seem creditable

Table 2: String Pot Location 2 – Close to Corridor

	Maximum Displacement (mm)	Displacement at April 2020 (mm)
Level 5	- 3.5	- 3.5
Level 4	- 5.5	- 5.5
Level 3	+ 5.0	+ 0.1
Level 2	- 6.0	- 6.0
Level 1	- 8.0	- 6.0
Upper Ground	+6.0	+6.0
Total	**- 12.0**	**- 14.9**

Table 3: String Pot Location 3 – Inside Apartment

	Maximum Displacement (mm)	Displacement at June 2019 (mm)
Level 5	+ 1.0	+ 0 .0
Level 4	+ 6.0	- 3.0
Level 3	- 4.2	- 4.0
Level 2	- 3.0	- 3.0
Level 1	- 3.1	- 2.1
Upper Ground	-	-
Total	**- 3.3**	**- 12.1**

Table 4: String Pot Location 4 – South/East Exterior Wall

	Maximum Displacement (mm)	Displacement at June 2019 (mm)
Level 5	+ 2.0	- 1.0
Level 4	+ 2.0	+ 1.8
Level 3	-	-
Level 2	-	-
Level 1	- 4.0	- 3.0
Upper Ground	+ 2.0	- 0.2
Total	**+ 2.0**	**- 2.4**

The displacement recorded is in most parts were considerably less than the estimated 6.0 mm movement per storey, suggested in the WoodSolutions Guide #50[1]. The north/east exterior wall (Position #1) recorded the most movement, but there is doubt that one of the sensors was reading correctly. The next most movement occurred at the interior corridor (Position #2) wall location with a total displacement of – 14.9 mm. The lowest movement was found in the south/east exterior walls (Position #4) with only a total movement of -2.4 mm. This relative low movement can be attributed to two sensors not working and the higher equilibrium moisture content found in the exterior walls, resulting in less shrinkage of the horizontal timber elements.

[1] WoodSolutions # 50, Mid-rise Timber Building Structural Engineering, 2019

CONCLUSION

The objective of this research was to obtain real data on the temperature, relative humidity, moisture content of timber and vertical displacement of a real, six-storey timber-framed building, during its construction and initial occupation.

The research was successful in obtaining fourteen months of data, being the construction, handover and the early occupation of the building. Thankfully, twelve months of data were obtained, representing the period the building was enclosed, representing the annual seasonal weather variations.

The building experienced extreme temperatures variation from minus 0.9 to 47°C, also experienced a very wet period, receiving 87 mm of rain, following six months of very dry conditions. Surprisingly with this variation of weather conditions, the movement recorded within the building was much less than the expected 6.0 mm per storey, suggested in the WoodSolutions Guide #50.

Much of this reduced movement can be attributed to the use of engineered wood floors – Cross-laminated timber and Laminated Veneer Lumber load-bearing studs. The use of these materials reduced movement from crushing and deflection.

Although beneficial information was found from this research, Western Sydney represents only one climate zone in Australia. It is recommended that further monitoring of timber buildings occur in regions such as Melbourne and Brisbane is undertaken. Furthermore, the data on moisture content is representative of subsurface conditions and not the average of the entire timber element. Explanation or advice is needed to convert subsurface moisture content reading, as recorded in the above research, to the average moisture content of the timber element. This advice is particularly relevant to thick timber elements such as CLT.

APPENDIX A - CONNECTION AND SENSOR POSITION

The following section details the position of the sensors and the input numbers used within the A3 Data Acquisition Unit.

The position of the sensors and the input numbers of the sensors in the A3 Data Acquisition Unit and I3's per level is recorded in Figure A1.

	Eternet		wireless		wire (one per sensor)						
L5		I3		A3 8R	PMM	PMM	PMM	PMM			
				A3 8R	PMM	PMM	PMM	PMM			
				A3 4R4V	RH/T	RH/T	RH/T	SPOT	SPOT	SPOT	SPOT
L4		I3		A3 8R	PMM	PMM	PMM	PMM			
				A3 8R	PMM	PMM	PMM	PMM			
				A3 4R4V	RH/T	RH/T	RH/T	SPOT	SPOT	SPOT	SPOT
L3	BIG	I3		A3 8R	PMM	PMM	PMM	PMM			
				A3 8R	PMM	PMM	PMM	PMM			
				A3 4R4V	RH/T	RH/T	RH/T	SPOT	SPOT	SPOT	SPOT
L2		I3		A3 8R	PMM	PMM	PMM	PMM			
				A3 8R	PMM	PMM	PMM	PMM			
				A3 4R4V	RH/T	RH/T	RH/T	SPOT	SPOT	SPOT	SPOT
L1		I3		A3 8R	PMM	PMM	PMM	PMM			
				A3 8R	PMM	PMM	PMM	PMM			
				A3 4R4V	RH/T	RH/T	RH/T	SPOT	SPOT	SPOT	SPOT
UG		I3		A3 8R	PMM	PMM	PMM	PMM			
				A3 8R	PMM	PMM	PMM	PMM			
				A3 4R4V	RH/T	RH/T	RH/T	SPOT	SPOT	SPOT	SPOT

Figure A1: Sensors per level

KEY: A3 8R and A3 4R4V: Data Acquisitions Units
PMM: Point Moisture Measure
RH/T: Relative Humidity and Temperature (Note: only Relative Humidity is recorded)
SPOT: String Pot displacement
I3: Wifi aerial
BIG: Building Intelligence Gateway

Figure A2 illustrates the resistance channels of the A3 Acquisition Units A3 4R4V and A3 8R.

A3 4R4V

24		23		22		21		ground	20		19		18		17	
B	A	B	A	B	A	B	A	C	Y	X	Y	X	Y	X	Y	X
								C								
								C								
								C								

A3 8CH 8

24		23		22		21			20		19		18		17	
P	O	E	D	P	O	E	D		P	O	E	D	P	O	E	D

Figure A2: A3 resistance channels for the sensors

Figure A3 shows which wire (colour code) of the sensor is to be placed in which resistance channel.

			pin	NAME
RH/T	BLUE	21-24	1	A
	White/orange	21-24	2	B
	white/blue	ground		C
SPOT		17-20	1	X
		17-20	2	Y
PMM				
Temperat ure 104JT	white	17-24	1	D
	green			E
Moisture content	red	17-24	2	O
	black			P

Figure 4: Position of where the sensor wires are connected at the A3's

Table A1 shows the change in colour code when the wires needed to be extended.

Table A1: Colour Coding to Wire Layup

sensor		**Sensor wire colour**	**Extension wire colour**
RH/T		Blue	Blue
RH/T		White/Orange	White/Orange
RH/T		White/Blue	White/Blue
PMM		White	White/Green
PMM		Green	Green
PMM	Red	Red	
PMM	Black	White Red	

Figure A4 shows the position of the sensors at each level. The item number of the A3, I3 and the String Pot sensors is included in this figure.

	Eternet		wireless		NR A3	#1	#2	#3	#4
L5		I3-647		A3 8R	9262	PMM	PMM	PMM	PMM
				A3 8R	9261	PMM	PMM	PMM	PMM
				A3 4R4V	9271			RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
						34	40	46	53
L4		I3-646		A3 8R	9260	PMM	PMM	PMM	PMM
				A3 8R	9259	PMM	PMM	PMM	PMM
				A3 4R4V	9270	RH/T		RH/T	
						SPOT	SPOT	SPOT	SPOT
						33	39	45	52
L3	BIG	I3-645		A3 8R	9258	PMM	PMM	PMM	PMM
				A3 8R	9256	PMM	PMM	PMM	PMM
				A3 4R4V	9269	RH/T	RH/T	RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
						32	38	44	51
L2		I3-644		A3 8R	9253	PMM	PMM	PMM	PMM
				A3 8R	9249	PMM	PMM	PMM	PMM
				A3 4R4V	9268	RH/T	RH/T	RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
						31	37	43	50
L1		I3-643		A3 8R	9248	PMM	PMM	PMM	PMM
				A3 8R	9233	PMM	PMM	PMM	PMM
				A3 4R4V	9267	RH/T	RH/T	RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
						30	36	42	49
UG		I3-642		A3 8R	8852	PMM	PMM	PMM	PMM
				A3 8R	*8912*	PMM	PMM	PMM	PMM
				A3 4R4V	9266			RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
									47

Figure A4: Position sensors at each level

Figure A5 shows the resistance channel number of the sensor. Figure 39 and 40 combined show us which sensor (position) is installed in which position at the A3 data loggers.

		NR A3	#1	#2	#3	#4	
L5	A3 8R	9262	24/23	22/21	19/20	18/17	input
	A3 8R	9261	24/23	22/21	19/20	18/17	input
	A3 4R4V	9271	17	-	18	-	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			34	40	46	53	sensor No.
L4	A3 8R	9260	24/23	22/21	19/20	18/17	input
	A3 8R	9259	24/23	22/21	19/20	18/17	input
	A3 4R4V	9270			18	17	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			33	39	45	52	sensor No.
L3	A3 8R	9258	24/23	22/21	19/20	18/17	input
	A3 8R	9256	24/23	22/21	19/20	18/17	input
	A3 4R4V	9269	17	18	19	20	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			32	38	44	51	sensor No.
L2	A3 8R	9253	24/23	22/21	19/20	18/17	input
	A3 8R	9249	24/23	22/21	19/20	18/17	input
	A3 4R4V	9268	17	18	19	20	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			31	37	43	50	sensor No.
L1	A3 8R	9248	24/23	22/21	19/20	18/17	input
	A3 8R	9233	24/23	22/21	19/20	18/17	input
	A3 4R4V	9267	20	19	18	17	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			30	36	42	49	sensor No.
UG	A3 8R	8852	24/23	22/21	19/20	18/17	input
	A3 8R	*8912*		17/18	19/20	21/22	input
	A3 4R4V	9266	-	-	17	18	input
			SPOT	SPOT	SPOT	SPOT 22	input
						47	sensor No.

Figure A5: Sensor input according to position and Level with the building

Figure A6 shows the species of the timber used for each installed PMM sensor. The PMM sensor used to monitor the CLT are positioned away from the String Pot locations. The sensor named "CLT GR" is located in the garbage room next to the A3 Data Acquisition Units on each level. The sensor named "CLT" measures the moisture content of the ceiling in the hallway on all levels, and their location can be found in Figure 19, marked as #A, #B, #C and #D.

		NR A3	#1	#2	#3	#4	
L5	A3 8R	9262	CLT	CLT	CLT GR	Spruce	species
	A3 8R	9261	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9271	17	-	18	-	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			34	40	46	53	sensor No.
L4	A3 8R	9260	CLT	CLT	CLT GR	Spruce	species
	A3 8R	9259	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9270			18	17	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			33	39	45	52	sensor No.
L3	A3 8R	9258	CLT	CLT	CLT GR	CLT	species
	A3 8R	9256	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9269	17	18	19	20	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			32	38	44	51	sensor No.
L2	A3 8R	9253	CLT	CLT	CLT GR	CLT	species
	A3 8R	9249	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9268	17	18	19	20	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			31	37	43	50	sensor No.
L1	A3 8R	9248	CLT	CLT	CLT GR	CLT	species
	A3 8R	9233	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9267	20	19	18	17	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			30	36	42	49	sensor No.
UG	A3 8R	8852	CLT	CLT	CLT GR	CLT	species
	A3 8R	*8912*	Spruce	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9266	-	-	17	18	input
			SPOT	SPOT	SPOT	SPOT 22	input
						47	sensor No.
rad. Pine =Pinus Radiata studs							
CLT GR = LT wall in garbage room							
CLT = CLT ceiling in hallway							
Spruce = Spruce studs							

Figure A6: Timer species according to position

Figure A7 combines Figure A4, A5 and A6. This combination of figures provides the position of the sensor and the input channel of each sensor in the one illustration. (Figure A4 showed the position of each sensor, Figure A5 is the resistance channel number belonging to the sensor marked, and Figure A6 is the timber species belonging to each PMM sensor).

Figure A7 showed the total setup of the sensors in the building, including the input of the sensors in the A3 data loggers and the timber species for the PMM's.

	Eternet		wireless		NR A3	#1	#2	#3	#4
L5		I3-647		A3 8R	9262	PMM	PMM	PMM	PMM
				A3 8R	9261	PMM	PMM	PMM	PMM
				A3 4R4V	9271			RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
						34	40	46	53
L4		I3-646		A3 8R	9260	PMM	PMM	PMM	PMM
				A3 8R	9259	PMM	PMM	PMM	PMM
				A3 4R4V	9270	RH/T		RH/T	
						SPOT	SPOT	SPOT	SPOT
						33	39	45	52
L3	BIG	I3-645		A3 8R	9258	PMM	PMM	PMM	PMM
				A3 8R	9256	PMM	PMM	PMM	PMM
				A3 4R4V	9269	RH/T	RH/T	RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
						32	38	44	51
L2		I3-644		A3 8R	9253	PMM	PMM	PMM	PMM
				A3 8R	9249	PMM	PMM	PMM	PMM
				A3 4R4V	9268	RH/T	RH/T	RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
						31	37	43	50
L1		I3-643		A3 8R	9248	PMM	PMM	PMM	PMM
				A3 8R	9233	PMM	PMM	PMM	PMM
				A3 4R4V	9267	RH/T	RH/T	RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
						30	36	42	49
UG		I3-642		A3 8R	8852	PMM	PMM	PMM	PMM
				A3 8R	*8912*	PMM	PMM	PMM	PMM
				A3 4R4V	9266			RH/T	RH/T
						SPOT	SPOT	SPOT	SPOT
									47

		NR A3	#1	#2	#3	#4	
L5	A3 8R	9262	24/23	22/21	19/20	18/17	input
	A3 8R	9261	24/23	22/21	19/20	18/17	input
	A3 4R4V	9271	17	-	18	-	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			34	40	46	53	sensor No.
L4	A3 8R	9260	24/23	22/21	19/20	18/17	input
	A3 8R	9259	24/23	22/21	19/20	18/17	input
	A3 4R4V	9270			18	17	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			33	39	45	52	sensor No.
L3	A3 8R	9258	24/23	22/21	19/20	18/17	input
	A3 8R	9256	24/23	22/21	19/20	18/17	input
	A3 4R4V	9269	17	18	19	20	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			32	38	44	51	sensor No.
L2	A3 8R	9253	24/23	22/21	19/20	18/17	input
	A3 8R	9249	24/23	22/21	19/20	18/17	input
	A3 4R4V	9268	17	18	19	20	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			31	37	43	50	sensor No.
L1	A3 8R	9248	24/23	22/21	19/20	18/17	input
	A3 8R	9233	24/23	22/21	19/20	18/17	input
	A3 4R4V	9267	20	19	18	17	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			30	36	42	49	sensor No.
UG	A3 8R	8852	24/23	22/21	19/20	18/17	input
	A3 8R	*8912*		17/18	19/20	21/22	input
	A3 4R4V	9266	-	-	17	18	input
			SPOT	SPOT	SPOT	SPOT 22	input
						47	sensor No.

		NR A3	#1	#2	#3	#4	
L5	A3 8R	9262	CLT	CLT	CLT GR	Spruce	species
	A3 8R	9261	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9271	17	-	18	-	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			34	40	46	53	sensor No.
L4	A3 8R	9260	CLT	CLT	CLT GR	Spruce	species
	A3 8R	9259	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9270			18	17	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			33	39	45	52	sensor No.
L3	A3 8R	9258	CLT	CLT	CLT GR	CLT	species
	A3 8R	9256	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9269	17	18	19	20	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			32	38	44	51	sensor No.
L2	A3 8R	9253	CLT	CLT	CLT GR	CLT	species
	A3 8R	9249	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9268	17	18	19	20	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			31	37	43	50	sensor No.
L1	A3 8R	9248	CLT	CLT	CLT GR	CLT	species
	A3 8R	9233	rad.Pine	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9267	20	19	18	17	input
			SPOT 21	SPOT 22	SPOT 23	SPOT 24	input
			30	36	42	49	sensor No.
UG	A3 8R	8852	CLT	CLT	CLT GR	CLT	species
	A3 8R	*8912*	Spruce	rad.Pine	rad.Pine	rad.Pine	species
	A3 4R4V	9266	-	-	17	18	input
			SPOT	SPOT	SPOT	SPOT 22	input
						47	sensor No.

rad. Pine =Pinus Radiata studs
CLT GR = LT wall in garbage room
CLT = CLT ceiling in hallway
Spruce = Spruce studs

Figure A7: Combination Figures 40, 41 and 42

					Position	#1			#2			#3			#4		
Level		I3 number		A3	A3 number	Sensor type	Sensor input	Timber species/ sensor number	Sensor type	Sensor input	Timber species/ sensor number	Sensor type	Sensor input	Timber species/ sensor number	Sensor type	Sensor input	Timber species/ sensor number
	Eternet		wireless														
L5		I3-647	(*2)	A3 8R	9262	PMM	24/23	CLT	PMM	22/21	CLT	PMM	19/20	CLT GR	PMM	18/17	Spruce
				A3 8R	9261	PMM	24/23	rad.Pine	PMM	22/21	rad.Pine	PMM	19/20	rad.Pine	PMM	18/17	rad.Pine
				A3 4R4V	9271	SPOT	17	34	SPOT	19	40	SPOT	18	46	SPOT	20	53
						RH/T	21					RH/T	23				
L4		I3-646	(*2)	A3 8R	9260	PMM	24/23	CLT	PMM	22/21	CLT	PMM	19/20	CLT GR	PMM	18/17	Spruce
				A3 8R	9259	PMM	24/23	rad.Pine	PMM	22/21	rad.Pine	PMM	19/20	rad.Pine	PMM	18/17	rad.Pine
				A3 4R4V	9270	SPOT	19	33	SPOT	20	39	SPOT	17	45	SPOT	18	52
												RH/T	23		RH/T	24	
L3	BIG	I3-645	(*2)	A3 8R	9258	PMM	24/23	CLT	PMM	22/21	CLT	PMM	19/20	CLT GR	PMM	18/17	CLT
				A3 8R	9256	PMM	24/23	rad.Pine	PMM	22/21	rad.Pine	PMM	19/20	rad.Pine	PMM	18/17	rad.Pine
				A3 4R4V	9269	SPOT	17	32	SPOT	18	38	SPOT	19	44	SPOT	20	51
						RH/T	21		RH/T	22		RH/T	23		RH/T	24	
L2		I3-644	(*2)	A3 8R	9253	PMM	24/23	CLT	PMM	22/21	CLT	PMM	19/20	CLT GR	PMM	18/17	CLT
				A3 8R	9249	PMM	24/23	rad.Pine	PMM	22/21	rad.Pine	PMM	19/20	rad.Pine	PMM	18/17	rad.Pine
				A3 4R4V	9268	SPOT	17	31	SPOT	18	37	SPOT	19	43	SPOT	20	50
						RH/T	21		RH/T	22		RH/T	23		RH/T	24	
L1		I3-643	(*2)	A3 8R	9248	PMM	24/23	CLT	PMM	22/21	CLT	PMM	19/20	CLT GR	PMM	18/17	Spruce
				A3 8R	9233	PMM	24/23	rad.Pine	PMM	22/21	rad.Pine	PMM	19/20	rad.Pine	PMM	18/17	rad.Pine
				A3 4R4V	9267	SPOT	20	31	SPOT	19	36	SPOT	18	42	SPOT	17	49
						RH/T	21		RH/T	22		RH/T	23		RH/T	24	
UG		I3-642	(*2)	A3 8R	8852	PMM	24/23	CLT	PMM	22/21	CLT	PMM	19/20	CLT GR	PMM	18/17	CLT
				A3 8R	8912	PMM	24/23	Spruce (*1)	PMM	17/18	rad.Pine	PMM	19/20	rad.Pine	PMM	21/22	rad.Pine
				A3 4R4V	9266										SPOT	18	47
												RH/T	21		RH/T	22	

(*1) = position #C
(*2) = Position #A, #B, #C, #D acording to plan and not position #1 -#4

rad. Pine =Pinus Radiata studs
CLT GR = CLCT wall in garbage room
CLT = CLT ceiling in hallway
Spruce = Spruce studs

Figure A8: Sensor setup and input

Table A2, A3, A4, A5, A6 and A7 illustrates the sensor and nodes according to the setup in the BIG by each level within the building. The first column shows the building's level and the number of the I3 aerial on that level. The second column shows the name of the A3 Data Acquisition Unit, which includes: building level, type of resistance unit, and what the sensor is monitoring. The third column shows the A3 Data Acquisition Unit identification number. The fourth column shows the input channel of the A3 Data Acquisition Unit. The fifth column contains the name of the sensor, which includes; Buildings level, position of the sensor, and what the sensor is monitoring.

Table A2 Sensor Position Building Level 5

Level	Node Name	Node	Input	Name and Position
Level 5	LV5 8R studs	9261	17	LV5 #4 Temperature
647	LV5 8R studs	9261	18	LV5 #4 Moisture
	LV5 8R studs	9261	19	LV5 #3 Temperature
	LV5 8R studs	9261	20	LV5 #3 Moisture
	LV5 8R studs	9261	21	LV5 #2 Temperature
	LV5 8R studs	9261	22	LV5 #2 Moisture
	LV5 8R studs	9261	23	LV5 #1 Temperature
	LV5 8R studs	9261	24	LV5 #1 Moisture
	LV5 8RCLT ceiling	9262	17	LV5 #A Temperature
	LV5 8RCLT ceiling	9262	18	LV5 #A Moisture
	LV5 8RCLT ceiling	9262	19	LV5 #B Temperature
	LV5 8RCLT ceiling	9262	20	LV5 #B Moisture
	LV5 8RCLT ceiling	9262	21	LV5 #C Temperature
	LV5 8RCLT ceiling	9262	22	LV5 #C Moisture
	LV5 8RCLT ceiling	9262	23	LV5 #D Temperature
	LV5 8RCLT ceiling	9262	24	LV5 #D Moisture
	String Pot LV5	9271	17	String Pot #1
	String Pot LV5	9271	18	String Pot #2
	String Pot LV5	9271	19	String Pot #3
	String Pot LV5	9271	20	String Pot #4
	String Pot LV5	9271	21	Humidity #1
	String Pot LV5	9271	22	Humidity #3
	String Pot LV5	9271	23	x
	String Pot LV5	9271	24	x

Table A3 Sensor Position Building Level 4

Level 4 646	LV4 8R studs	9259	17	LV4 #4 Temperature
	LV4 8R studs	9259	18	LV4 #4 Moisture
	LV4 8R studs	9259	19	LV4 #3 Temperature
	LV4 8R studs	9259	20	LV4 #3 Moisture
	LV4 8R studs	9259	21	LV4 #2 Temperature
	LV4 8R studs	9259	22	LV4 #2 Moisture
	LV4 8R studs	9259	23	LV4 #1 Temperature
	LV4 8R studs	9259	24	LV4 #1 Moisture
	LV4 8RCLT ceiling	9260	17	LV4 #A Temperature
	LV4 8RCLT ceiling	9260	18	LV4 #A Moisture
	LV4 8RCLT ceiling	9260	19	LV4 #B Temperature
	LV4 8RCLT ceiling	9260	20	LV4 #B Moisture
	LV4 8RCLT ceiling	9260	21	LV4 #C Temperature
	LV4 8RCLT ceiling	9260	22	LV4 #C Moisture
	LV4 8RCLT ceiling	9260	23	LV4 #D Temperature
	LV4 8RCLT ceiling	9260	24	LV4 #D Moisture
	String Pot LV4	9270	17	String Pot #1
	String Pot LV4	9270	18	String Pot #2
	String Pot LV4	9270	19	String Pot #3
	String Pot LV4	9270	20	String Pot #4
	String Pot LV4	9270	21	Humidity #3
	String Pot LV4	9270	22	Humidity #4
	String Pot LV4	9270	23	x
	String Pot LV4	9270	24	x

Table A4 Sensor Position Building Level 3

Level 3 645	LV3 8R studs	9256	17	LV3 #4 Temperature
	LV3 8R studs	9256	18	LV3 #4 Moisture
	LV3 8R studs	9256	19	LV3 #3 Temperature
	LV3 8R studs	9256	20	LV3 #3 Moisture
	LV3 8R studs	9256	21	LV3 #2 Temperature
	LV3 8R studs	9256	22	LV3 #2 Moisture
	LV3 8R studs	9256	23	LV3 #1 Temperature
	LV3 8R studs	9256	24	LV3 #1 Moisture
	LV3 8RCLT ceiling		17	LV3 #A Temperature
	LV3 8RCLT ceiling		18	LV3 #A Moisture
	LV3 8RCLT ceiling		19	LV3 #B Temperature
	LV3 8RCLT ceiling		20	LV3 #B Moisture
	LV3 8RCLT ceiling		21	LV3 #C Temperature
	LV3 8RCLT ceiling		22	LV3 #C Moisture
	LV3 8RCLT ceiling		23	LV3 #D Temperature
	LV3 8RCLT ceiling		24	LV3 #D Moisture
	String Pot LV3	9269	17	String Pot #1
	String Pot LV3	9269	18	String Pot #2
	String Pot LV3	9269	19	String Pot #3
	String Pot LV3	9269	20	String Pot #4
	String Pot LV3	9269	21	Humidity #1
	String Pot LV3	9269	22	Humidity #2
	String Pot LV3	9269	23	Humidity #3
	String Pot LV3	9269	24	Humidity #4

Table A5 Sensor Position Building Level 2

Level 2	LV2 8R studs	9249	17	LV2 #4 Temperature
644	LV2 8R studs	9249	18	LV2 #4 Moisture
	LV2 8R studs	9249	19	LV2 #3 Temperature
	LV2 8R studs	9249	20	LV2 #3 Moisture
	LV2 8R studs	9249	21	LV2 #2 Temperature
	LV2 8R studs	9249	22	LV2 #2 Moisture
	LV2 8R studs	9249	23	LV2 #1 Temperature
	LV2 8R studs	9249	24	LV2 #1 Moisture
	LV2 8RCLT ceiling	9253	17	LV2 #A Temperature
	LV2 8RCLT ceiling	9253	18	LV2 #A Moisture
	LV2 8RCLT ceiling	9253	19	LV2 #B Temperature
	LV2 8RCLT ceiling	9253	20	LV2 #B Moisture
	LV2 8RCLT ceiling	9253	21	LV2 #C Temperature
	LV2 8RCLT ceiling	9253	22	LV2 #C Moisture
	LV2 8RCLT ceiling	9253	23	LV2 #D Temperature
	LV2 8RCLT ceiling	9253	24	LV2 #D Moisture
	String Pot LV2	9268	17	String Pot #1
	String Pot LV2	9268	18	String Pot #2
	String Pot LV2	9268	19	String Pot #3
	String Pot LV2	9268	20	String Pot #4
	String Pot LV2	9268	21	Humidity #1
	String Pot LV2	9268	22	Humidity #2
	String Pot LV2	9268	23	Humidity #3
	String Pot LV2	9268	24	Humidity #4

Table A6 Sensor Position Building Level 1

Level 1	LV1 8R studs	9233	17	LV1 #4 Temperature
643	LV1 8R studs	9233	18	LV1 #4 Moisture
	LV1 8R studs	9233	19	LV1 #3 Temperature
	LV1 8R studs	9233	20	LV1 #3 Moisture
	LV1 8R studs	9233	21	LV1 #2 Temperature
	LV1 8R studs	9233	22	LV1 #2 Moisture
	LV1 8R studs	9233	23	LV1 #1 Temperature
	LV1 8R studs	9233	24	LV1 #1 Moisture
	LV1 8RCLT ceiling	9248	17	LV1 #A Temperature
	LV1 8RCLT ceiling	9248	18	LV1 #A Moisture
	LV1 8RCLT ceiling	9248	19	LV1 #B Temperature
	LV1 8RCLT ceiling	9248	20	LV1 #B Moisture
	LV1 8RCLT ceiling	9248	21	LV1 #C Temperature
	LV1 8RCLT ceiling	9248	22	LV1 #C Moisture
	LV1 8RCLT ceiling	9248	23	LV1 #D Temperature
	LV1 8RCLT ceiling	9248	24	LV1 #D Moisture
	String Pot LV1	9267	17	String Pot #4
	String Pot LV1	9267	18	String Pot #3
	String Pot LV1	9267	19	String Pot #2
	String Pot LV1	9267	20	String Pot #1
	String Pot LV1	9267	21	Humidity #4
	String Pot LV1	9267	22	Humidity #3
	String Pot LV1	9267	23	Humidity #2
	String Pot LV1	9267	24	Humidity #1

Table A7 Sensor Position Building Level Upper Ground

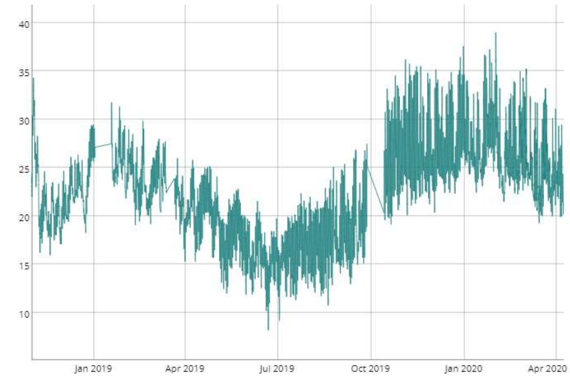
Upper Ground	UG 8R studs	8912	17	UG #2 Temperature
642	UG 8R studs	8912	18	UG #2 Moisture
	UG 8R studs	8912	19	UG #3 Temperature
	UG 8R studs	8912	20	UG #3 Moisture
	UG 8R studs	8912	21	UG #4 Temperature
	UG 8R studs	8912	22	UG #4 Moisture
	UG 8R studs	8912	23	UG #B Temperature
	UG 8R studs	8912	24	UG #B Moisture
	UG 8RCLT ceiling	8852	17	UG #A Temperature
	UG 8RCLT ceiling	8852	18	UG #A Moisture
	UG 8RCLT ceiling	8852	19	UG #B Temperature
	UG 8RCLT ceiling	8852	20	UG #B Moisture
	UG 8RCLT ceiling	8852	21	UG #C Temperature
	UG 8RCLT ceiling	8852	22	UG #C Moisture
	UG 8RCLT ceiling	8852	23	UG #D Temperature
	UG 8RCLT ceiling	8852	24	UG #D Moisture
	String Pot UG	9266	17	String Pot #4
	String Pot UG	9266	18	x
	String Pot UG	9266	19	x
	String Pot UG	9266	20	x
	String Pot UG	9266	21	Humidity #4
	String Pot UG	9266	22	Humidity #3
	String Pot UG	9266	23	x
	String Pot UG	9266	24	x

x= Not connected

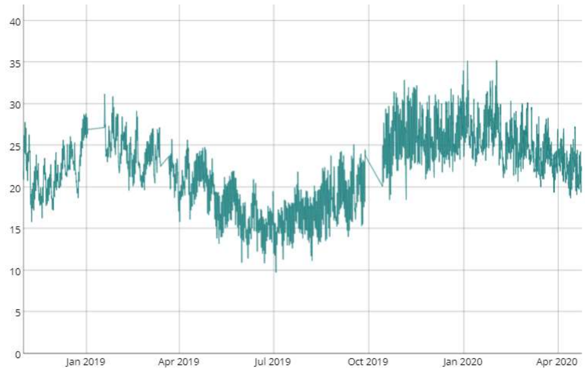
APPENDIX B - INDIVIDUAL SENSOR RESULTS

The following graphs are the individual sensor results of all points measure with the building. Caution is given to the data collected in the first quarter of 2020, as some data may be affected by the data logger batteries nearing the end of their life.

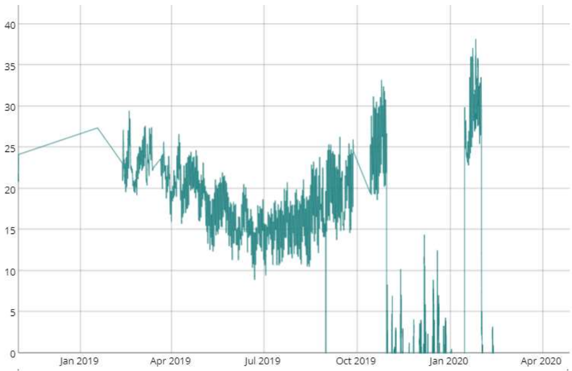
Temperature Measured in the Exterior Wall Facing North/East – Position #1



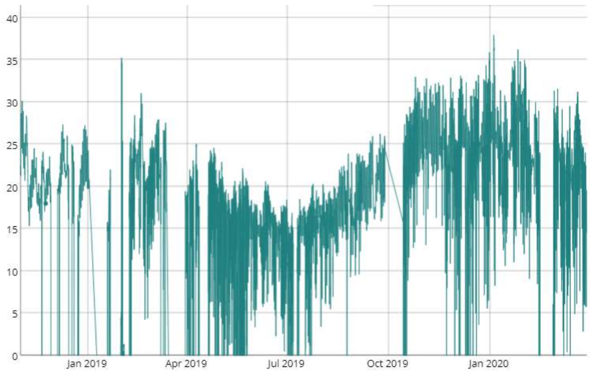
LV1 #1



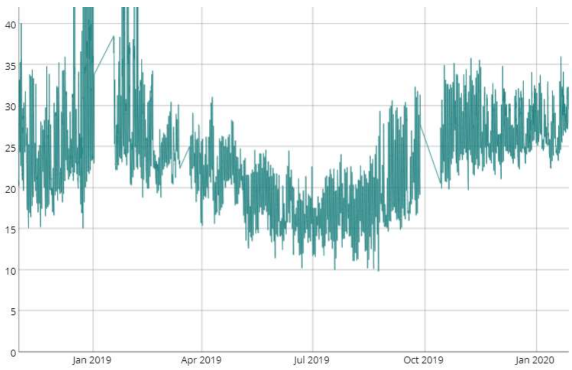
LV2 #1



LV3 #1

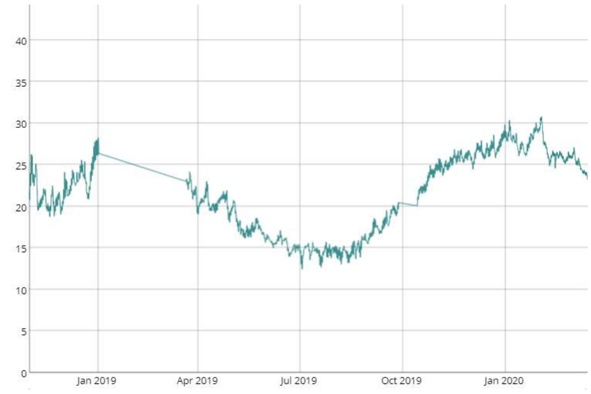


LV4 #1

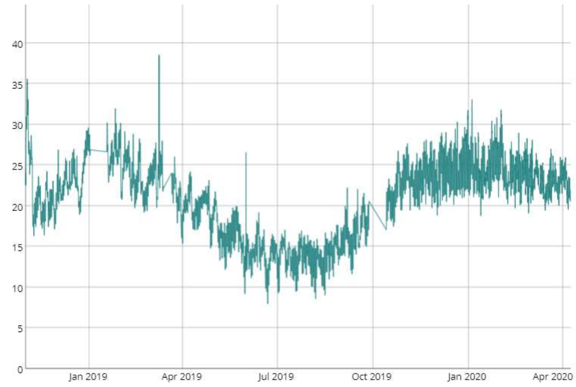


LV5 #1

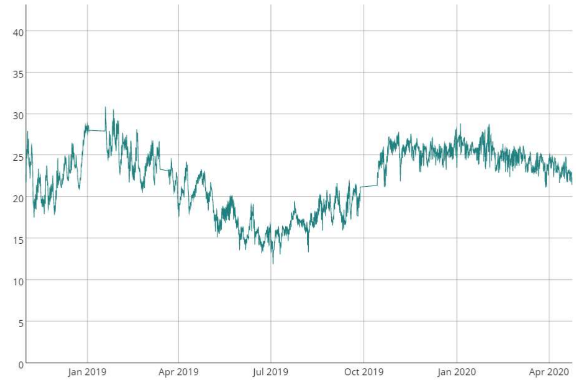
Temperature Measured in the Wall next to the Hallway – Position # 2



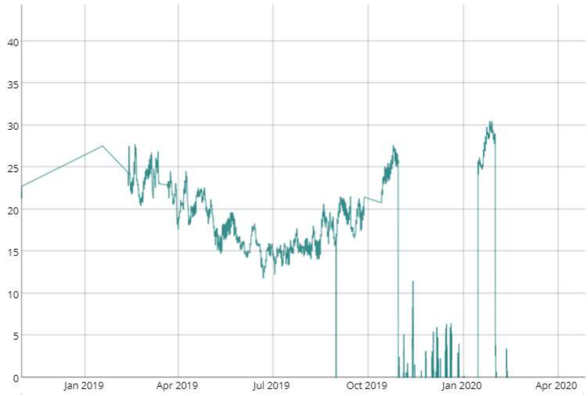
UG #2



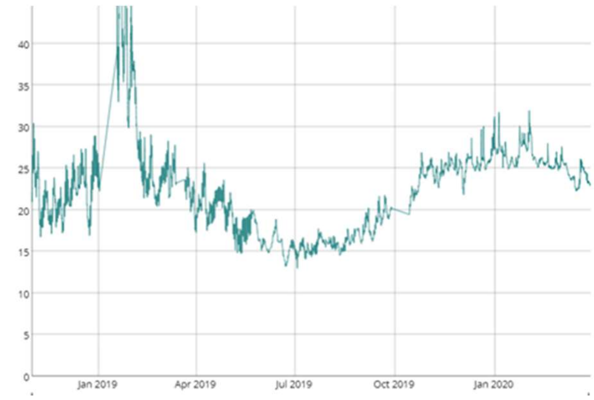
LV1 #2



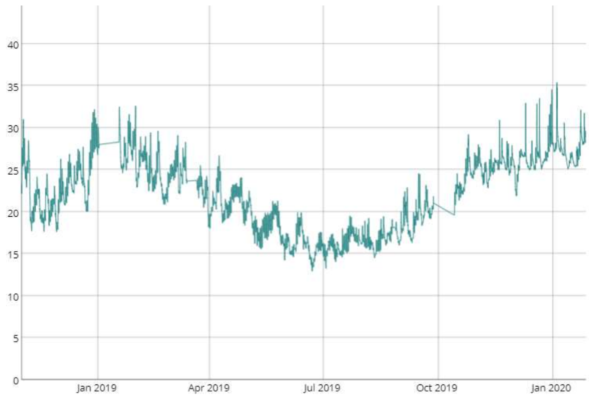
LV2 #2



LV3 #2

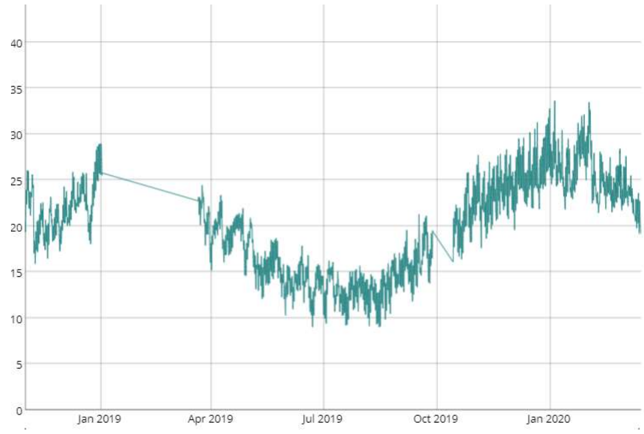


LV4 #2

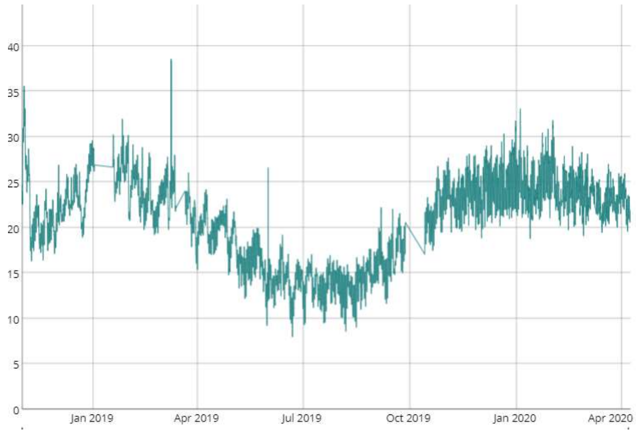


LV5 #2

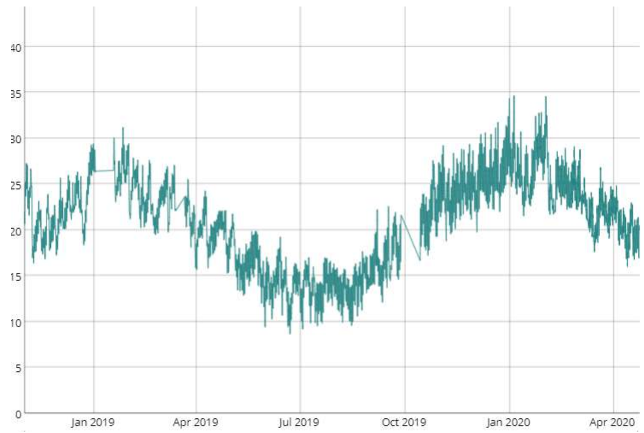
Temperature Measured in a Wall Positioned within an Apartment – Position #3



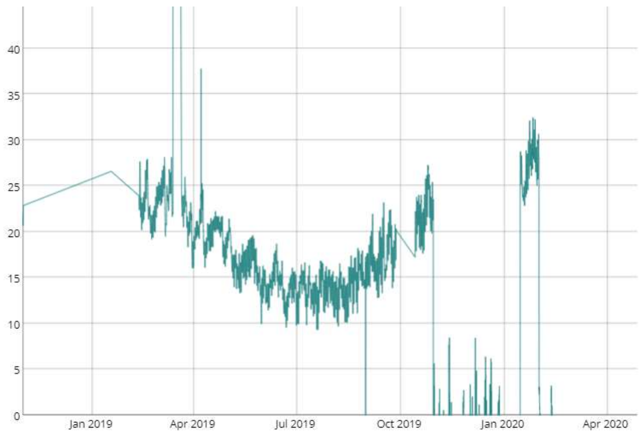
UG #3



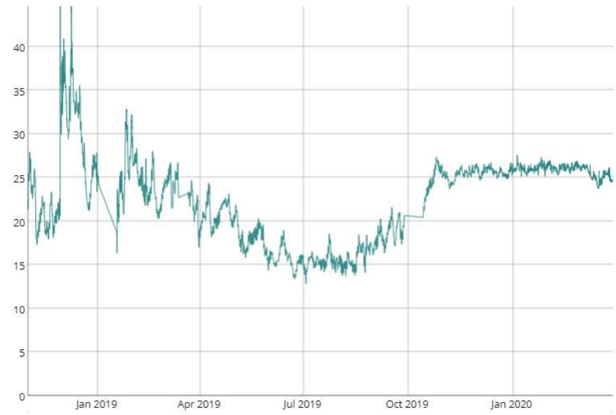
LV1 #3



LV2 #3



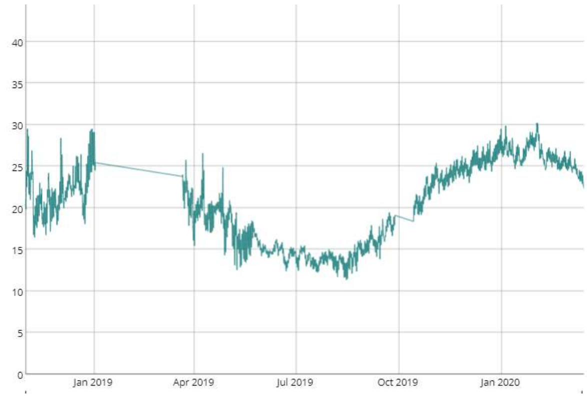
LV3 #3



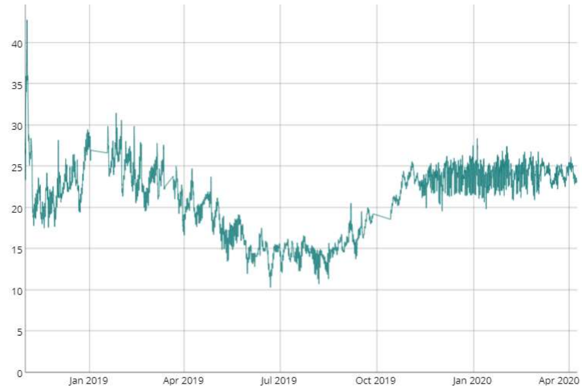
LV4 #3

LV5 #3

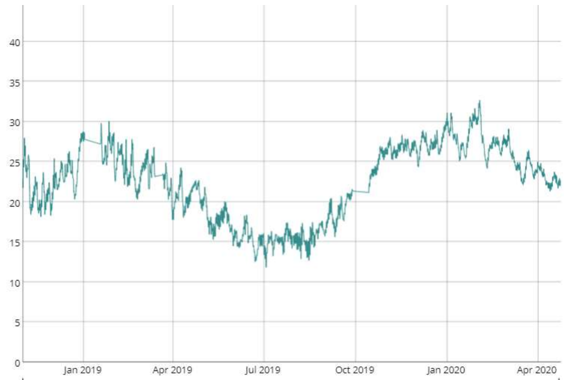
Temperature Measured in an Exterior Wall Facing South/West – Position #4



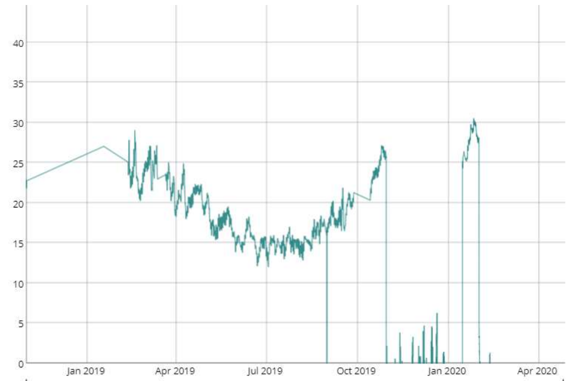
UG #4



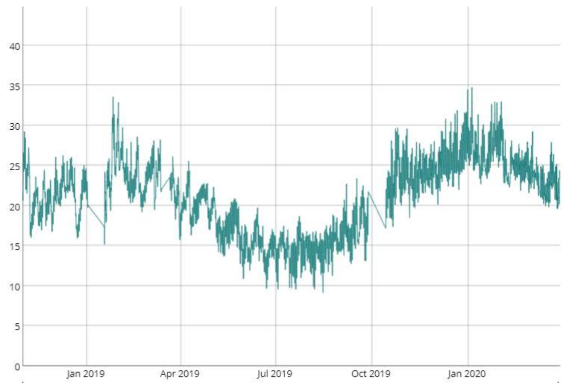
LV1 #4



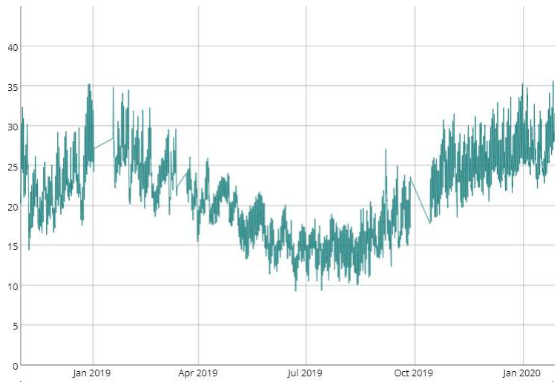
LV2 #4



LV3 #4

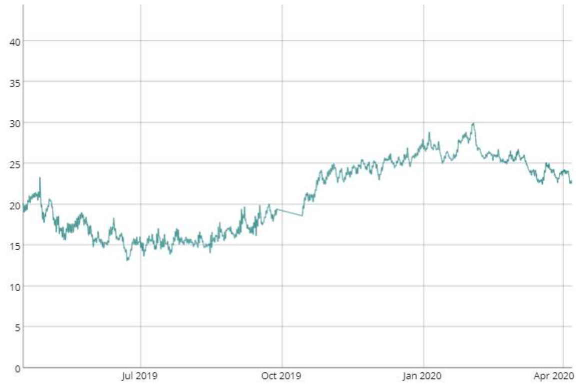


LV4 #4

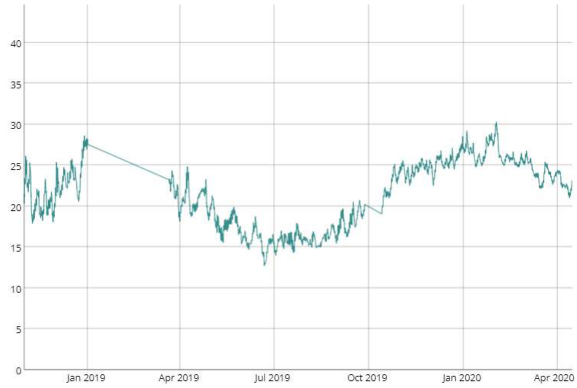


LV5 #4

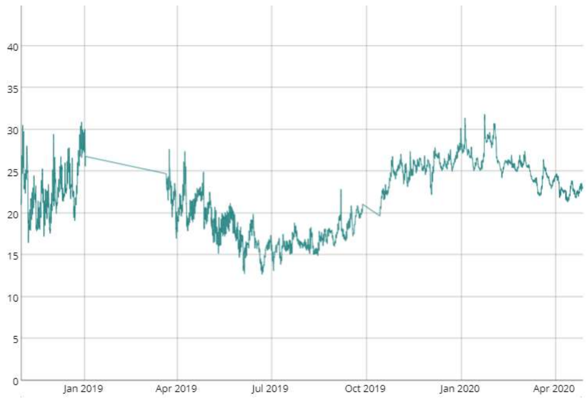
Temperature Measured in the Hallways Position #A – CLT Floor Underside



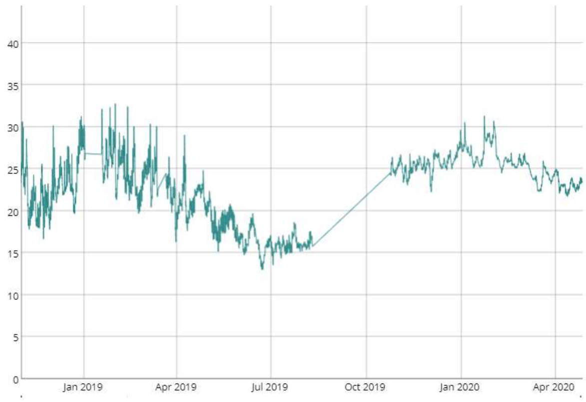
UG #A



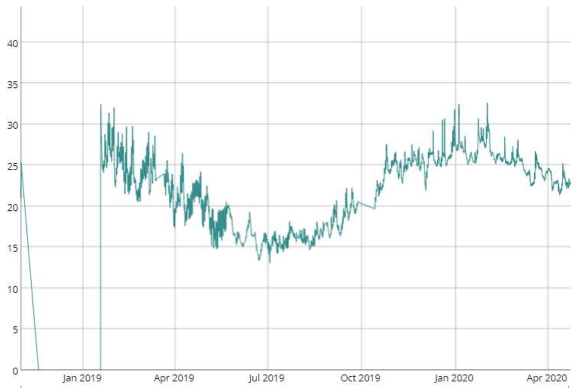
LV1 #A



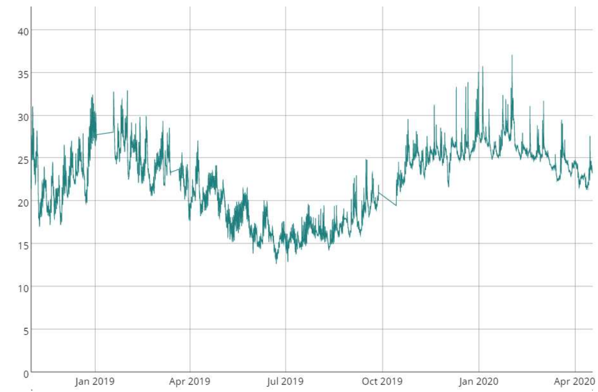
LV2 #A



LV3 #A

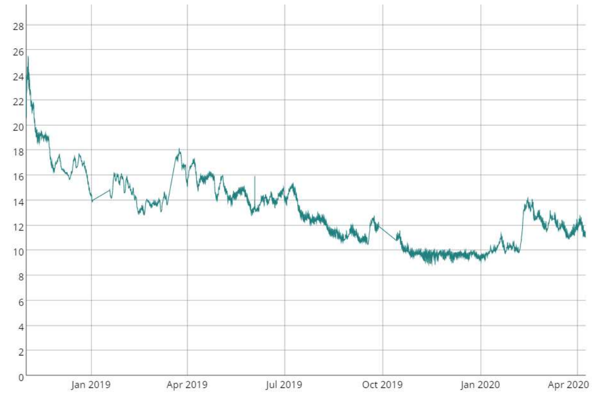


LV4 #A

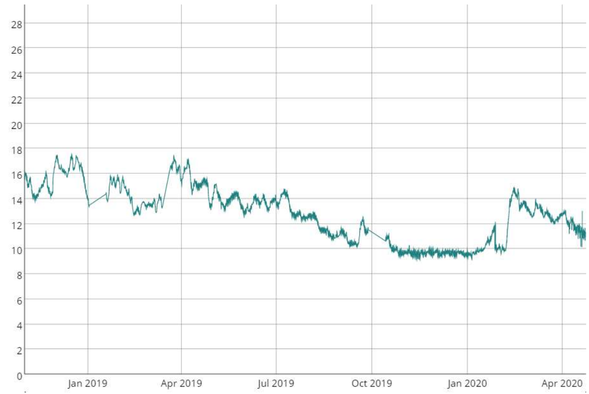


LV5 #A

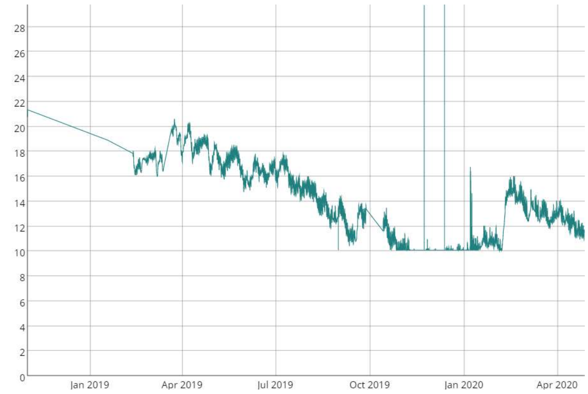
Moisture Content Measured in an Exterior Wall Facing North/East – Position #1



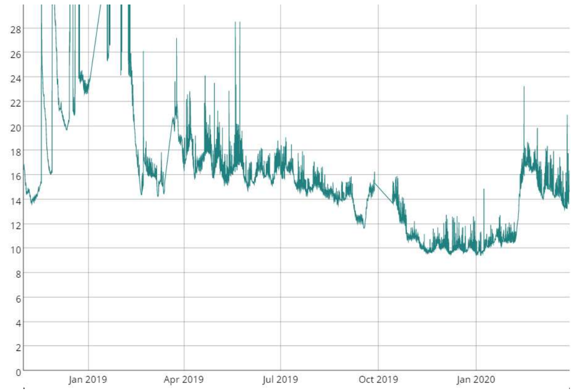
LV1 #1



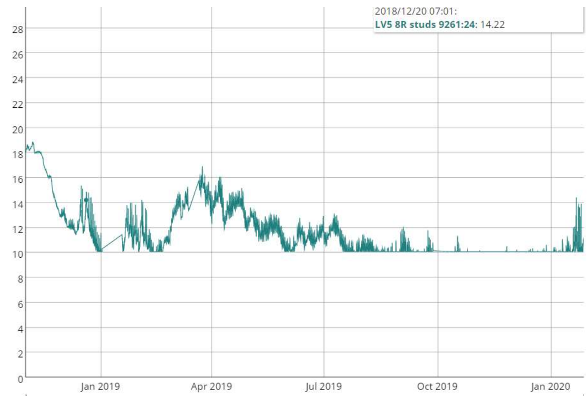
LV2 #1



LV3 #1



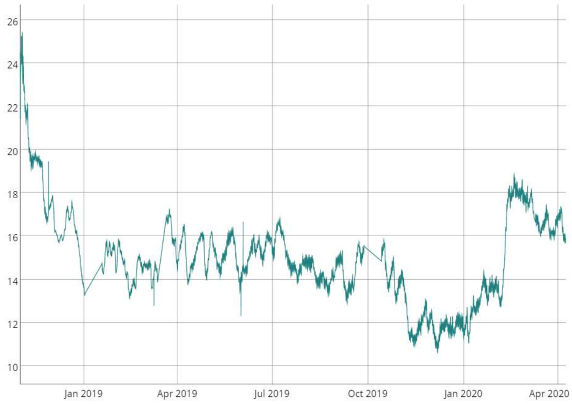
LV4 #1



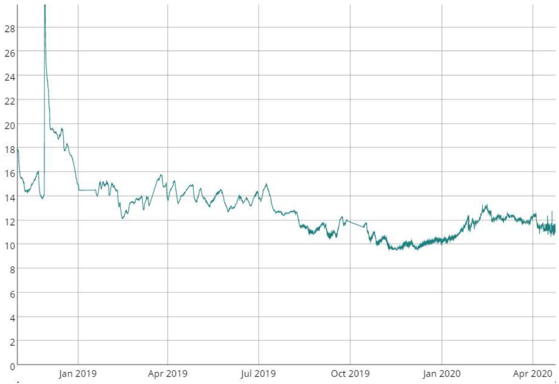
LV5 #1

Moisture Content Measured in the Wall next to the Hallway – Position # 2

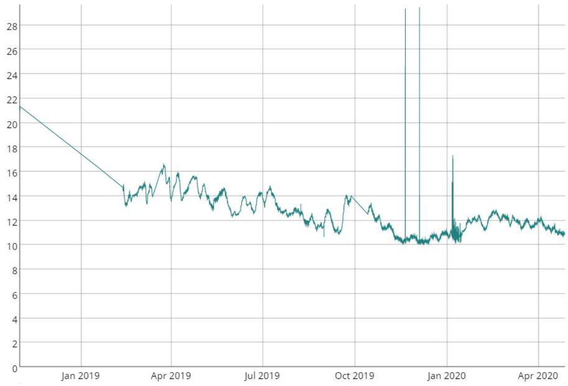
UG #2



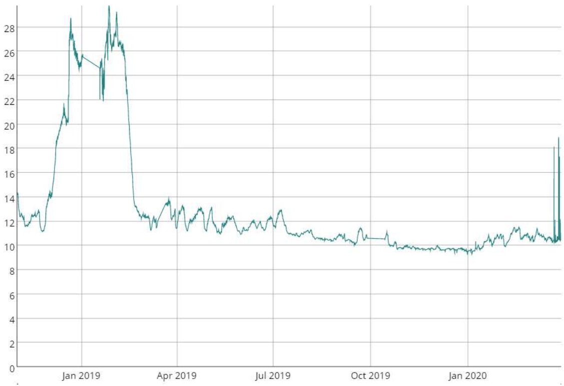
LV1 #2



LV2 #2



LV3 #2

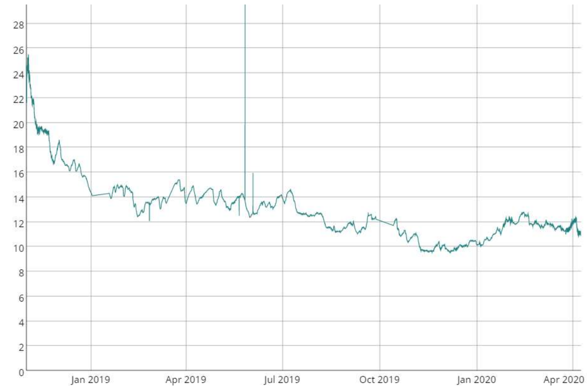


LV4 #2

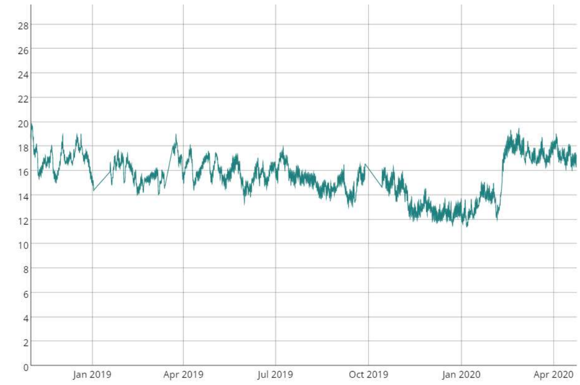
LV5 #2

Moisture Content Measured in a Wall Positioned within an Apartment – Position #3

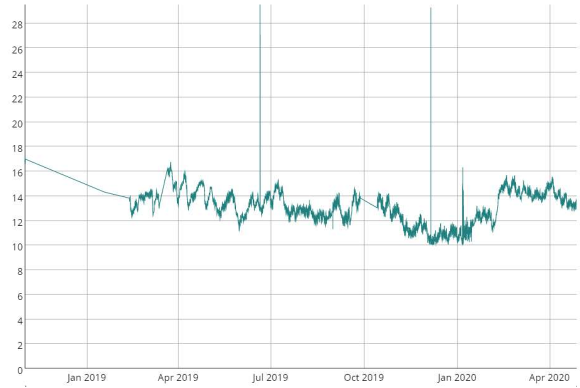
UG #3



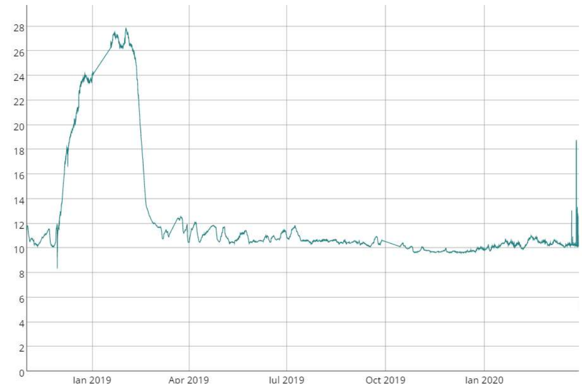
LV1 #3



LV2 #3



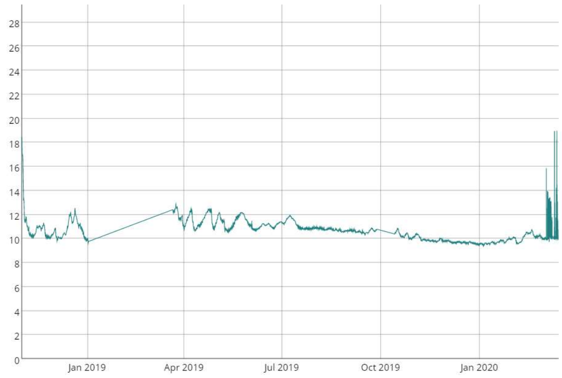
LV3 #3



LV4 #3

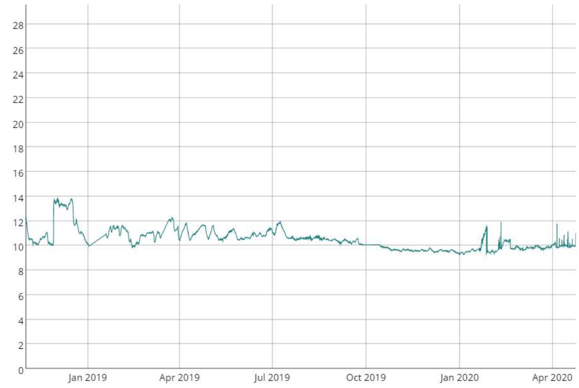
LV5 #3

Moisture Content Measured in an Exterior Wall facing South/West – Position #4

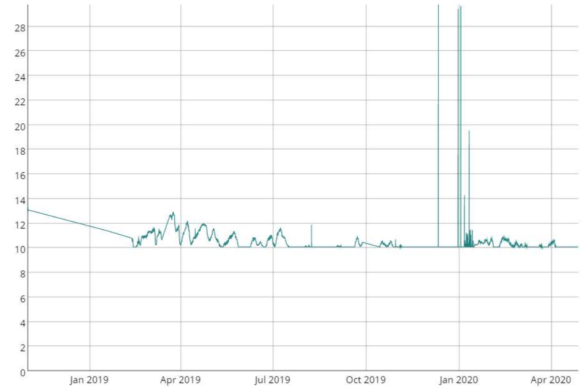


UG #4

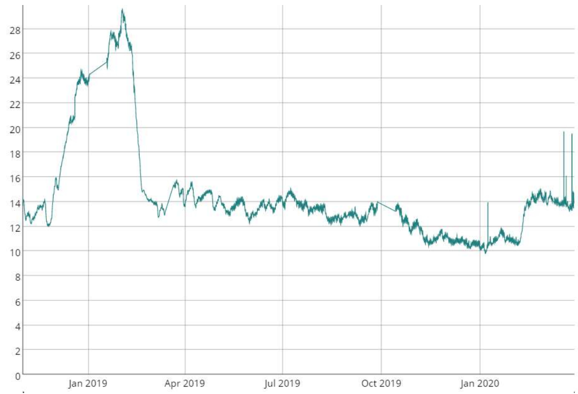
LV1 #4



LV2 #4



LV3 #4

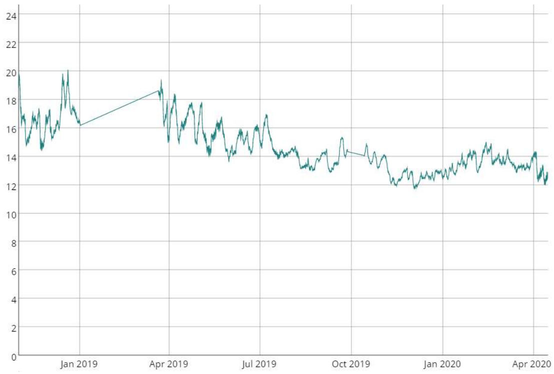


LV4 #4

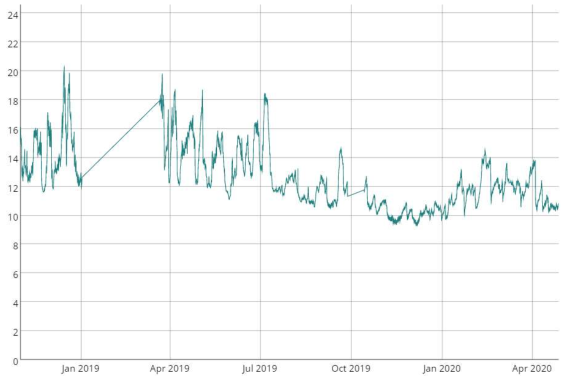
LV5 #4

Moisture Content Measured in the Hallways Position #B – CLT Floor Underside

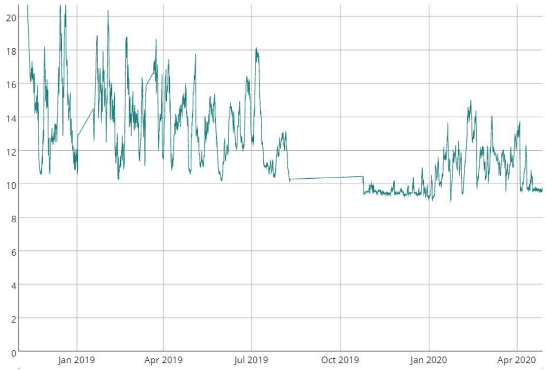
UG #B



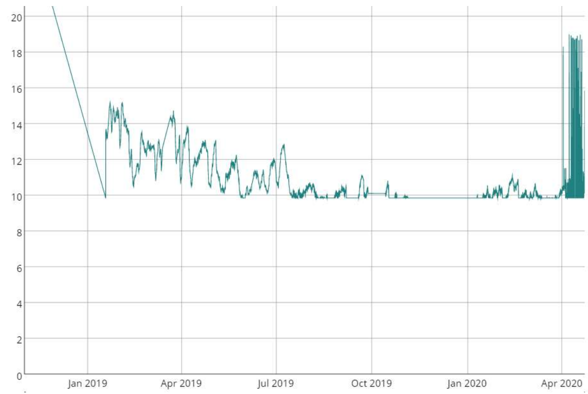
LV1 #B



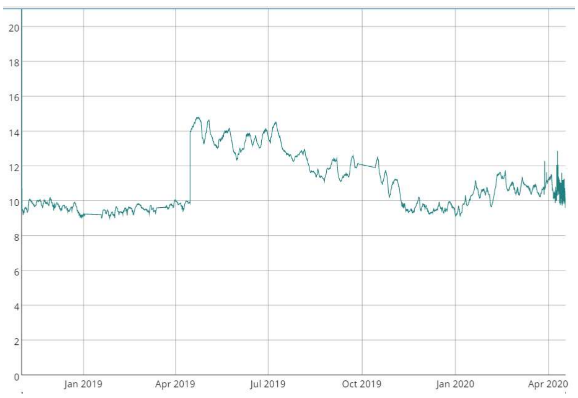
LV2 #B



LV3 #B

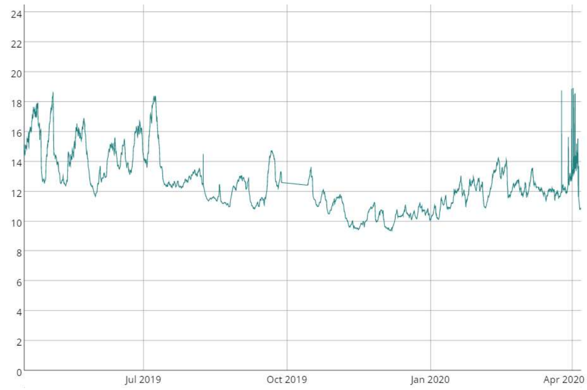


LV4 #B

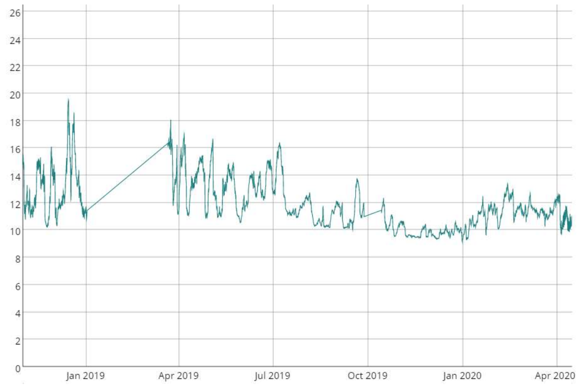


LV5 #B

Moisture Content Measured in the Hallways Position #C – CLT Floor Underside



UG #C

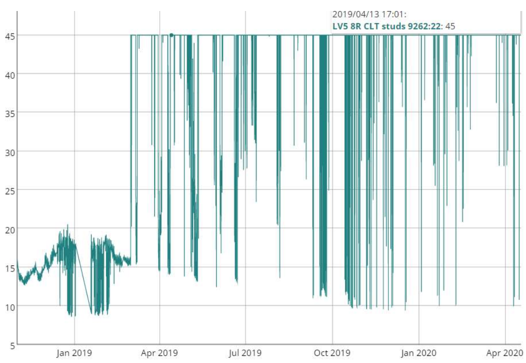


LV1 #C

LV2 #C

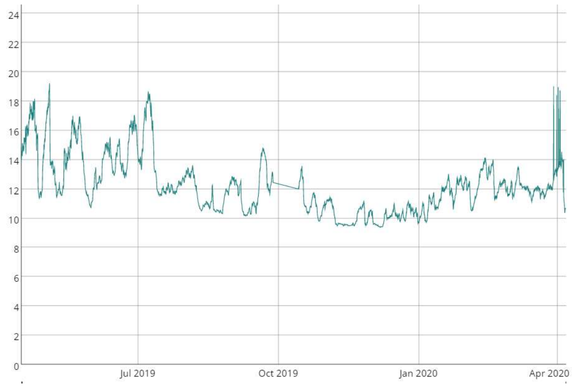
LV3 #C

LV4 #C



LV5 #1C

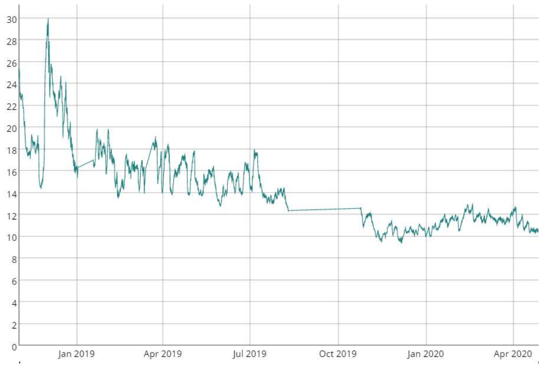
Moisture Content Measured in the Hallways Position #D – CLT Floor Underside



UG #D

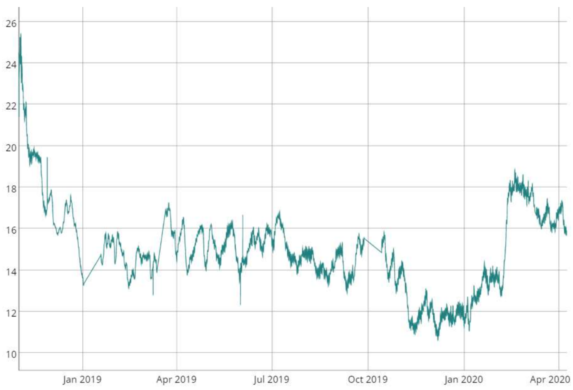
LV1 #D

LV2 #1



LV3 #D

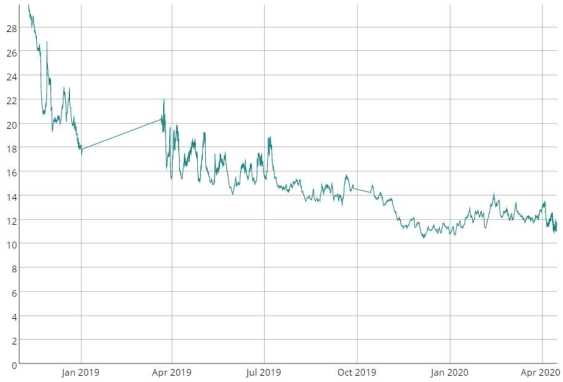
LV4 #D



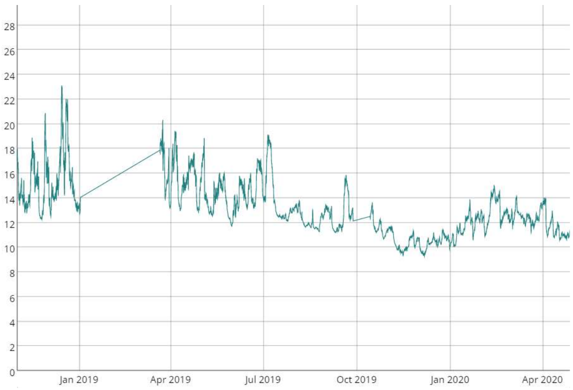
LV5 #D

Moisture Content Measured in the Garbage Room Position #A – CLT Wall

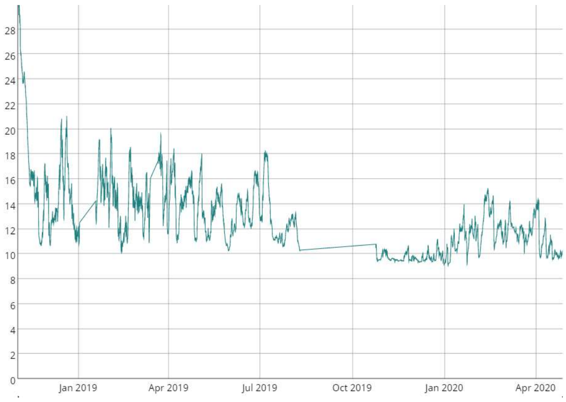
UG #A



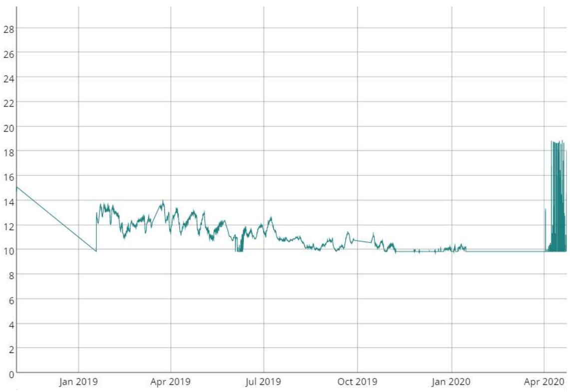
LV1 #A



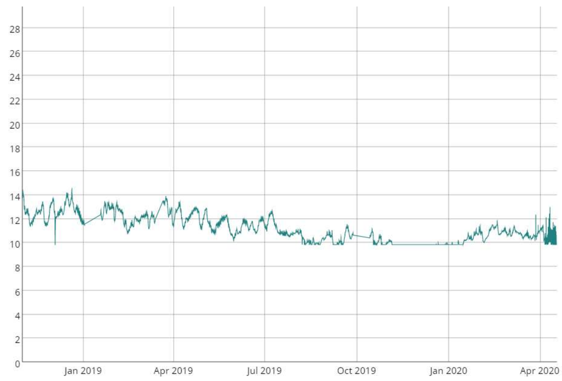
LV2 #A



LV3 #A



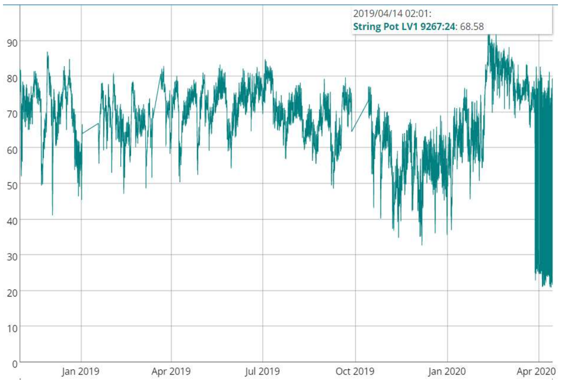
LV4 #A



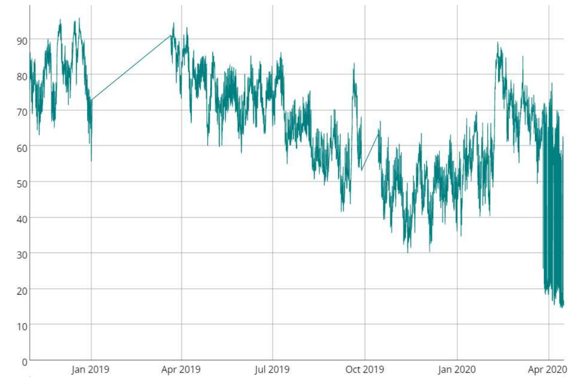
LV5 #A

Relative Humidy Measured in an Exterior Wall Facing North/East – Position #1

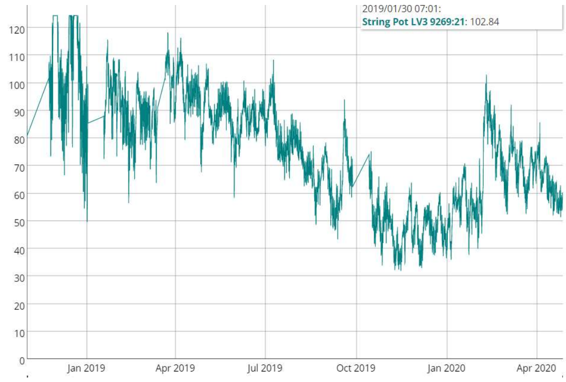
UG #1



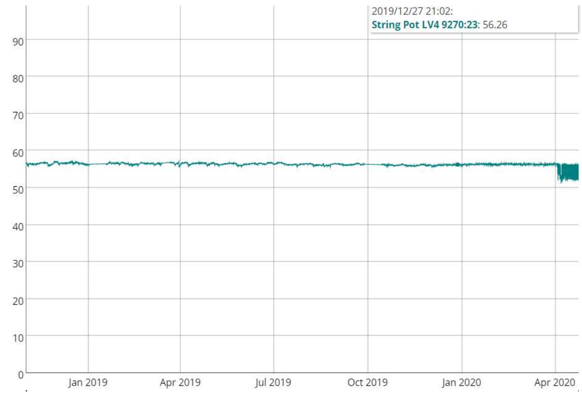
LV1 #1



LV2 #1



LV3 #1

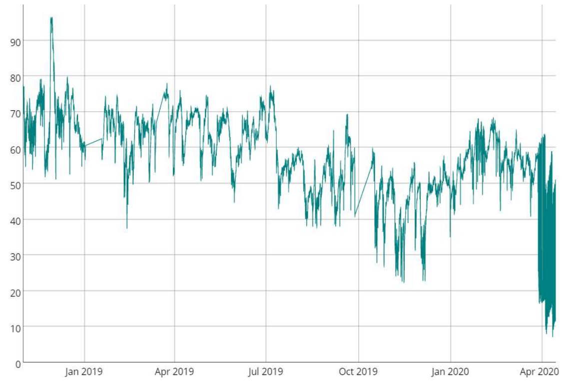


LV4 #1

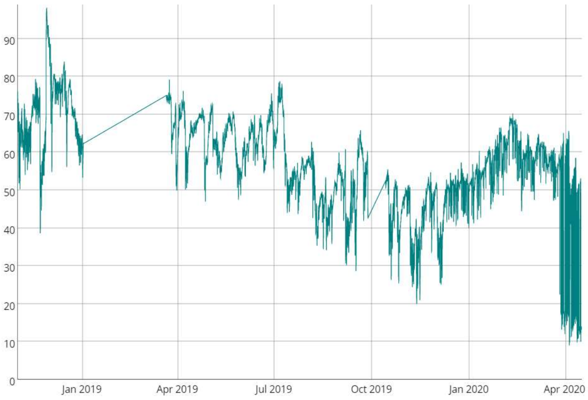
LV5 #1 – No Sensor

Relative Humidity Measured in the Wall next to the Hallway – Position # 2

UG #2 – No Sensor



LV1 #2



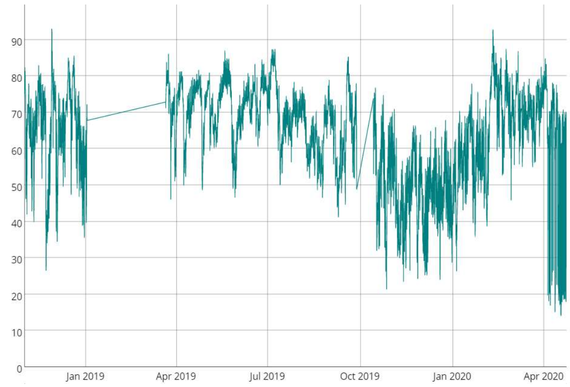
LV2 #2

LV3 #2

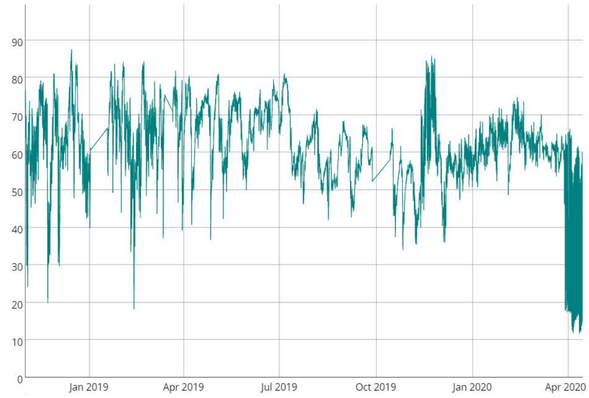
LV4 #2

LV5 #2 – No Sensor

Relative Humidity Measured in an Exterior Wall facing South/West – Position #4

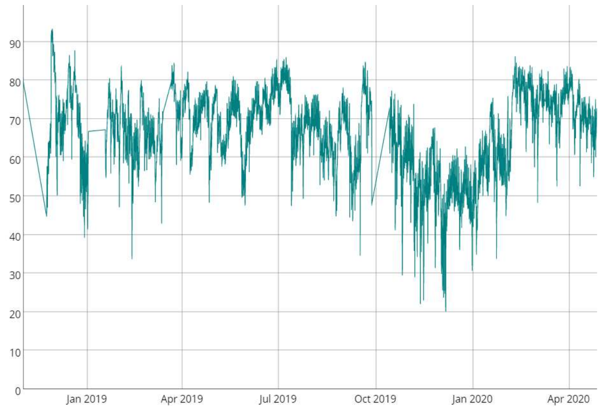


UG #4

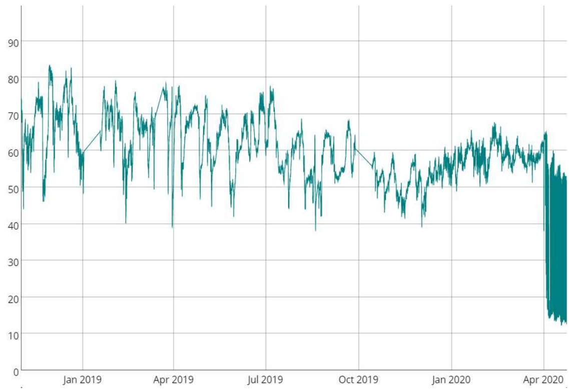


LV1 #4

LV2 #4



LV3 #4

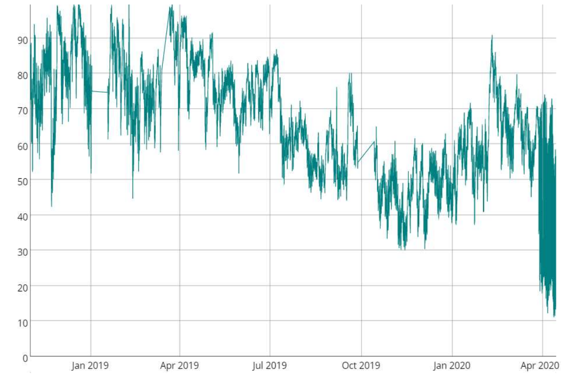


LV4 #4

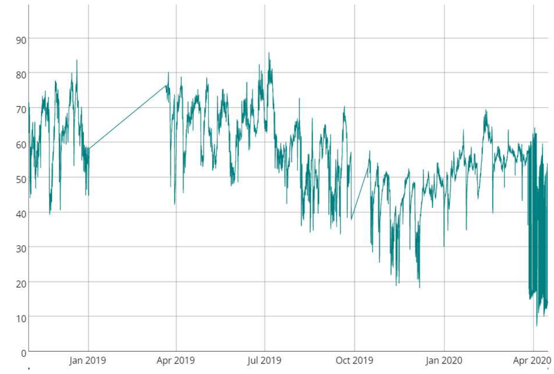
LV5 #5

Relative Humidty Measured in a Wall Positioned within an Apartment – Position #3

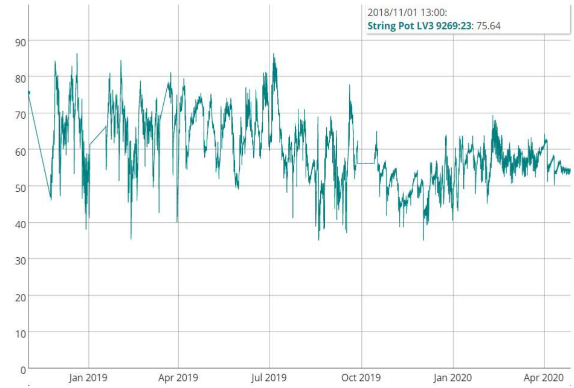
UG #3



LV1 #3

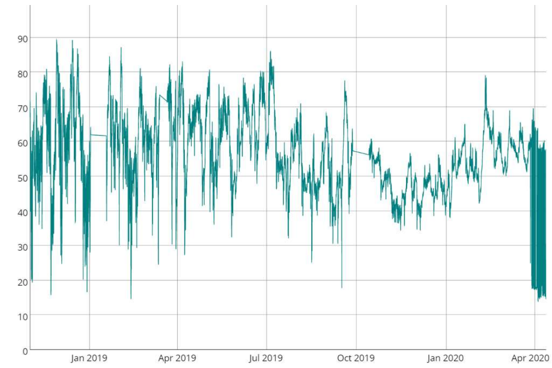


LV2 #3



LV3 #3

LV4 #3 – No Sensor



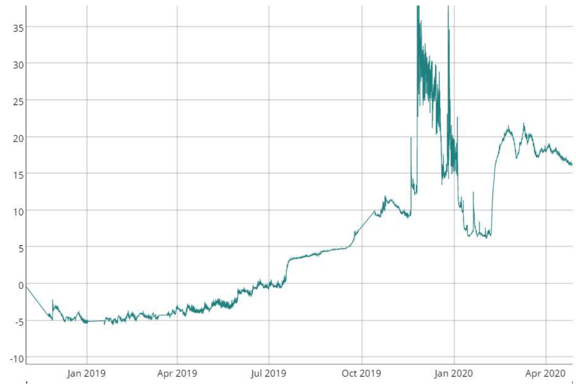
LV5 #3

Movement Measured in the Exterior Wall Facing North/East – Position #1

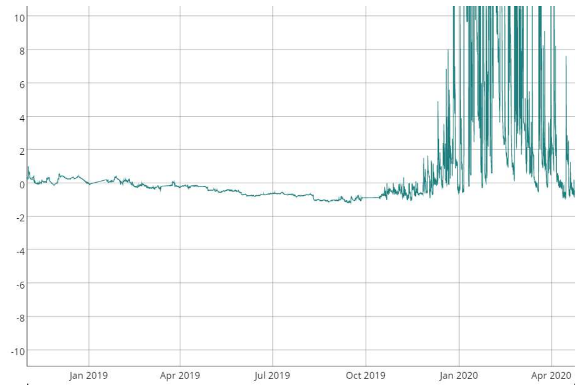
UG #1

LV1 #1

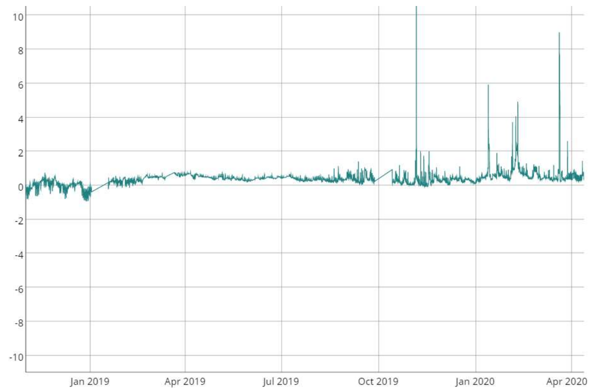
LV2 #1



LV3 #1



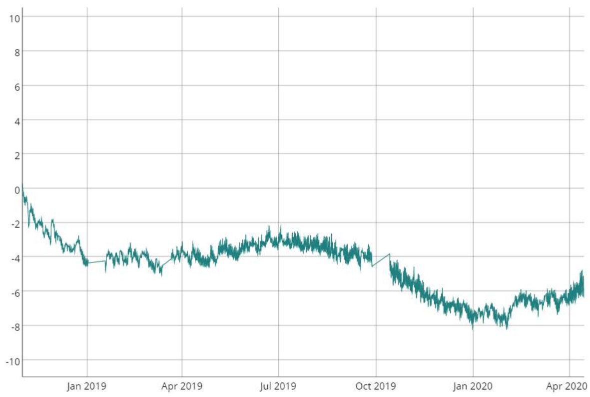
LV4 #1



LV5 #1

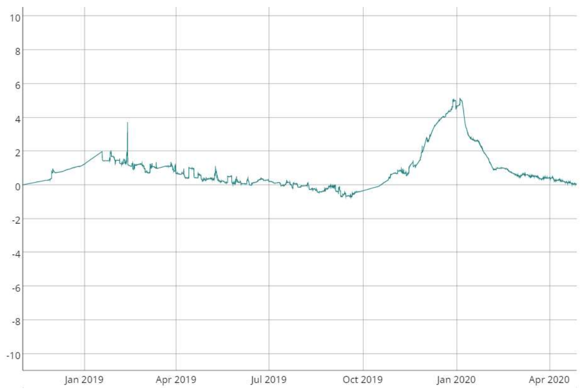
Movement Measured in the Wall next to the Hallway – Position # 2

UG #2

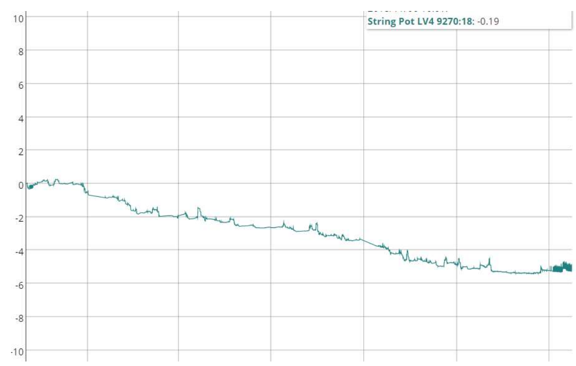


LV1 #2

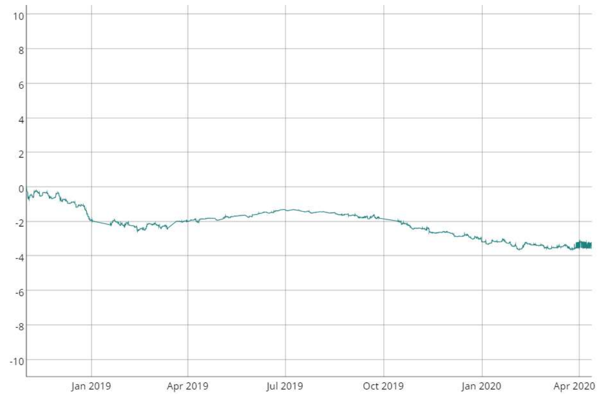
LV2 #2



LV3 #2



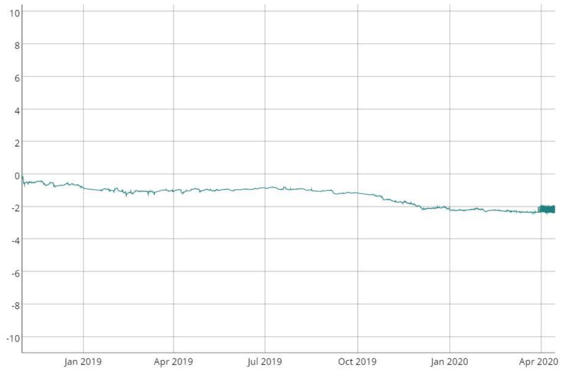
LV4 #2



LV5 #2

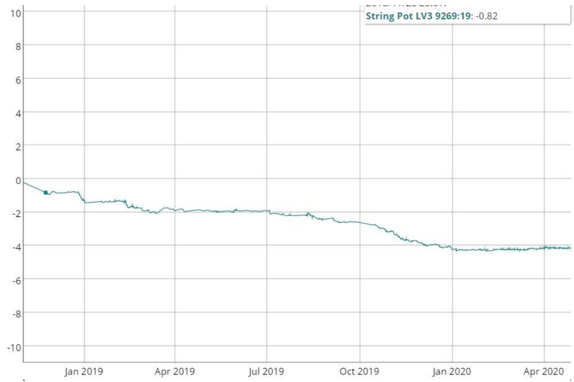
Movement Measured in a Wall Positioned within an Apartment – Position #3

UG #3



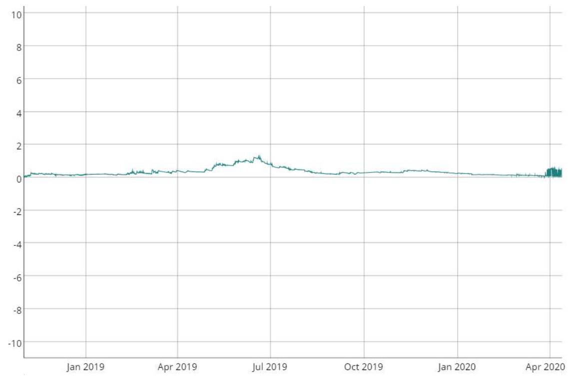
LV1 #3

LV2 #3



LV3 #3

LV4 #3



LV5 #3

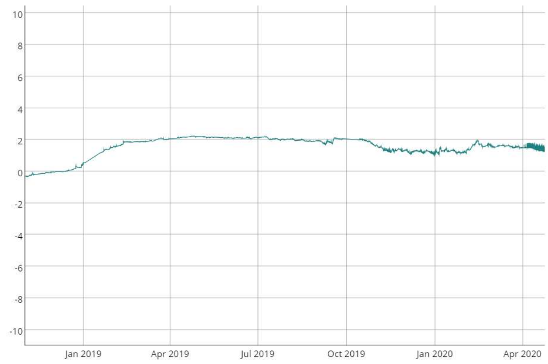
Movement Measured in an Exterior Wall Facing South/West – Position #4

UG #4

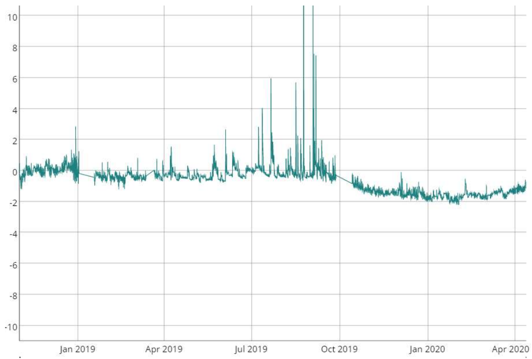
LV1 #4

LV2 #4

LV3 #4



LV4 #4



LV5 #4