THE INFLUENCE OF CAVITY VENTILATION ON THE PERFORMANCE OF BRICK VENEER PANELS WHEN EXPOSED TO WIND DRIVEN RAIN: AN EXPERIMENTAL ANALYSIS

by

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AUTHOR'S DECLARATION

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ABSTRACT

This study investigates the influence of cavity ventilation on the wind driven rain (WDR) performance of brick veneer walls. Two types of walls (type C and D) both bonded with N-type mortar were studied. The volume and frequency of WDR was based on weather station data from York University. Cavity conditions were mocked with a cavity chamber and ventilation was simulated with a fan providing air suction out of the cavity. Ventilation rates were simulated at 0, 5 and 10 ACH. Higher ventilation rates resulted in more efficient drying and lower RH within the cavity chamber. Wall type C exhibited more absorption with increased ventilation rates. Moisture content readings were generally irrelevant due to failure of the prescribed method. Measuring the influence of cavity ventilation on the amount of penetrated water should be further investigated by applying different ventilation rates to the same wall specimens to reduce the impact of physical variations within the same brick type.

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1.0 Introduction

1.1 Background

The cladding component of a rainscreen envelope system is the primary shield against weather elements. The principle function of this layer is to protect the building from bulk water infiltration. A common application of this system is the modern brick veneer cavity wall. Brick masonry has a history of strong performance as a cladding material, which consistently outperforms popular cladding systems such as EIFS, textured fiber cement and stucco (Basset & McNeil, 2007). However, water infiltration is inevitable and envelope design must address it. Water entry can be exacerbated by wind, which causes greater pressure differentials between the inner and outer layers of the envelope, thus pushing more water through the wall. A secondary system to block and remove water is a necessity. The air space behind the brick veneer provides drying potential. A drainage plane provides a surface for moisture to condense and drain to the exterior. According to the Ontario Building Code, the air space must be at least 50mm and shall be no greater than 350 mm as of January 1st 2015 for commercial walls. This space can be drained, vented or pressure-equalized. Typical drained cavities will have weep holes at the bottom of each wall section, while vented systems allow air to circulate in the cavity with vents at the top and bottom. Pressure equalization uses compartmentalization to reduce pressure gradients through the wall, however this phenomenon is not a focus in this investigation.

There is a wide assortment of brick available on the market, and three primary categories of mortar, type N, S and M. The physical characteristics of bricks will vary between types, but also within the same type. Porosity and connectivity of a brick will change over time, allowing it to absorb more water as it ages (Richman, personal communication, 2015). This influences the performance of the brick as it ages.

1.2 Research Objectives

This research paper addresses the influence of brick/mortar combinations and cavity ventilation on the performance of brick veneer walls under simulated wind driven rain (WDR) conditions. A rain delivery system was developed to simulate WDR. A chamber with artificial ventilation was attached to the back of a veneer wall to mimic cavity conditions. The objectives of this study were as follows:

1. To observe behaviour of veneer walls with two brick types under conditions of WDR.

2. To measure the drying capacities of brick veneer panels with three different ventilation conditions.

3. To measure moisture content changes in brick veneer walls during a series of wetting and drying cycles.

4. To determine a relationship between cavity conditions and the relative performance of brick veneer walls to WDR.

1.3 Research Questions

1. Does cavity ventilation at 5 and 10 air changes per hour increase absorption and decrease penetration through the wall specimens?

2. How does cavity ventilation influence the moisture content of brick veneer walls? How are initial, peak and final MC influenced by cavity ventilation?

3. Is there a negative relationship between cavity RH and ventilation? Is there a positive relationship between cavity ventilation and evaporation loss?

4. How effective is the study method in measuring the performance of brick veneer walls subjected to WDR?

1.4 Scope of Research

1. Reviewed current research while identifying the major factors influencing the performance of brick veneer panels subjected to WDR. The literature review included research from a broad spectrum of sources, and a detailed review of previous research performed at Ryerson University on the same wall specimens examined in this study.

2. Performed a review of weather data obtained from a weather station located at York University, Toronto Canada. The weather station reported averaged values over 5 minutes for wind speed and rainfall. Other information was available but not used for this study. The review period was from 2012 to 2014, which provided a basis for the volume of water delivered to the wall specimen.

3. Designed a new rain delivery system based on the findings in step 2. Constructed a cavity chamber to mock the conditions found in a typical 50 mm brick cavity wall. Designed and implemented a ventilation solution to mimic ventilated cavity walls.

4. Integrated rain delivery system and ventilation solution in a simulated wind driven rain test on two types of brick veneer panels. Panel type C brick was a standard 89 mm thick brick with moderate IRA (20.84 g/min/193.55 cm^2) (Ou, 2011) and type-n mortar. Type D brick was a thin veneer at 75 mm thick with a high IRA (33.76 g/min/193.55 cm^2) (Ou, 2011). Cavity chamber ventilation was simulated at theoretical values of 0 ACH, 5 ACH and 10 ACH.

1.5 Research Significance

This study is intended to enhance the current understanding of cavity wall design and the benefits of ventilated brick veneer cavity walls.

1.6 Research Organization

Section 2.0 – Literature review, which examines previous work and discusses relevant investigations as they relate to the investigation performed in this paper

Section 3.0 – A detailed description of the investigation process used in this paper. The main feature of the methodology is the development of an original experiment to test WDR performance of brick veneer panels.

Section 4.0 – A description of the test results with some analysis.

Section 5.0 – A comparative analysis of test results between the two wall types and to previous research at Ryerson University complete with concluding remarks summarizing the results.

Section 6.0 – This section discusses the trials and tribulations experienced by the researcher during the investigation process. It also discusses the sources of error and recommendations for future work.

2.0 Literature Review

A review of the current research was performed to ascertain a basis for the development of a new investigation on WDR and brick veneer panels. Information was gathered from a variety of sources including research performed using the same wall specimens examined in this investigation. The literature review covers WDR measurement, cavity ventilation rates and brick veneer wall performance in general.

2.1 Brick Veneer WDR Performance.

The performance and reliability of brick veneer has been studied extensively over the years. WDR has been studied at Ryerson University, with three major research projects conducted prior to this investigation. These three studies have provided insight into the performance of brick veneer panels specifically with regards to absorption and penetration quantities. The studies include Benjamin (2010, 2011), Ou (2011), Listerman (2012), Straka (2013) and Straka & Gorgolewski (n.d). Ou (2011) was the only researcher who investigated the same wall panels examined in the current study.

Benjamin (2010)

The objective of this study was to quantify the resistance to water penetration and amount of absorption of two different brick types A, and B. Type A brick is a Cortes Max 257 x 90 x 80 mm brick and type B is a Premier Plus, 257 x 75 x 80 mm brick. The author performed one series of tests following the ASTM standard E514. The author also performed an additional series of tests at a lower water flow rate and pressure than what is called for in the standard.

The author found the thinner brick (Type B) to have less water penetration than the thicker brick. This is likely because of the higher IRA brick had a stronger bond at the brick and mortar interface. The author further supports this theory by observing that water entering the back of the panel at joint locations did so sooner on wall type A.

In addition, reducing the flow and pressure differential to the wall resulted in a lower amount of water penetration through both wall types. The author concludes this is because once the brick became saturated, water was shed off the wall due to a lack of pressure gradient to push moisture through the wall.

Ou (2011)

A thorough review of the factors affecting water penetration and leakage of brick veneer walls is outlined in this MRP. The factors are as follows:

- Workmanship
- Rain-water deposition rate (rainfall intensity on vertical wall)
- Air pressure difference
- Brick unit dimensions
- Brick-mortar bond
- Absorption values of brick and mortar
- Initial rate of absorption value for brick

The author investigated water penetration and absorption of four different wall types. Wall types C and D are the same specimens used in the current investigation. The author performed water penetration test as per the ASTM E514 standard. The results show wall type D had the lowest amount of water penetration and a higher absorption than wall type C, despite being thinner. The author concludes the high IRA of brick type D (33.76 g/min/193.55 cm2) was matched appropriately to the high moisture retention property of mortar type-n, which allowed for a strong bond to form. This resulted in less penetration.

Wall type C had a moderate amount of water retention and penetration relative to the other wall types in the study. This wall type also has a relatively high IRA (20.84 g/min/193.55 cm^2) which according to the author meant a strong brick-mortar bond is formed with the type-n mortar. A flexural bond strength test further confirmed this theory.

Listerman (2012)

This author did not study the same wall specimens as that in the present MRP (Richards, 2016), however it did attempt to address the impact of sequential wetting cycles. Test standard ASTM E514 was performed on wall types A and B. Two pressures were used, 500 Pa and 120 Pa with three tests at each pressure. There was a 0 hour, 24 hour and 48 hour gap between each test. Conditions of the wall were not measured apart from specimen weight between tests.

The results showed wall type A has a significantly greater ability to prevent water penetration at lower pressure differentials.

2.2 Wind Driven Rain Measurement

WDR is the single most important factor effecting the durability of external building envelopes, specifically brick veneer. The quantification of WDR has been studied using a variety of methods over the years to develop frameworks for estimating WDR exposure on buildings.

Blockden and Carmeliet (2006)

These authors performed a review of the various measurement processes in place for WDR quantification. Semi-empirical and numerical methods are becoming increasingly popular after the turn of the century as a method to measure WDR. Computational fluid dynamics (CFD) is the current go-to method which has left a gap in the research available for actual measured WDR according to the authors.

One of the issues with current WDR measurement is a non-standardized approach to the manufacturing of WDR devices. There is no standard design for these instruments, which means they need to be custom made by individual researchers. The authors conclude this creates unnecessary variation among different research investigations. The majority of WDR measurement devices are plate type gauges, which come with a fair share of error. Water which lands on the plate and does not fall into the reservoir for measurement will evaporate and not be measured.

Blockden et al., (2010)

The authors outline the three mainstream models used for calculating WDR on walls, they are as follows:

i) Semi-empirical method employed by the ISO standard
ii) Semi-empirical model (SB model) developed by Straube and Burnett (1998)
iii) CFD model by Choi (1991, 1993, 1994)

The two semi-empirical methods are similar in terms of the WDR relationship. However, they differ significantly, as the ISO standard (used in this MRP) uses a constant “free-field” WDR coefficient of 0.222 m/s and the SB model uses a DRF, which is a stronger function of horizontal rain intensity.

Both semi-empirical methods are relatively quick to use but rely on several assumptions, which creates a reasonable degree of uncertainty regarding their accuracy. The authors conclude, CFD represents a more accurate method of estimating WDR because the semi-empirical methods have a difficult accuracy to predict.

CFD is too complex and too expensive a process, which could not be performed in the timeframe of this research investigation. An earlier semi-empirical method, which the ISO standard is based on, was used in this investigation. The equation is as follows;

$$R_{wdr} = 0.222 \ x \ U \ x \ {R_h}^{0.88}$$

The application of this equation is discussed in section 3.1.2 of the methodology section.

2.3 Cavity Ventilation

Envelope design is the primary factor, which influences the ventilation profile within a cavity wall.

Bassett and McNeil (2005, 2007)

These two authors investigated cavity ventilation rates in seven different envelope designs, including brick and cement cladding. They opted for the gas tracer method to measure the flow of air through the cavity. The wall panels were 1.2 m x 2.4 m in dimension. The three configurations of ventilation were:

i) Drained and vented – deliberate opening at top of panels to allow airflow down the cavity and a drainage plane at the bottom
ii) Open rainscreen – similar to the drained and vented but does not have deliberate openings at the top of the panel. This relies more on infiltration
iii) Drained – the cavity is designed only to drain water.

The authors measured ventilation air in the drained and vented wall to travel at 1.4 l/s.m. They believe open rainscreen design may have similar ventilation performance to drained and vented systems. Measured ventilation rates are always higher than what was calculated through theoretical values because of air infiltration. The authors were able to factor in these leakage rates through pressurization testing for open rainscreen systems.

Straube and Finch (2009)

This study investigated cavity ventilation through measurement and hydrothermal modelling. The four types of cladding studied were stucco, wood siding, vented brick veneer and metal panels with slot vents. Test huts were constructed to examine each wall type. Modelled stucco rainscreen and wood rainscreen systems had very high ventilation rates (300-500 ACH) at low pressures (1 Pa). The brick veneer had low ventilation rates, approximately 4 ACH. Measured ventilation rates in the brick veneer cavity wall had an average of 2.3 ACH on the South side of the hut and 2.1 ACH on the North side. Maximum ACH reached 9.6 ACH on the South side and 8.4 ACH on the north.

Ge et al., (2009)

The authors constructed six brick veneer test walls with two different variables of wall height and vent size. The indoor conditions were controlled at 22 degrees Celsius and 55% RH. Moisture content, temperature, relative humidity, and pressure differentials were all measured. Hot sphere anemometers were used to measure air speeds.

One storey test walls had an hourly average ACH of 6 and a maximum ACH of 10. The two storey specimen had an average of 4 ACH and a maximum of 6 ACH. These results fall into the same range measured by Straube and Finch (2009). Air velocities within the six cavities ranged from 0.03 m/s to 0.23 m/s depending on the type of vent configuration.

It became clear early on that is was not practical to control the ventilation rates by targeted cavity air velocity in this MRP. The author was limited to one hot-wire anemometer which had to be manually held in place to take measurements. Controlling the ACH through suction was determined to be a more practical approach to simulating ventilation air.

2.4 Summary

The literature review has revealed some gaps in knowledge from previous investigations. Moisture content was not addressed in any of the previous research studies at Ryerson University. In addition, all investigation used the ASTM E514 standard which is really a stress test for water penetration and does not reflect typical rainfall conditions found in Toronto, Canada. Moreover, previous work has not addressed any of the layers typically found behind the brick veneer. In the proposed investigation here, a cavity chamber was constructed to mimic a cavity wall.

The review has provided a basis for the theoretical calculation of WDR, cavity ventilation rates and physical properties of the wall specimens.

3.0 Methodology

3.1 Introduction

Weather station data was reviewed to determine the volume and frequency of water delivered to the wall specimens. A WDR simulation apparatus and chamber were constructed to mock WDR and cavity space, respectively. A fan provided air suction out of the cavity at three ventilation rates of 0 ACH, 5 ACH and 10 ACH. The WDR test consisted of two phases; the first phase consisted of five wetting cycles 15 minutes in length, separated by 40 minute drying cycles. The second phase was a prolonged drying period 43.5 hours in length, extending the entire test length to 48 hours. Each of wall type had three replicates, with one replicate receiving a treatment of one ventilation rate. Performance was measured via absorption, deflection (blockage), penetration, evaporation, moisture content and cavity temp/RH.

3.2 Test Specimen

Six wall specimens were investigated in this report, three replicates of each wall type. “Wall specimen” shall refer to the area of brick and mortar exposed to simulated wind driven rain. The brick and mortar specifications are as follows:

	Type C	Type D
Average Brick Dimensions	189mm x 90mm x 58mm	245mm x 75mm x 70mm
Average % Void	23%	13.60%
Average Weight of single brick (kg)	1.399	2.383
Average brick IRA	15.8	29.1
Mortar	N-type	N-type

Table 1 – Wall specifications extracted from manufacturers reports

The dimensions of each wall specimen are approximately 1.58 m x 1.40 m. Previous tests on the walls required a parging layer be placed on the exterior perimeter of the wall. This left an area of 1.06 x 1.06 m^2 available for testing. The walls are supported by two TJI members held in compression to each other on the top and bottom surfaces of the wall surface. Long steel bolts were tightened between the TJI members and compressed the wall specimen. Once the wall was in place, a steel angle was screwed to the top of the TJI and to a ledge support on the interior wall of the lab, providing lateral support to the specimen and preventing tipping during the experiment.

3.2.1 Test Nomenclature

3 x 2 Factorial		
	Wall Type	
Ventilation Rate	**189mm x 90mm x 56mm, N-type mortar (Type C Wall)**	**249mm x 75mm x 70mm, N-type mortar n (Type D Wall)**
No Vent	C3_NoVent_V1 C3_NoVent_V2 C3_NoVent_V3	D1_NoVent_V1 D1_NoVent_V2 D1_NoVent_V3
5 ACH	C1_5ACH_V1 C1_5ACH_V2 C1_5ACH_V3	D3_5ACH_V1 D3_5ACH_V2 D3_5ACH_V3
10 ACH	C2_10ACH_V1 C2_10ACH_V2 C2_10ACH_V3	D2_10ACH_V1 D2_10ACH_V2 D2_10ACH_V3

Table 2 – Test factors and nomenclature

The nomenclature for each test consists of three components: the first letter-number combination indicates the wall type and specimen number, the second term indicates the ventilation rate and the third letter-number combination represents the test version or repetition number. For example, D3_5ACH_V2 is wall type D, the third replicate, 5 air changes per hour and the second test repetition.

3.3 Design of Test Equipment

3.3.1 Water Delivery System

The phenomena considered in this research are the co-occurrence of wind and rain, and cavity ventilation. Listerman (2012) looked at random sets of daily rainfall data from Environment Canada and concluded that rainfalls in clustered periods. This led the author's experimental set up to include the 0h, 24h and 48h drying periods between tests. After further review of sub-hourly weather data from York University, it can be said that rainfall is sporadic throughout the day and varies in intensity. The periods for drying between rain events are often much smaller than one or two days. The periods can range from 5 minutes (reporting limit of the weather station) to 8 hours. This is an important function to incorporate when using averaged weather data.

The previous investigations on the wall specimens used in this study involved pressurized conditions at 120 Pa and 500 Pa. This simulates wind speeds of 50 km/h (13.8 m/s) and 100 km/h (27.7 m/s), respectively. The amount of water applied to the wall specimens was 155 l/hr. The test length was 4 hours. They were tested according to ASTM E514. The amount of water and simulated wind, which is applied in this test, represents an extreme weather event. In reality, wind and rain occur simultaneously, however more sporadically and with varying intensities on a minute-to-minute basis. This requires weather data, which is averaged over less than one-hour increments. Smaller increments will provide more accuracy when correlating wind and rain. For instance, in one hour, there may be an average of 5mm horizontal rainfall and 5 m/s average wind speed. The rain may not fall evenly over the one hour; it may come in short bursts along with the wind. The only way for rain to fall on a vertical wall is for it to be "pushed" by the wind. This requires the co-occurrence of wind and rain. The average wind speed may be 5 m/s but if it is not simultaneously occurring with rain, no water is deposited on the walls, or there is a significant variation in the amount of water which arrives on the wall. In summation, it is not appropriate to use hourly averaged weather data as this will cause a significant underestimation of the volume of water deposited on vertical surfaces. Averaged hour weather data disregards the co-occurrence of wind and rain (Blocken & Carmeliet, 2010). The amount of water and length of wetting period was determined by a review of the weather data from York University. The most extreme rain event during the study period was calculated to reach 87 l/hr at the wall surface area on July 31st 2012. The new distribution grid used for water delivery in the proposed experiment could not supply water at a rate of less than 100 l/hr without causing the nozzles to drip and the water to lose its horizontal displacement. The rate of water used required in this experiment is higher than the highest calculated value during the weather review period however; it does represent a possible wetting scenario.

The drying periods were originally designed to reflect the variability in wetting periods throughout a 24-hour period. The original intent of the experiments was to have multiple drying periods at varying lengths, to mimic the sporadic nature of rainfall. For instance, the drying cycle would start at 5 minutes and double in length after each wetting cycle until 160 minutes was reached. After mock tests were performed, it became clear the required time to perform all the necessary measurements between wetting cycles was 40 minutes. In addition, 40 minutes was needed to quantify any differences in wall specimen weight during the course of the drying intervals. The equipment was unable to pick up any change in weight during the short intervals. This made the short intervals irrelevant. 40 minutes was chosen as the single drying cycle length to accommodate all the measurements and simplify the experiment. A full list of revisions made to the original experimental setup can be found in Appendix D.

The amount of water flow during the wetting period was chosen to remain constant. Varying the flow requires significantly more sensitive equipment than what was used in this investigation. The total amount of water provided would have differed significantly between tests thus limiting the validity of the experiment.

3.3.1.1 Weather Station Data

The coordinates and elevation of the weather station are 43.7753N 79.5100W and 198m respectively. It is located to the North of downtown Toronto at York University. It is managed by the ESSE (Department of Earth Space Science and Engineering). The station monitored a number of climatic conditions such as air temperature, wind speed, horizontal rainfall, and snow depth. The two datasets used in this investigation are wind speed and horizontal rainfall. Figure 1 shows the station and its immediate surroundings.

Figure 1 – ESSE weather station with immediate surroundings. There are no buildings in the immediate area to affect measurements

Weather data from 2012 to 2014 was reviewed to provide a basis for the amount of water which was delivered to the wall, and the length of time for drying between delivery cycles. The three variables pulled from the weather station data were time of day, 5 min average precipitation and average wind speed. Wind direction was ignored because wind was assumed to be acting perpendicular to the wall specimen for flow calculations. Horizontal rainfall was sorted from high to low to determine which reporting periods had the largest volume of rainfall. Days which consisted of the highest volume of rainfall were prioritized. The corresponding time of day and wind speed were pulled from the dataset and used to calculate the amount of water which falls on a vertical surface.

3.3.1.1.1 Analysis

Table 3 represents a summary of the weather station data review. April to October was the focused time period as months falling outside this time period have increased snowfall as precipitation, and thus were not applicable to this research. The values presented in the table were calculated from days in which a rain event occurred. Wind speed values were not included for days which experienced no rain. However, wind speed values are present for non-raining periods within a designated rain event day.

	2012			**2013**			**2014**		
Month	**Rainfall (mm)**	**Avg Wind speed (m/s)**	**Avg wind speed w/ rain (m/s)**	**Rainfall (mm)**	**Avg Wind speed (m/s)**	**Avg wind speed w/ rain (m/s)**	**Rainfall (mm)**	**Avg Wind speed (m/s)**	**Avg wind speed w/ rain (m/s)**
April	32.4	3.41	4.80	89.9	3.49	3.23	83	3.61	3.90
May	38.5	2.01	1.48	90	3.00	2.95	45.2	2.35	2.45
June	75.4	2.65	3.95	129.8	2.57	2.57	62.4	2.29	2.50
July	93.8	2.39	2.25	134.4	2.10	1.86	118.6	2.60	2.63
August	51.7	2.32	1.98	80	1.96	1.72	62.7	1.96	2.50
September	92.7	1.66	2.11	74.1	2.12	1.97	113.6	2.53	2.64
October	98.5	3.02	3.32	82.4	2.62	2.92	97.2	2.34	2.10

Table 3 – Monthly averaged rainfall and wind speeds during weather review period

The month with the largest volume of rainfall over the three years was July, while the month with the smallest amount of rainfall was May. The same two months also hold the highest and lowest average rainfall. Average wind speed was calculated for the full length of the rain event. In addition, the average wind speed was calculated during simultaneous occurrence of wind and rain. Average wind speed was slightly higher during rain events. The number of months with higher wind speeds during co-occurrence of wind and rain was twelve. Nine months had higher average wind speeds during periods with no rain.

3.3.1.1.2 Determination of WDR

In this investigation, the term "flow" is used as a synonym for "calculated wind driven rain". Flow is the volume of water which was applied to the wall specimens. The basic relationship used to determine the amount of wind driven rain on a vertical surface can be determined by; (Lacy, 1965; Hoppestad S., 1955)

$$R_{wdr} = \frac{U}{V_t}\, x\, R_h \quad (1)$$

where u is the wind speed (m/s), V_t (m/s) is the raindrop terminal velocity for a specific diameter and R (mm/h) is the horizontal rainfall intensity. This relationship assumes the wind is acting perpendicular to the wall, and there is no interference from other surfaces which may alter the airflow. This is known as the "free-field" calculation method (Blockden & Carmeliet, 2010). The use of V_t as a variable, limits the calculation to a specific diameter of rain drop. Raindrop size can range from 0.5 mm to 5 mm in diameter (Horstmeyer, 2008) and thus, equation (1) would need to be repeated for each size of rain drop to accurately represent a typical raindrop size distribution. The median raindrop size can be described as a function of horizontal rainfall intensity and terminal raindrop velocity through Equation (2); (Lacy, 1965)

$$R_{wdr} = 0.222\ x\ U\ x\ {R_h}^{0.88} \quad (2)$$

The median raindrop size is expressed as a constant in equation (2), which is based on empirical measurements made from real wind-driven rain gauges. The implementation of equation (1) would require separate calculations for each size of raindrop, therefore making the process inherently more complex. To simplify the process, equation two was used to calculate the amount of water which would be delivered to the wall specimens.

Table 4 summarizes the method used to calculate wind driven rain. The sample day of July 31st 2012 was selected because it had rainfall intensities which were closely matched by the WDR simulation equipment. The original intent was to simulate WDR at flow rates of less than 50 L/hr, based on the weather station data, however this was not possible with the available equipment. The lowest flow rate which could be effectively simulated was 100 L/hr.

Data from York University weather station				WDR	Flow to wall specimen	
Time of day	Horizontal Rainfall (mm) or	Rainfall intensity (mm/hr) or R_h	Wind Speed (m/s)	WDR on vertical surface (mm) or R_{wdr}	(l/hr)	(l/5 min)
17:00	5.3	63.6	5.89	50.53	56.77	4.73
17:05	9.6	115.2	5.354	77.47	87.04	7.25
17:10	5.7	68.4	6.902	63.12	70.92	5.91
17:15	4.9	58.8	2.87	22.98	25.82	2.15
17:20	2.2	26.4	2.107	8.34	9.37	0.78
17:25	0.2	2.4	2.888	1.39	1.56	0.13
17:30	0.1	1.2	1.789	0.47	0.5	0.04
17:35	0.2	2.4	1.7	0.82	0.92	0.08
17:40	0.1	1.2	1.965	0.51	0.58	0.05

17:45	1.9	22.8	3	10.43	11.73	0.98
17:50	0.2	2.4	2.908	1.39	1.57	0.13

Table 4 – Outine of processing horizontal rainfall and windspeed to WDR on a vertical surface

The horizontal rainfall in mm was obtained from the weather station. The horizontal rainfall was converted to intensity (mm/hr) through multiplying by a factor of 12. The amount of rain which falls on a vertical surface is described in the WDR column, an application of equation (2). The volume of water per hour on a vertical surface area is calculated in the next column by multiplying R_{wdr} by the surface area. The wall specimens in this research investigation had a surface area of 1.1236 m^2. These volumes become the flow requirement for the water distribution grid. The last column converts the volume per hour back to 5-minute intervals to demonstrate the amount of water which falls on a vertical surface during one 5 minute interval on the weather station.

3.3.1.2 System Components

The water delivery system consists of two main components; supply and distribution. The materials are as follows:

Supply Side:

- Standard 3/8” (9.5 mm) garden hose
- Standard 3/8” (9.5 mm) male to female hose fittings
- 25 PSI (172 kPa) faucet to hose water pressure regulator
- Magic Flow Minimag E416 Display/Transmitter Unit
- Inline 3/8” (9.5 mm) shut-off valve

Distribution Side:

- 3/8” (12.7 mm) t-faucet connectors
- ½” (12.7 mm) header hose
- ½” (12.7 mm) header compression end
- ½” (12.7 mm) straight connectors
- ¼” (6.35 mm) feeder hose
- ¼” (6.35mm) feeder t-connectors
- ¼” (6.35mm) feeder straight connectors
- ¼” (6.35mm) feeder plug
- Variable flow misting heads by Lee Valley ™ (0-5 GPM)

- 40” x 40” (1m x 1 m) welded wire mesh grid
- 8’ perforated steel L angles
- 4 x nut, bolt and washer combinations
- Steel trolley with wheels
- Counterweights as needed
- GE Silicone II ™ Waterproof Silicone Sealant

The header and feeder hose connections were press fitted. A heat gun was used to temporarily enlarge the PVC hose and make connections easier. A hot air gun was used to straighten the hose. The misting heads were tested to examine their spread pattern. A typical spread at 30 cm is shown in FIGURE 2.

Figure 2 – spread pattern from Lee Valley misting head at 30 cm, 25 PSI

This pattern was used to determine the number of misting heads required to provide an even spread of water to the wall specimen area. Twelve misting heads were chosen to provide the coverage. All joints on the distribution side were sealed with silicone waterproof sealant.

Initial spread tests showed that the center area of the wall would receive larger amounts of water compared to the edges when the misters were placed at even intervals. This is because of the overlapping spread patterns which occur in the center, and not on the edges. It was decided to decrease the gap between misting heads near the edges, and increase the gap near the center. This resulted in a rectangular grid configuration.

3.3.2 Cavity Construction and Ventilation

A modular unit was constructed to provide an airtight chamber at the back of the wall to simulate a cavity. A sheet of acrylic glass was cut to 1.10 x 1.10 m and screwed to a 2" x 4" notched wood frame. 50 mm thick Styrofoam™ insulation was adhered to the perimeter of the glass with doubled sided foam tape. The insulation provided the air space gap between the acrylic sheet and the back of the wall specimen. The frame was clamped to the wall to provide the seal. Each wall surface had to be prepped before clamping as mortar droppings hindered to ability to create an air seal. The full sheet minus the width of the foam perimeter resulted in a 1.06 x 1.06 m sheet of acrylic which is the same dimension as the wall which is exposed to water. The bottom piece of insulation was removed as mock tests showed water collecting on the bottom insulation rather than falling to the cloths. The exterior perimeter was sealed with adhesive putty. The cavity frame and sealing can be seen in Figure 3.

Figure 3 – Cavity frame with putty adhesive acting as an air seal. Note the eyehole punched through the insulation, this was used for air velocity measurements.

3.3.2.1 Ventilation Strategy

Ventilation air was simulated by introducing air at lab conditions through a small opening at the top of the cavity. This opening was cut to 1.5 cm x 5 cm. A small USB powered fan was placed and centered within a 101mm diameter PVC pipe fitting. This unit was placed overtop the top vent with the fan positioned to blow air at the ceiling, thus creating air suction out of the cavity. See FIGURE 4 below.

Figure 4 – Components of suction system used to simulate ventilation air

A small hole was drilled into the side of the PVC pipe to feed through the USB power cord. The hole was sealed with putty adhesive.

The fan initially provided a considerably larger amount of airflow than what was required to meet the typical ACH found in brick veneer cavity walls. A paper shutter was used to vary the amount of suction which was applied to the cavity chamber. The shutter was moved across the opening to reduce the amount of exterior vent area which was exposed to the suction forces of the fan. Please see FIGURE 5.

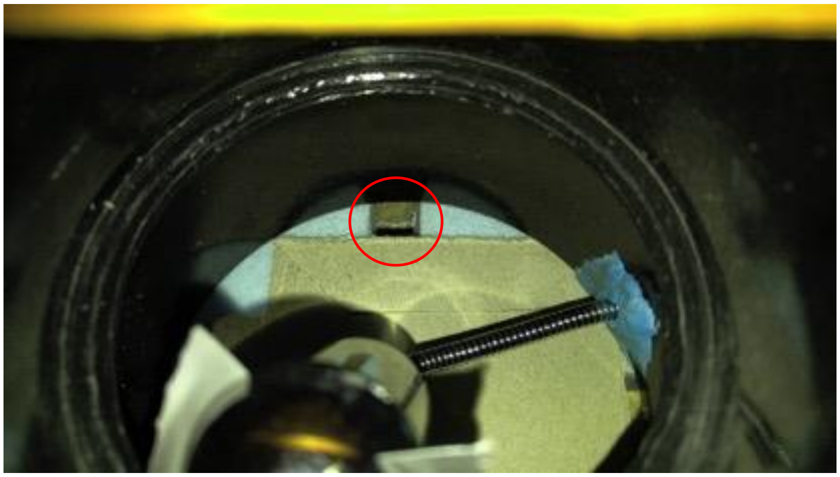


Figure 5 – Interior view of ventilation device. The grey paper is the shutter which can be shifted to change the size of the exterior vent. The red circle shows the vent hole which leads to the cavity chamber.

A hot-wire anemometer was used to measure the air speed at the exit vent. Figure 6 shows locations where measurements were taken. The instrument used was the VelociCalc Air Velocity Meter Model 9515 by TSI™. The device has a velocity range of (0 to 20 m/s) with an accuracy of ±0.025 m/s or 5%, whichever is greater.

Figure 6 – Hot-wire anemometer probe at position closest to backside of wall specimen. Three measurements taken at vent opening and an average used for ACH calculations.

The ventilation device was used to manipulate the velocity of air exiting the cavity. This in turn enabled the air changes per hour (ACH) within the cavity to be adjusted to the desired value. The following steps show the relationship between exit vent air velocity and ACH;

$$Volume\ of\ cavity\ chamber = 1.06\ m\ \times 1.06\ m\ \times 0.05\ m = 0.05618\ m3\ (1\ air\ change)\ (3)$$

$$@10\ ACH,\ 0.05618\ m3\ \times 10 = 0.5618\ m3\ (10\ air\ changes)\ (4)$$

The mass flow of air out the exit vent is set to be equal to the desired air changes per second (expressed as volume of air), as calculated in equation (4). The air speed at the vent is set as “x” and then solved for:

$$length\ \times width\ \times air\ speed\ at\ vent\ \left(\frac{m}{s}\right) = air\ changes\ per\ second\ (5)$$

$$0.015\ m\ \times\ 0.05\ m\ \times x\ = \frac{0.5618\ m3}{3600}$$

$$x = 0.208\ m/s$$

The calculated air speed at the exit vent was 0.208 m/s, to reach 10 ACH within the cavity chamber. This number is halved to 0.104 m/s to reach 5 ACH. The grey shutter was shuffled across the opening while air speed measurements were taken, until the desired air speed was achieved. Once the position of the ventilation device was set, a C-clamp was used to lock everything in place.

Initial trials and air velocity measurements revealed a small current of air was travelling through the top vent when no simulated ventilation air was occurring. Measured air speeds varied from 0.01 m/s to 0.04 m/s. It was determined that the local diffuser on the mechanical system was blowing air across the top of the wall specimen and interfering with the cavity conditions.

3.4 Test Setup

Figure 8 – Wall specimen with cavity chamber

Figure 7 – Water delivery grid

The test set up includes the wall specimen with cavity chamber attached on the rear, and the water distribution grid.

3.5 Testing Procedure

3.5.1 Sequence

The test started after the initial weighing of the wall specimen. The test had two primary stages. The first was a wetting phase consisting of 15 minute wetting separated by drying periods of 40 minutes. The second phase was a 43.5 hour drying phase. The entire length of each test was 48 hours. The schedule can be seen below in Figure 9. The wall specimens sat in lab conditions for 24 hours between tests.

	Phase 1										Phase 2			
Interval Length (min)	15	40	15	40	15	40	15	40	15	40	720	720	720	720
Water	on	off	on	off	on	off	on	off	on	off	off	off	off	off
Elapsed Time (min)	15	55	70	110	125	165	180	220	235	275	720	1440	2160	2880

Figure 9 – Test schedule showing phase 1 and phase 2 of the experiment

3.5.1.1 Procedure

1. Initiate data loggers
2. Clamp chamber to back of wall.
3. Weigh wall specimen prior to initial wetting. Record moisture content.
4. Record date, time, temperature, relative humidity and reference point on flow meter.
5. Apply water at constant rate of 100 l/hr for 15 minutes. Total volume delivered should be 25 L.
6. Weigh wall immediately after 15 minute wetting period (three times for accuracy).
7. Record time, temperature, and cumulative flow.
8. Measure amount of water which was shed by the wall specimen. Weigh cloths for penetrated water.
9. Wait for allotted drying period according to testing schedule.
10. Weigh wall again after drying period for evaporation and drainage loss (three times for accuracy).
11. Repeat steps 3 to 8 as per test schedule until 5 intervals of wetting and drying have been completed.
12. Record specimen weight and moisture content every 12 hours from beginning of test for two days total

3.5.2 Measurements and Instrumentation

3.5.2.1 Water Blockage, Absorption, Penetration and Evaporation

The amount of water applied to the wall was theoretically 125 L over the test period. Metal flashing was installed at the bottom of the exterior face of each wall to direct water that was not absorbed or deflected by the brick wall. The flashing was attached to the wall specimen at three locations with anchors and masonry screws. Waterproof silicone was used to seal the upper lip of flashing to the wall. This is depicted in Figure 10.

Figure 10 – Flashing and trough showing drainage path of deflected water

The water flowed off the flashing into a trough which drained to a bucket. The bucket was weighed to determine the amount of water which drained off the exterior side of the wall.

Weighing the wall immediately before and after wetting was performed to determine the amount of water absorbed by the wall. An additional weighing was performed after the drying period to determine the amount of water which was lost from evaporation, and this value became the new starting weight for the next wetting cycle. The amount of moisture lost during the drying cycle was a significant factor in determining the effectiveness of cavity ventilation

Water, which penetrated through the brick veneer, was measured by weight with a moisture absorbent cloth which lined the bottom of the cavity. Penetrated water would make its way down the backside of the wall. The bottom piece of insulation was intentionally removed from the cavity chamber frame to allow any water which dropped off the mortar to be collected. The cloths were weighed before and after each wetting cycle to determine the amount of liquid water penetration.

The materials and instruments used for the measurements were as follows:

	Type of Measurement		
	Blockage	**Absorption/Evaporation**	**Penetration**
Materials	1 x 50 mm x 50 mm L angle flashing	Pump Truck with Scale – Model PM 2478-SCL-LP by Vestil Manufacturing ™, 20 g increments, 1,000,000 Resolution.	1 x Synthetic Chamois by Simoniz ™ cut into eight 80 mm x 430 mm pieces
	3 x 6.35 mm anchors with masonry screws		1 x Ohaus Champ ™ Benchscale, 11.33 kg max, 2 g increments, 1:5000 Resolution
	1 x metal toft, cut and angled to drain water off wall		
	1 x Ohaus Champ ™ Benchscale, 11.33 kg max, 2 g increments, 1:5000 Resolution		

Table 5 – List of instruments used for measurements

3.5.2.2 Moisture Content

Moisture content of various construction materials can be difficult to measure. Different devices yield varying results. An electrical resistance moisture meter (Extech MO230) was used to measure moisture content in brick and mortar independently. Two pins were placed on the material and electrical conductivity was measured between the two pins. The inherent disadvantage of this unit is the moisture content is read only on the surface. In situ data was preferred for this experiment as it would give a more accurate representation of moisture profile in the wall. To combat this problem, holes were drilled to the center of each wall specimen. Masonry nails were then tapped into the holes, which essentially acted as extension probes for the contact pins. For example, wall type C would have nails driven 45mm in depth, equal to half the total depth of the brick. The holes were then sealed with waterproof silicone sealant to stop water from entering the hole. This can be seen in Figure 11.

Figure 11 – Typical installation of moisture meter pins shown on left. Extech MO230 Moisture meter shown on right

Four holes at each location were drilled to measure brick and mortar conditions. Holes were placed at dead center, and half way along the outer perimeter of both vertical and horizontal dimensions. The location of holes is depicted in Figure 12. The moisture meter is shown in Figure 11. Moisture content readings were taken after each wetting period and after each drying period.

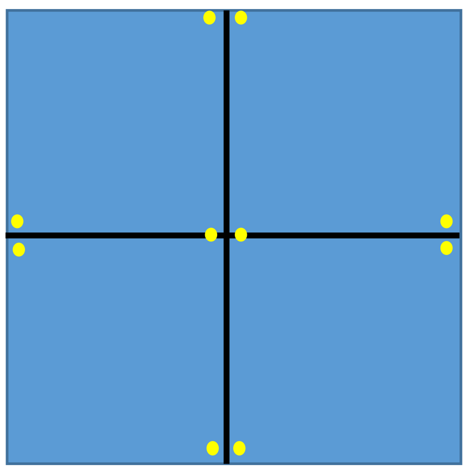


Figure 12 - Location of moisture content readings, marked with yellow circles. Blue area represents the test area. Black lines represent mid points

An important function of the moisture content readings was to build a general moisture profile of the walls before, during and after each test. The test design required one wall specimen from each wall type to be tested twice, which meant the initial starting condition for the wall would be damper than the others. Based on the moisture content readings obtained from the first series of tests, the 4th test of each wall type could be performed once they reached initial starting conditions.

3.5.2.3 Temperature and Relative Humidity

Air temperature and RH was monitored for both lab and cavity conditions. The data loggers used for measurement were six Onset HOBO U10-003 Internal RH/Temp units. These units were attached to the cavity glass panel with double-sided tape. Styrofoam was used to shield the units from possible water damage. The units were programmed to record conditions at 30-second intervals. They were placed at the same locations as the moisture content readings were taken, however in the cavity, on the reverse side of the wall. One logger was placed on a desk within 6 feet of the wall to measure lab conditions.

Figure 13 - Image courtesy of Onset Corporation ™

4.0 Results

4.1 Introduction

The results portion of this paper is separated into six main components. Each component represents a series of three tests performed on a specific wall type at a specific ventilation rate. Each group of three tests were performed in succession to each other, with a 24-hour gap between each test.

Results for absorption, evaporation, penetration, blocked water, moisture content, air temperature and relative humidity are reported. A brief review of the methodology for each measurement is found in Table 6.

Reference to individual test nomenclature will be shortened to strictly the test repeat number "V1, "V2" or "V3. For example, when addressing test "D3_NoVent_V2", only the last term "V2" will be used.

Measurement	**Explanation**
Absorption:	Measurement taken before and after each wetting cycle during phase one. Determines absorption during one cycle of wetting.
Evaporation:	Measurement taken after each drying cycle and at 12h, 24h, 36h and 48h intervals.
Penetration:	Measurement taken after each wetting cycle.
Moisture Content:	Taken initially, after each wetting cycle, after last drying cycle, at 12h, 24h, 36h and 48h intervals. All reported values are averaged between the five measurement locations.
Air Temperature/RH:	30-second intervals throughout entire 48 hour test.
Blocked water:	Blocked water is funnelled to a bucket, where it is measured by weight on a scale and converted to litres.

Table 6 – Brief review of measurement methodology

4.2 D3 Series – No Ventilation

4.2.1 Absorption, Evaporation and Penetration

4.2.1.1 Absorption

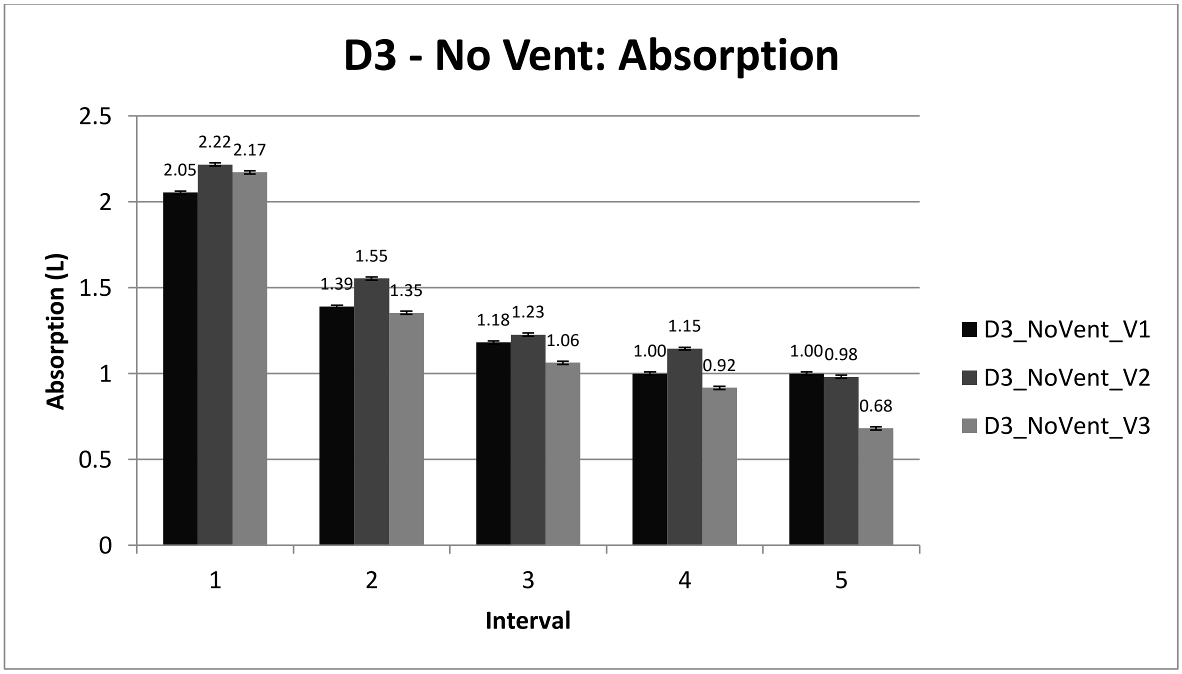


Figure 14 – D3, no ventilation: Absorption

Absorption rates follow a "ski-slope" trend through subsequent wetting cycles. The brick walls were stored inside for over 5 years, without exposure to external environmental conditions. They were considerably drier than a wall exposed to external conditions. This influenced the absorption rate as the walls absorbed significantly more water during the first wetting period. Subsequent tests have absorption values which were closer together. The first test (V1) was performed 5 days before the subsequent tests due to a scheduling error, which meant the wall had more time to dry, which explains why absorption did not decrease between tests V1 and V2. The third test (V3) shows lower absorption than V2 which is a typical result.

4.2.1.2 Evaporation

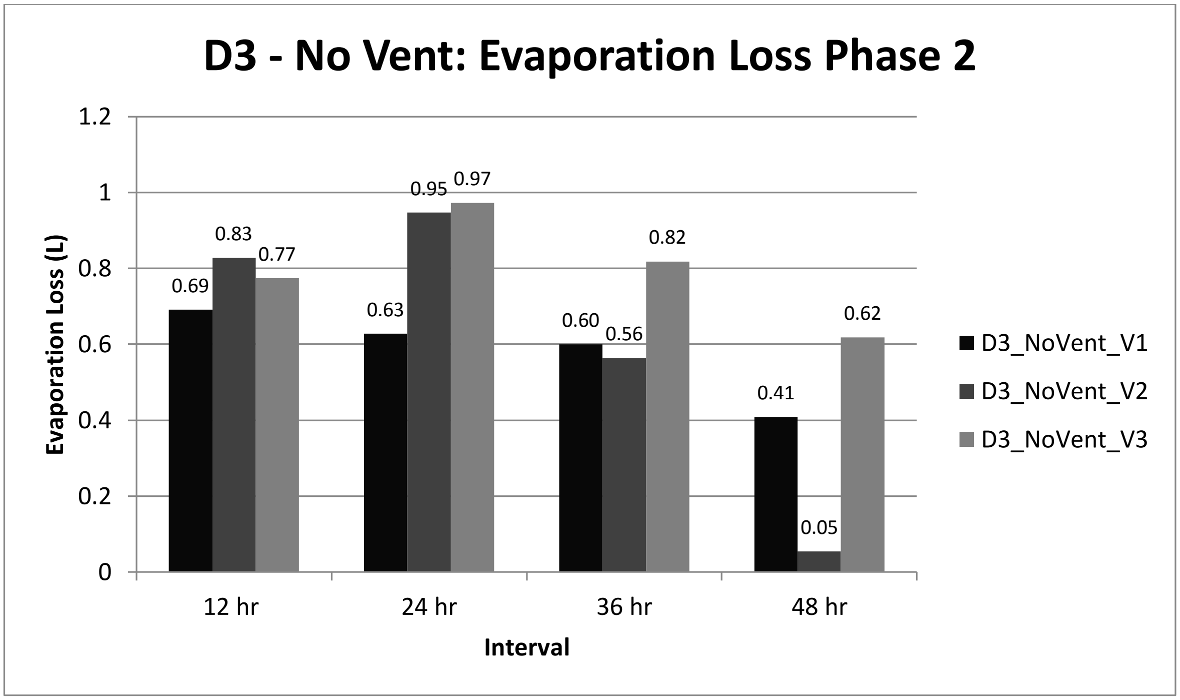


Figure 15 – D3, no ventilation, evaporation loss during phase 2

Tests V2 and V3 show the largest amount of evaporation occurred between the 12 hour and 24 hour time points. This trend did not occur during the first test (V1).

4.2.1.3 Penetration

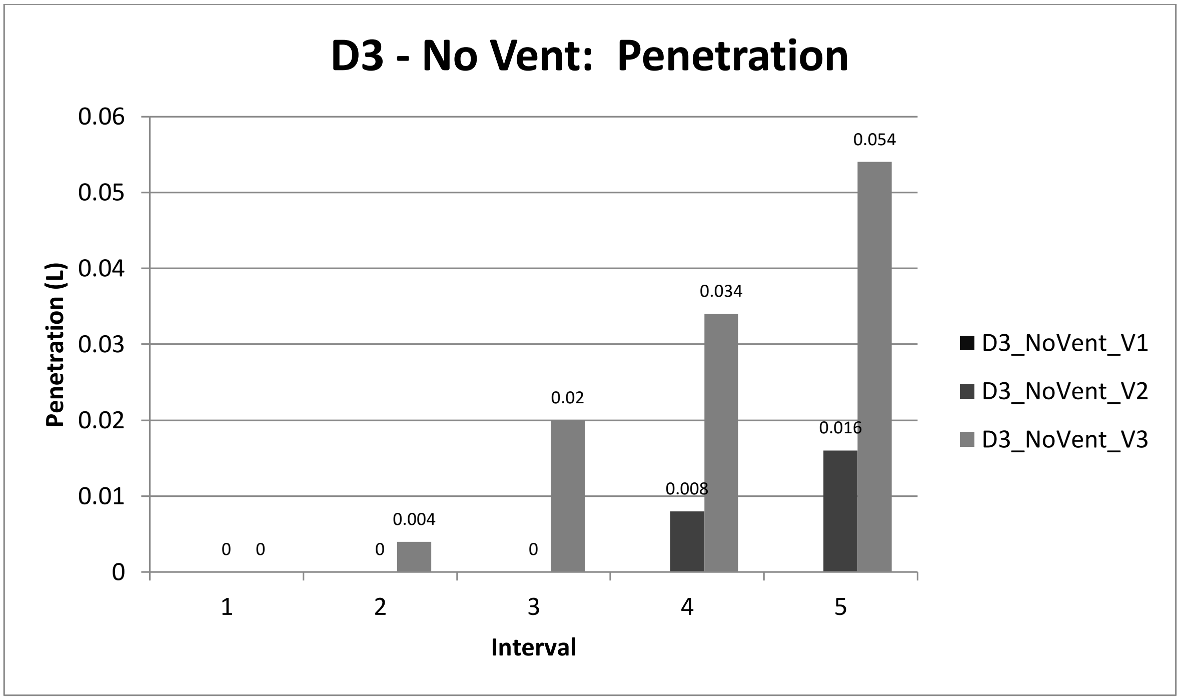


Figure 16 – D3, no ventilation, penetration

The quantity of water penetration was measured by weighing moisture absorbent cloths before and after each wetting cycle. The first test, (D3_NoVent_V1) had no penetration which could be measured through this technique. Water was observed to be penetrating through the brick during the first test cycle of wetting, but it travelled down the length of the wall and was reabsorbed by brick outside the testing area before it could be collected by the moisture absorbent cloths. This event occurred during each wetting cycle of test D3_NoVent_V1. As the walls became damp, more water penetrated the brick veneer, resulting in more bulk water collected at the base of the cavity chamber. The larger amounts of water became quantifiable. The results clearly show an increase of water penetration in consecutive tests.

4.2.2 Moisture Content

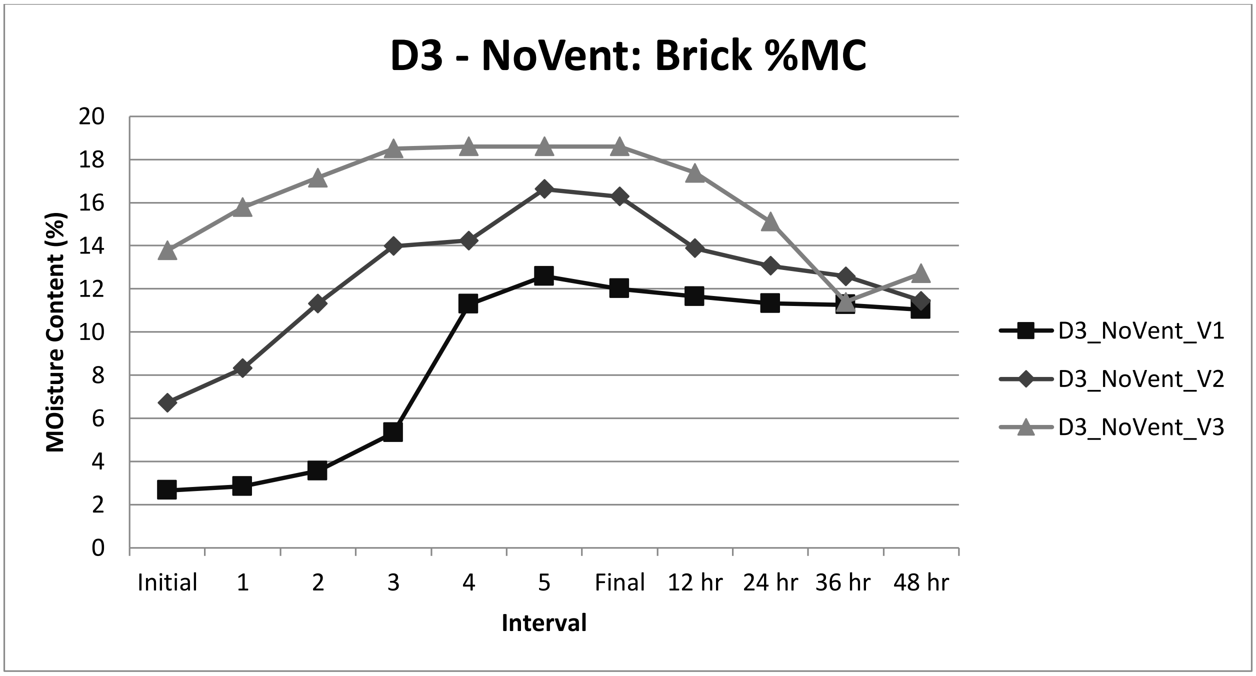


Figure 17 – D3 , no ventilation, brick %MC

The progression of walls becoming damper is shown clearly in figure 17 above. Initial moisture content was 2.66% for test V1. Initial Brick MC rose to 6.72% and 13.78% for subsequent tests V2 and V3.

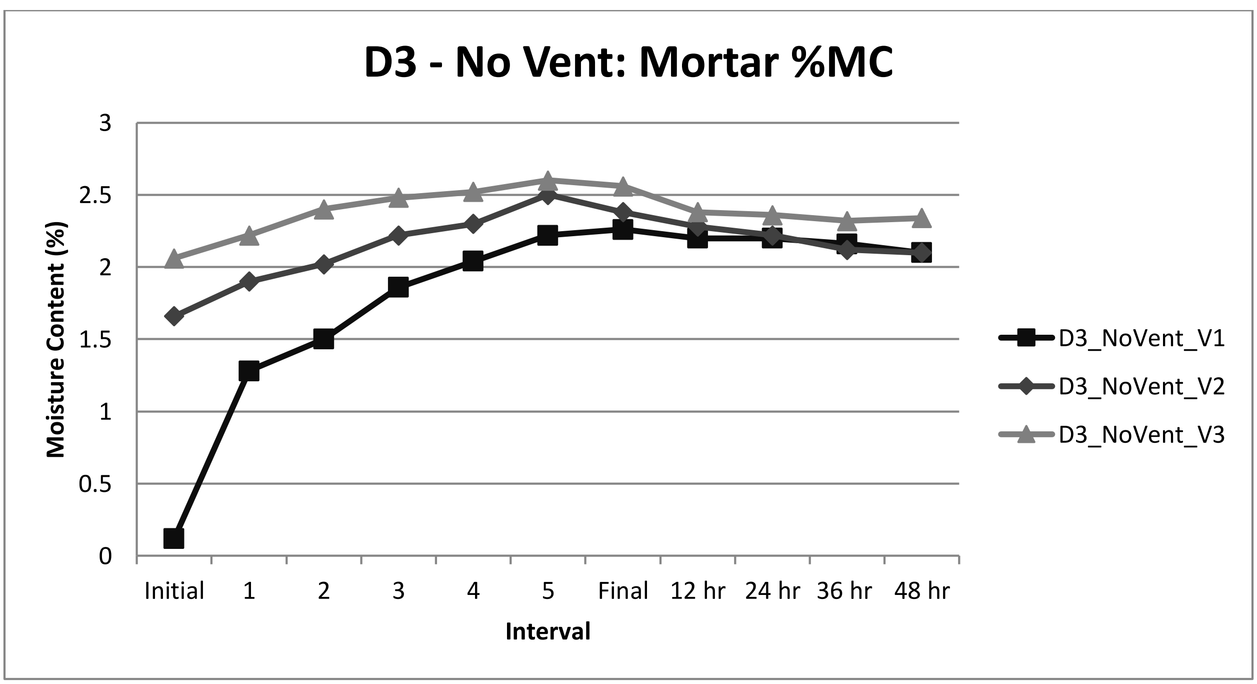


Figure 18 – D3, no ventilation, mortar %MC

4.2.3 Air Temperature and Relative Humidity

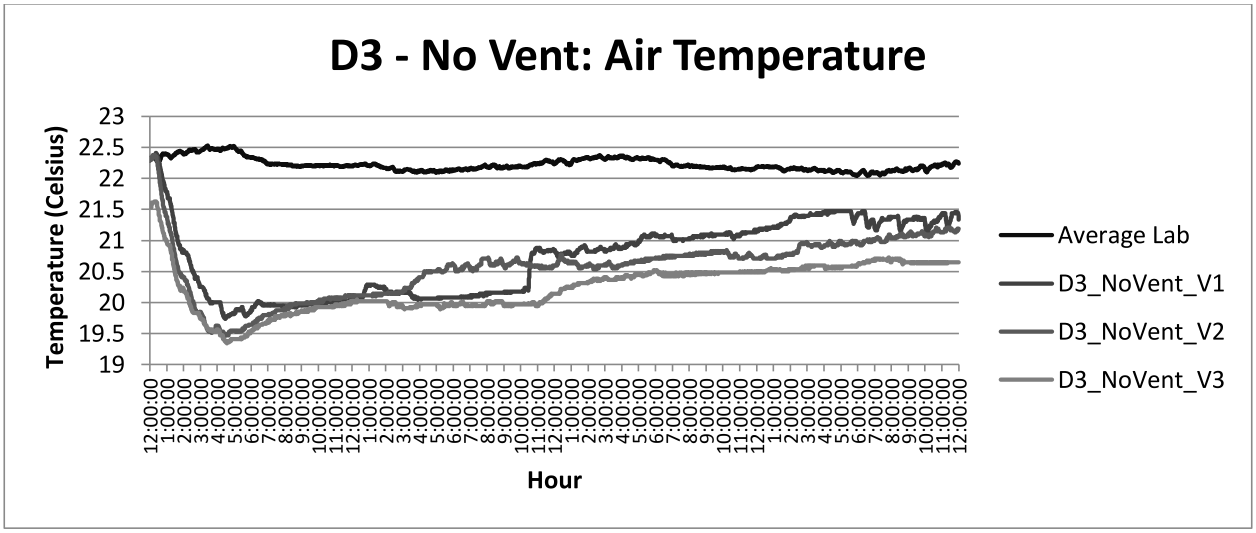


Figure 19 – D3, no ventilation, air temperature

Air temperature and relative humidity readings confirm the cavity chamber has simulated a microclimate found in a cavity wall.

Air temperatures dropped by approximately two degrees Celsius during phase one of the experiment. This is likely a result of the tap water cooling the wall specimen via conduction, and evaporation (requires heat energy) of water vapour into the cavity. The first test (V1) has the highest cavity air temperatures upon conclusion of the 48 hour test. Subsequent tests V2 and V3 have lower temperatures at the 48 hour time point. Tests V2 and V3 dropped to lower temperatures during phase 1 of the experiment, which explains why it would take longer for cavity temperatures in those tests to reach temperatures found in test V1. Extending the test to beyond 48 hours would allow for further quantification of this difference.

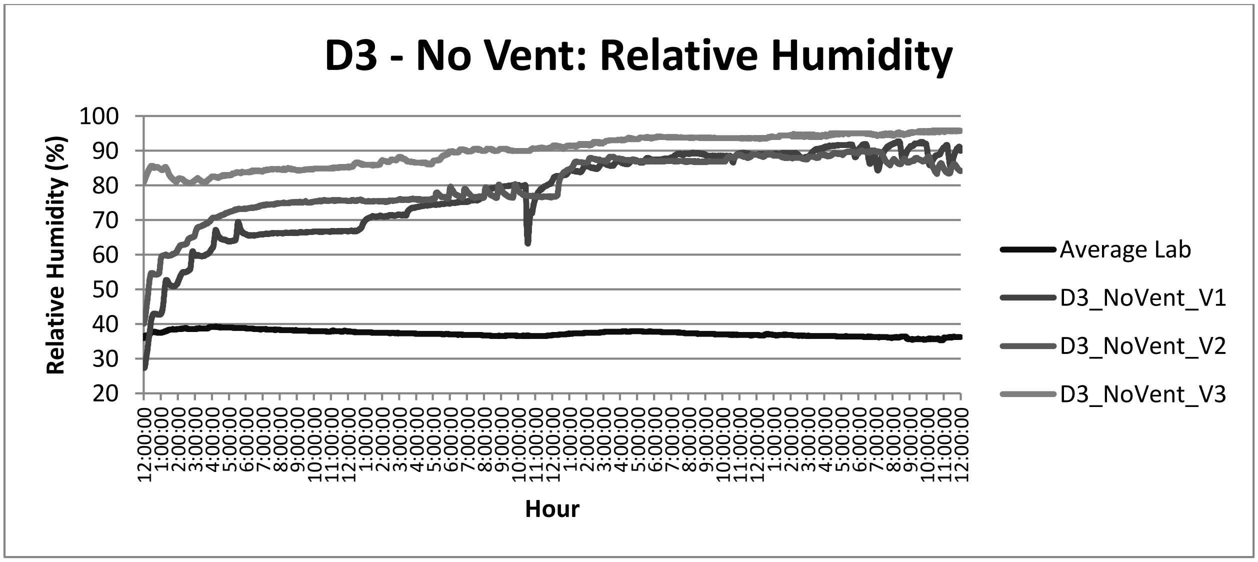


Figure 20 – D3, no ventilation, relative humidity

Relative humidity in the cavity chamber during the first two tests, V1 and V2 started at levels near to lab conditions. RH quickly rose as water was introduced. RH slowly rose during phase two of the experiment. RH levels during phase one of the experiments were higher in V3 than V2, however during phase two there was little difference between the two. V3 showed higher RH levels throughout the entire length of the test. This was expected as the wall was at the dampest pre-test condition. The initial RH is not in equilibrium with the external lab conditions because the cavity chamber was installed too early prior to the start of the test. This allowed moisture to accumulate in the chamber before wetting began. This likely negatively influenced the drying capacity of the chamber throughout the 48 hour test.

The major dip at the 23 hour mark of test V1 resulted from the removal of the cavity chamber during the test. One of the data loggers had become dislodged and was re-attached. This procedure was not performed again in subsequent tests as the loggers were properly installed.

The “curtain drapes” effect on the trend lines was likely influenced by poor placement of the wall specimens in the lab. The local fan coil was blowing air over top of the wall specimen and into the vent opening. This theory was confirmed by measuring airflow at the cavity vent openings. The fan coils were blocked for remaining tests, the effect on the trend line was lost in test V3.

4.3 D1 Series – 5ACH

4.3.1 Absorption, Evaporation and Penetration

4.3.1.1 Absorption

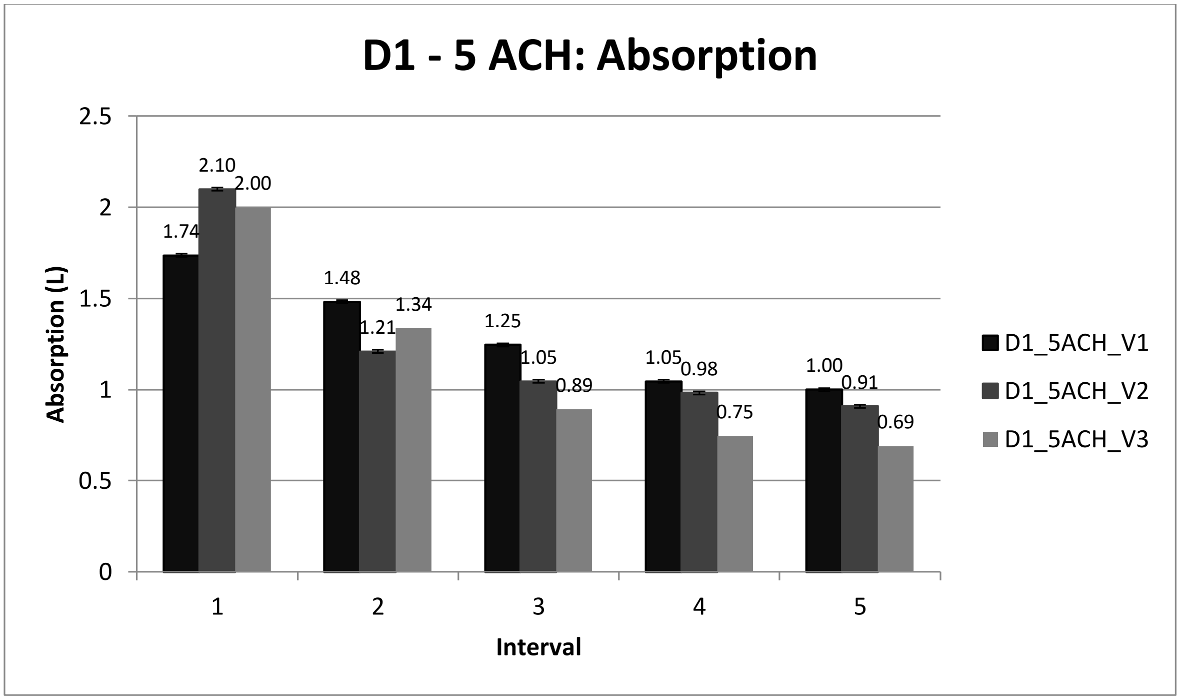


Figure 21 – D1, 5 ACH, absorption

Absorption rates follow a “ski-slope” trend with the largest amounts of absorption occurring during the first interval of wetting. Subsequent tests absorbed less water overall than previous ones. Between the three tests, absorption ranged from 0. 69 L to 2.10 L.

4.3.1.2 Evaporation

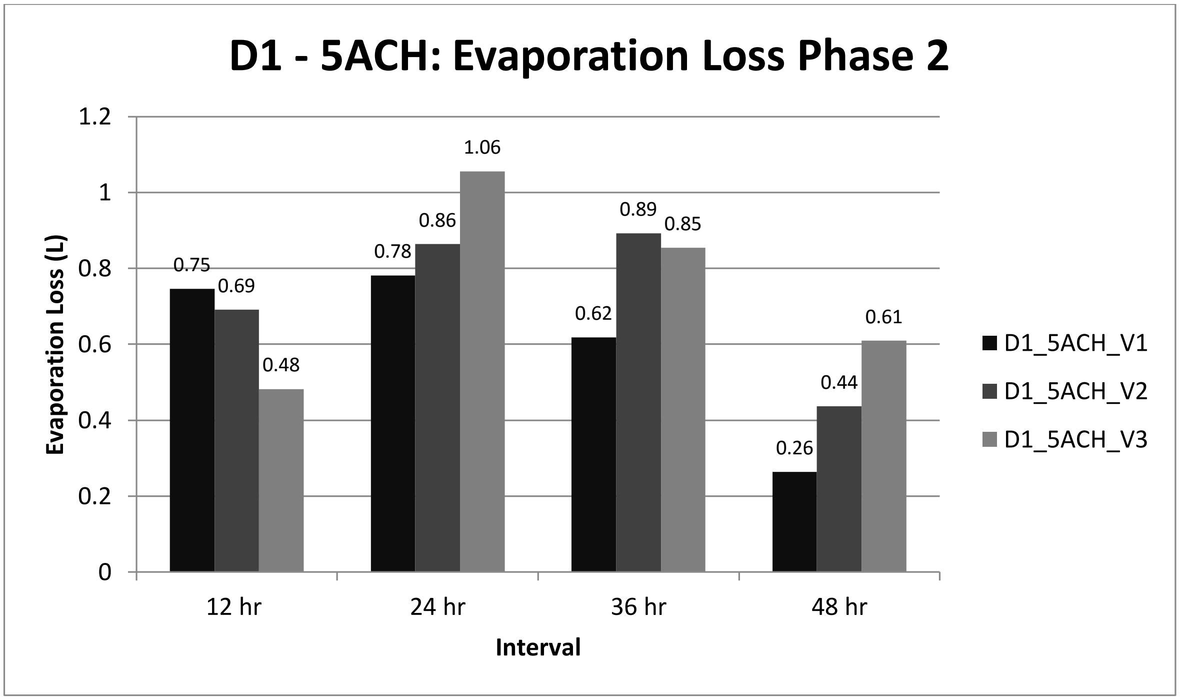


Figure 22 – D1, 5 ACH, evaporation loss phase 2

Evaporation rates were highest during 12 to 24 hours after the initial wetting. Test V3 had the largest increase in drying rate between the 12 and 24 hour time points. The range of evaporation was from 0.26 L to 1.06 L.

4.3.1.3 Penetration

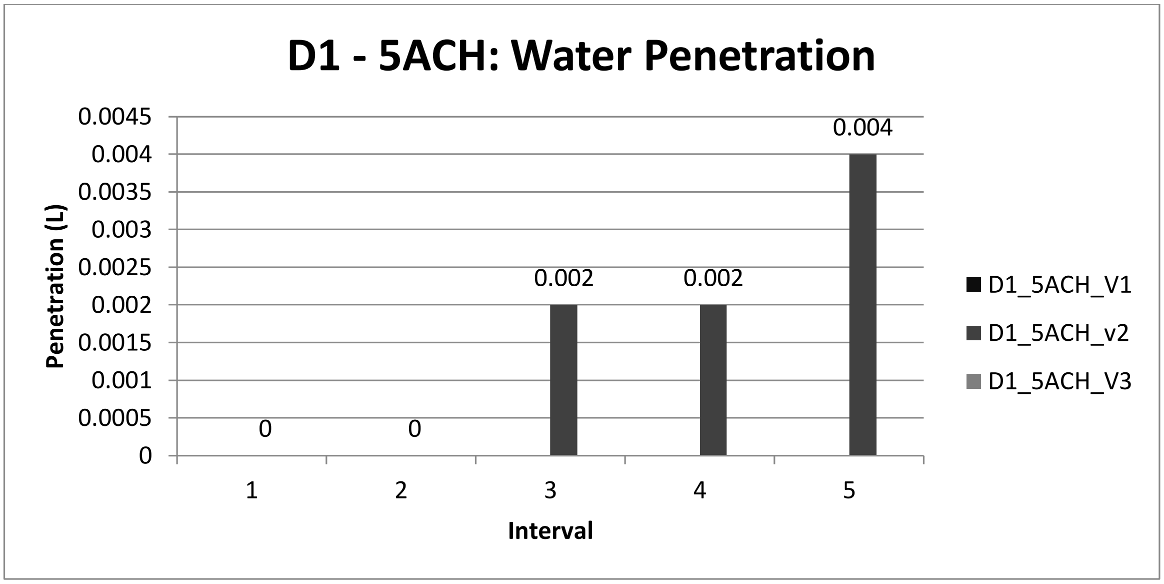


Figure 23 – D1, 5 ACH, penetration

There was no penetration in test V1 and V3. Test V2 had minor leakage at intervals three, four and five. Leakage ranged from 2 ml to 4 ml. Overall, the water penetration results are unusual because Test V3 was expected to have the largest amount of water penetration.

4.3.2 Moisture Content

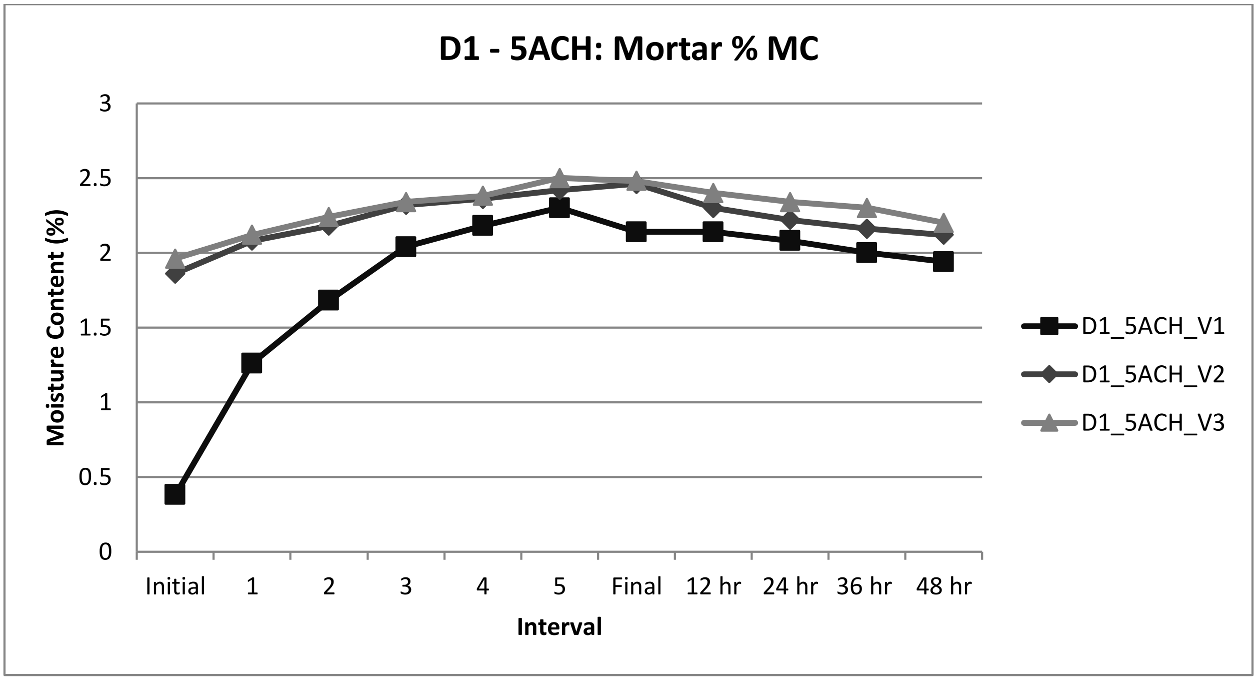


Figure 24 – D1, 5 ACH, mortar %MC

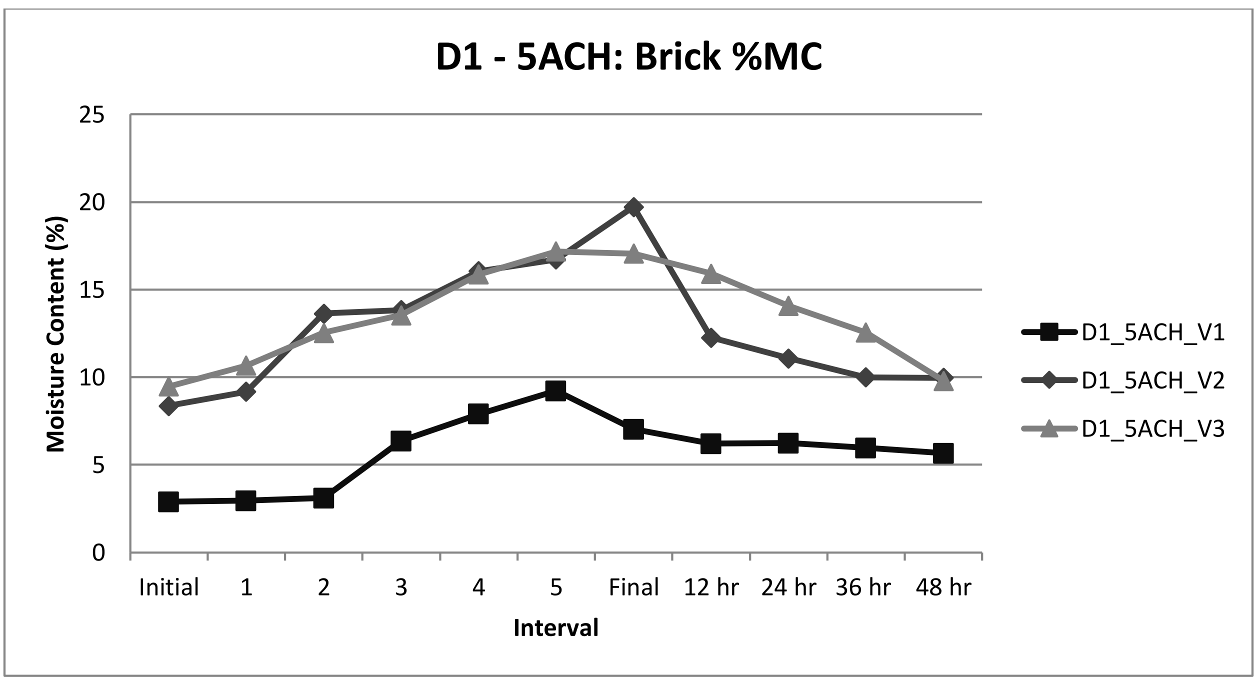


Figure 25 – D1, 5 ACH, brick %MC

Moisture content readings at initial time points and upon conclusion of the test for both V2 and V3 were nearly identical. There is clear indication of higher moisture content in these two tests compared to V1.

4.3.3 Air Temperature and Relative Humidity

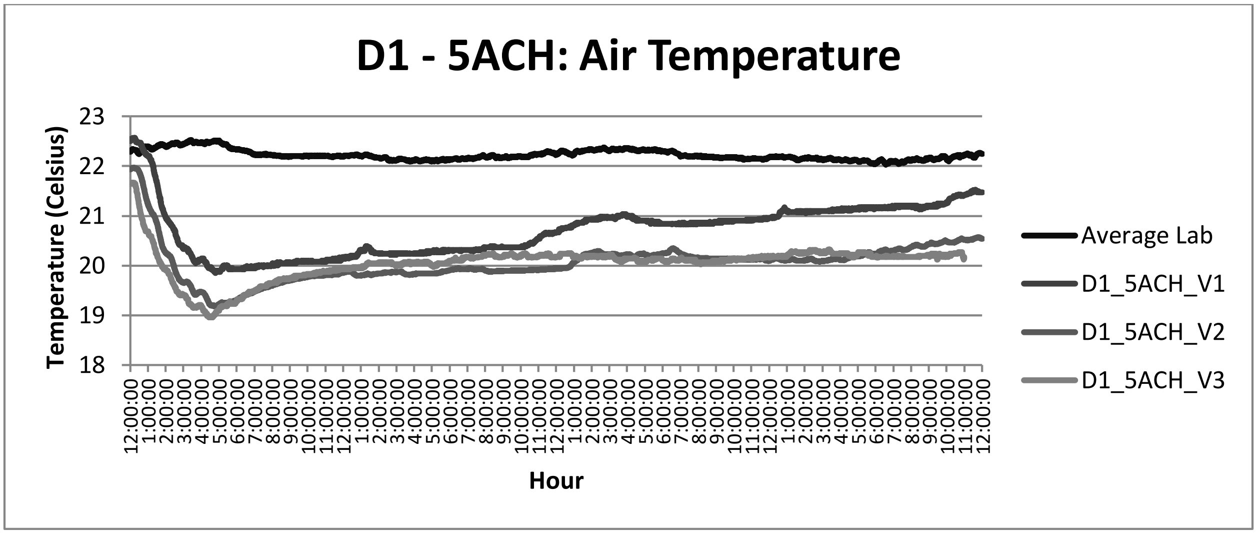


Figure 26 – D1, 5 ACH, air temperature

Air temperature within the cavity was lowest during the wetting phase in test V3. The first tests V1 and V2 resulted in similar temperature profiles throughout the length of the test. The number of degrees in temperature drop during each test was approximately the same, however the initial temperatures differed which appeared to influence warming of the cavity throughout the remainder of the test. Overall, V1 data showed the quickest increase in temperature during phase two of the experiment.

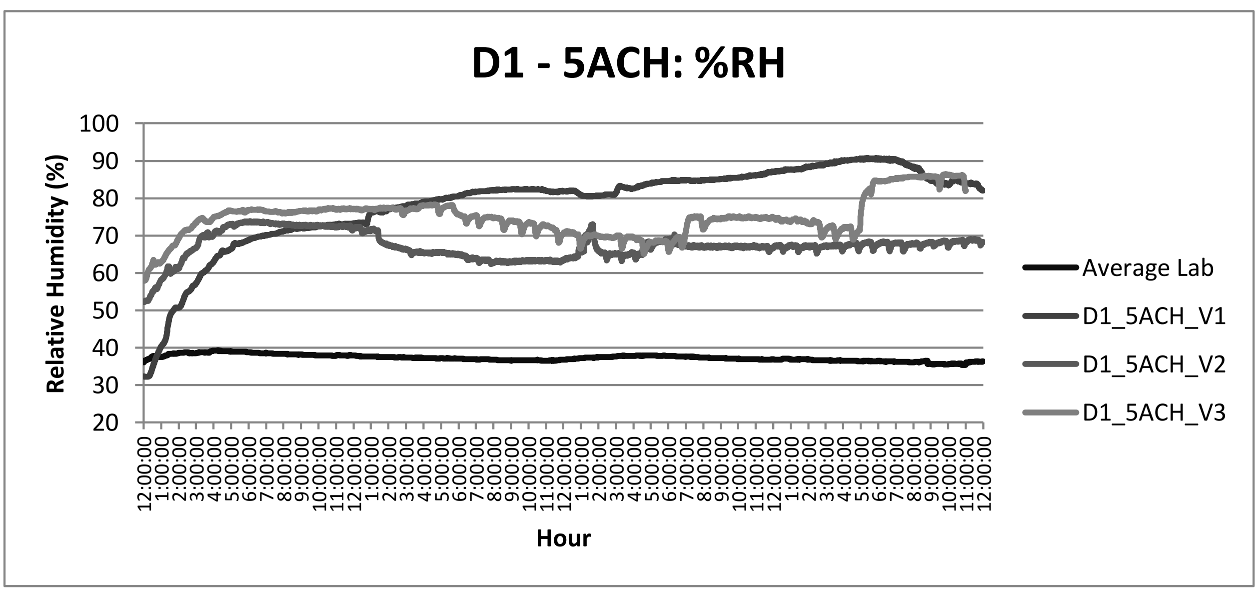


Figure 27 – D1, 5 ACH, %RH

4.4 D2 Series – 10 ACH

4.4.1 Absorption, Evaporation and Penetration

4.4.1.1 Absorption

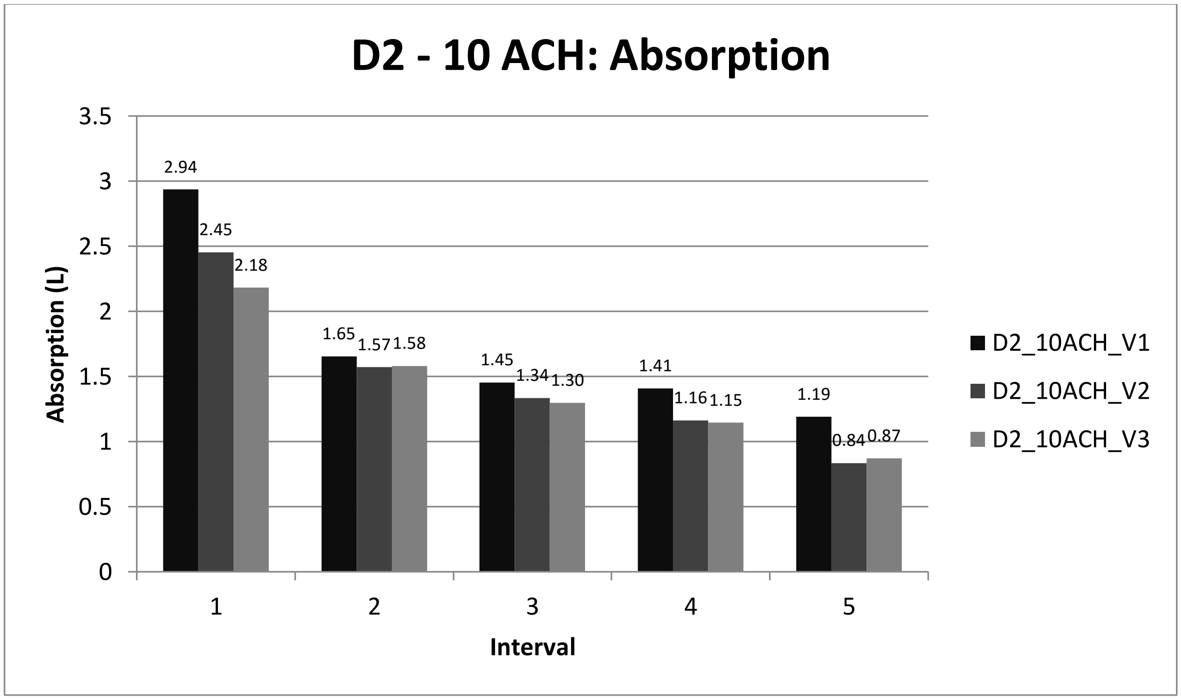


Figure 28 – D2, 10 ACH, absorption

Absorption follows the typical "ski-slope" trend with quantities ranging from 2.94 L to 0.84L. This test series is an excellent example of the reduced absorption capacity of brick veneer walls as they become damper.

4.4.1.2 Evaporation

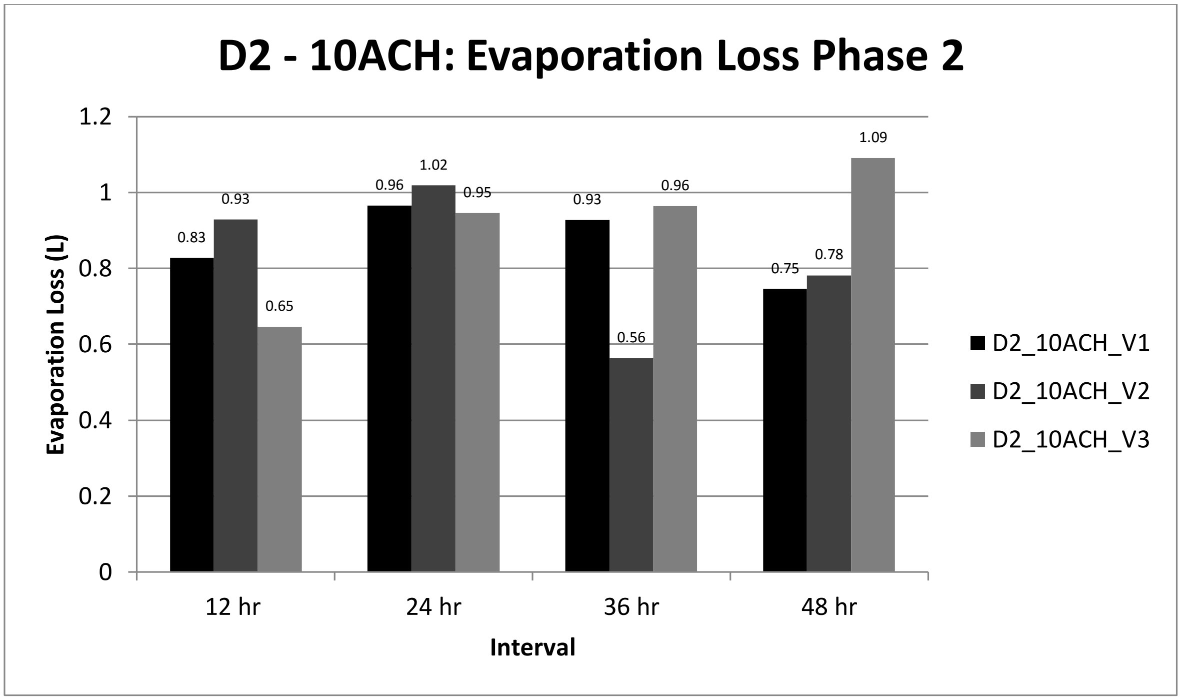


Figure 29 – D2, 10 ACH, evaporation loss phase 2

Absorption rates are strongest between the 12 and 24 hour time points. Test V3 had increasing evaporation rates throughout the entire 48 hour test, which was a-typical based on the other two tests in this series and other test series in this study.

4.4.1.3 Penetration

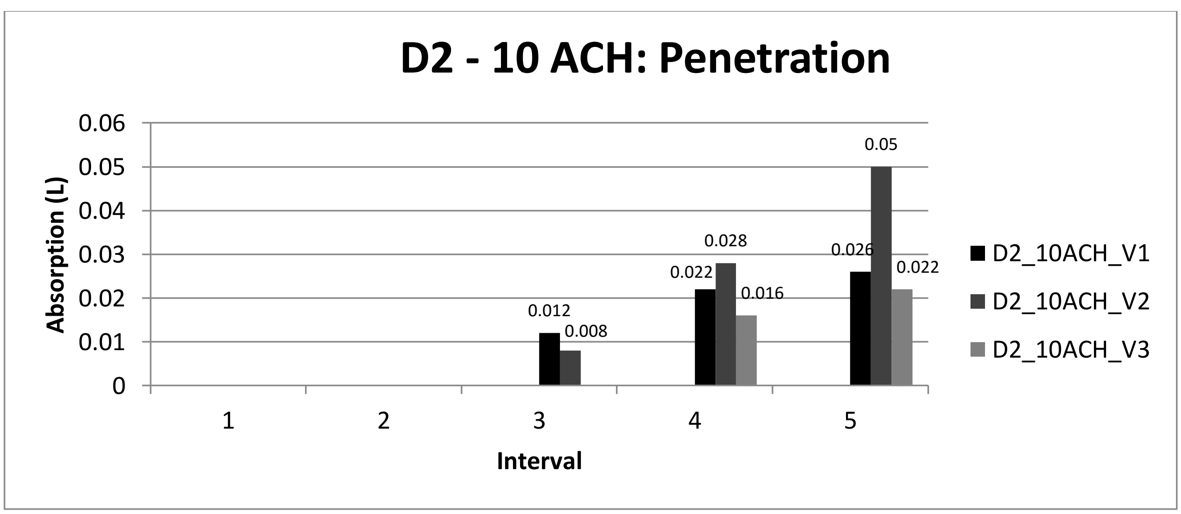


Figure 30 – D2, 10 ACH, penetration

Penetration ranged from 0.008 L to 0.05 L. The largest amount of penetration occurred during test V2

4.4.2 Moisture Content

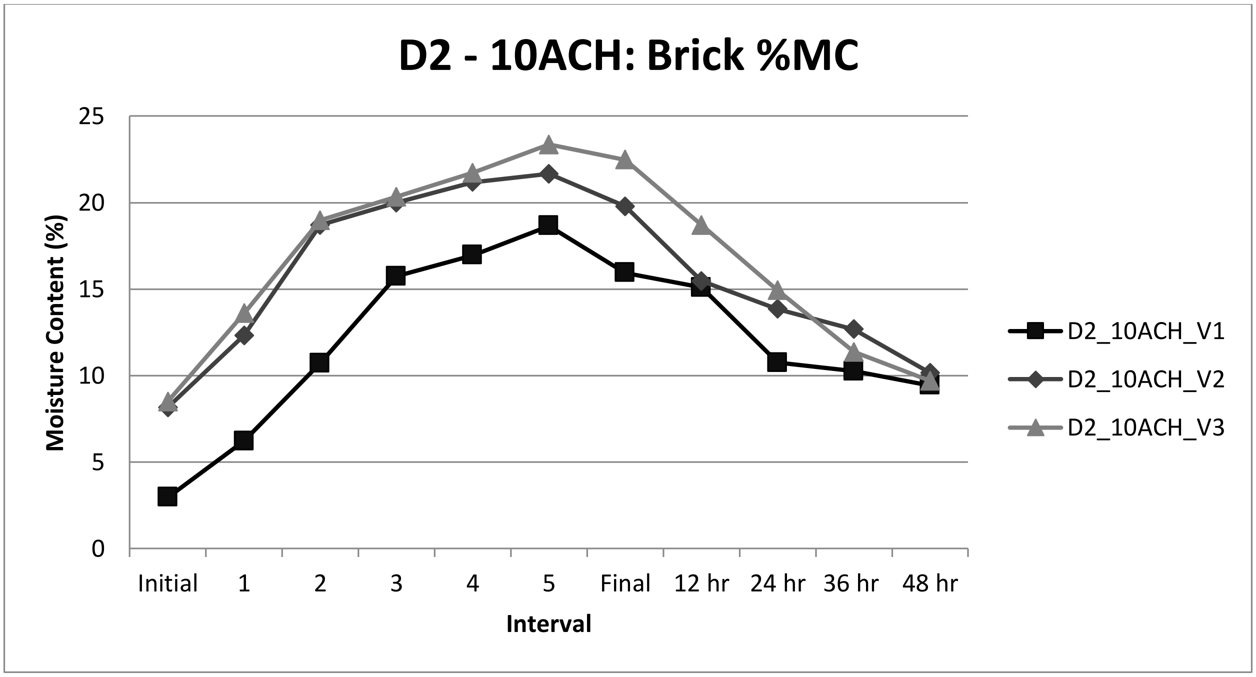


Figure 31 – D2, 10 ACH, brick %MC

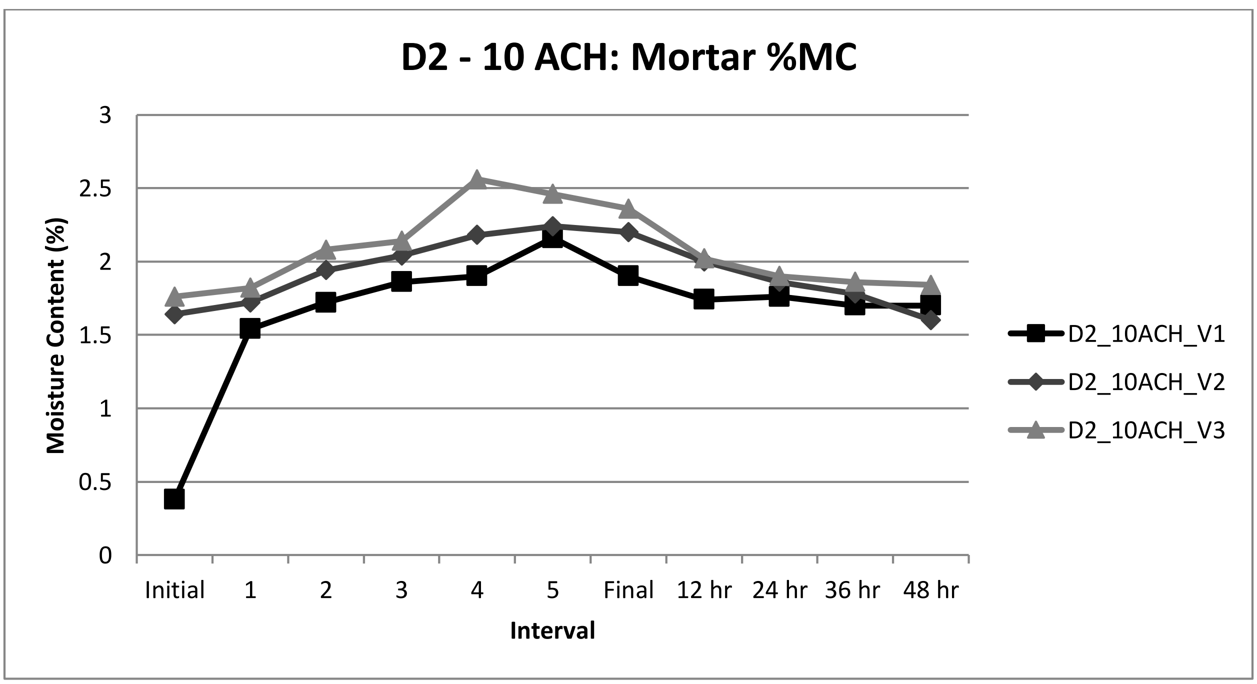


Figure 32 – D2, 10 ACH, mortar %MC

There are increased in MC levels in the brick during phase one of test V2 and V3 compared to V1. All three tests in this series ended with similar MC readings in the brick. This result could suggests a higher ventilation rate was in effect during later tests of this series.

4.4.3 Air Temperature and Relative Humidity

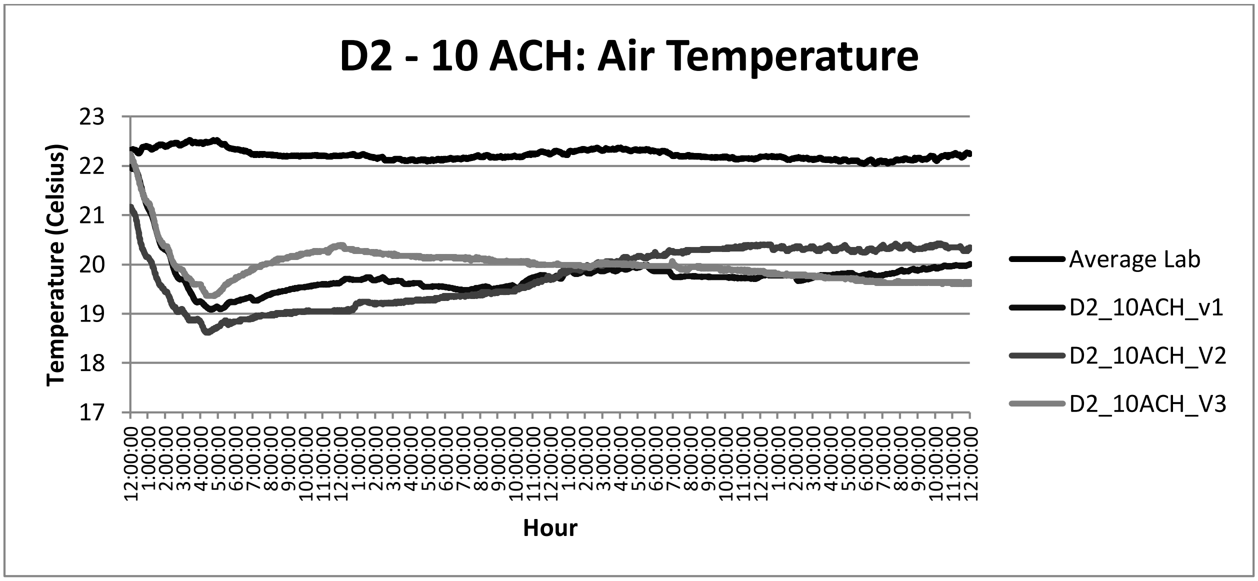


Figure 33 – D2, 10 ACH, air temperature

Air temperature drops during phase one of the experiment are similar through all tests. V2 test results showed a consistent temperature increase until the 36th hour, during phase two of the experiment. V3 test results showed a slow decrease in temperature from the 12th hour onwards.

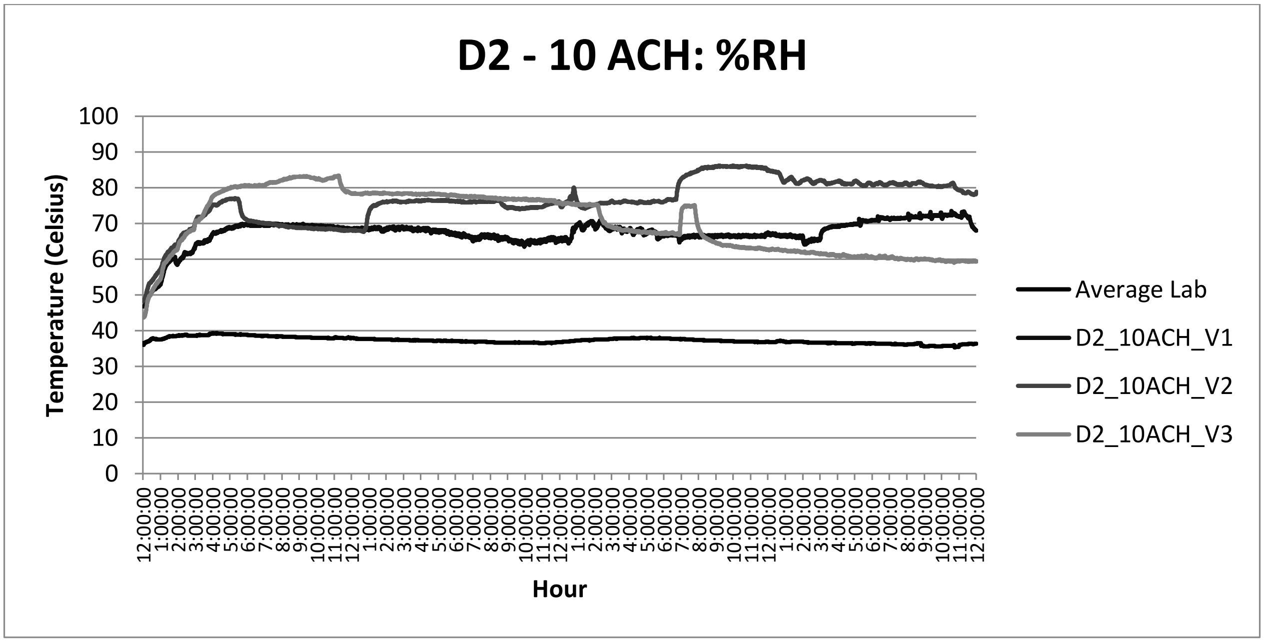


Figure 34 – D2, 10 ACH, %RH

The relative humidity readings show a clear issue with the consistency of simulated ventilation air rates. The prolonged drops or increases in RH were likely a result from fan malfunction. The problem appears to be exacerbated with higher ventilation rates. The overall relative humidity is lower in this series of experiments compared to the non-ventilated series. The last "hump" in test V2 was a result of a complete failure of the fan which allowed RH levels to approach 90%. The problem of fan failure was an ongoing issue throughout the study.

4.5 C1 Series – No Ventilation

4.5.1 Absorption Evaporation and Penetration

4.4.1.1 Absorption

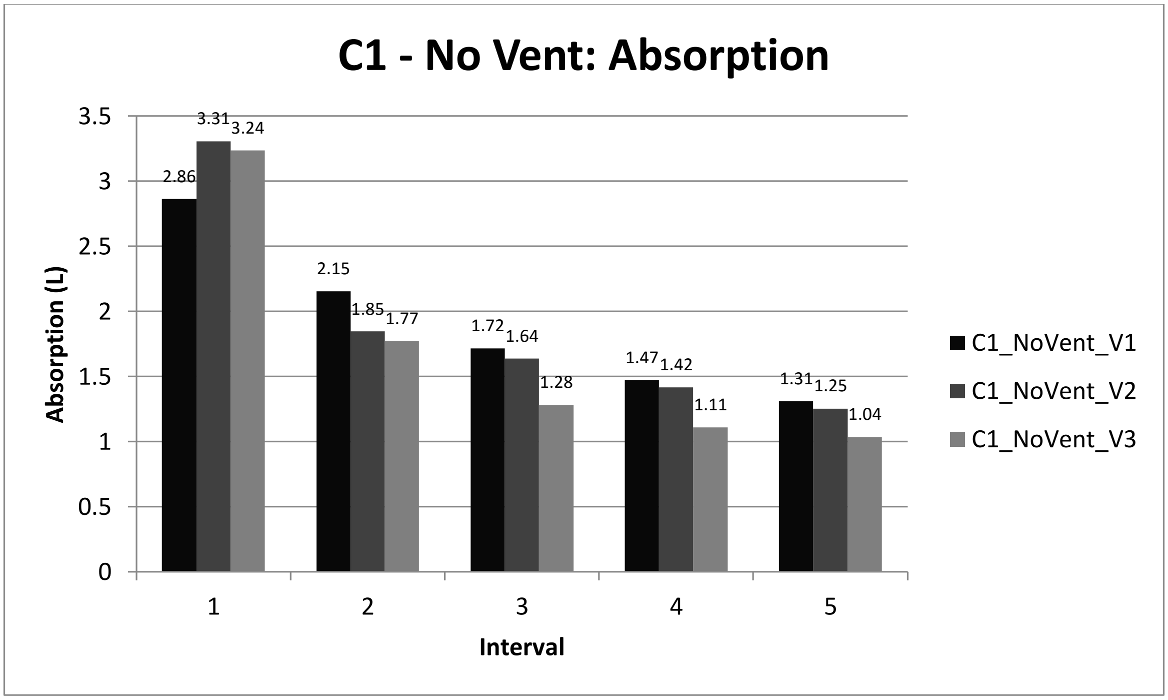


Figure 35 – C1, no ventilation, absorption

Absorption follows the familiar "ski-slope" trend through successive wetting cycles. Apart from the first wetting cycle, each subsequent test has diminished absorption quantities through remaining wetting cycles.

4.4.1.2 Evaporation

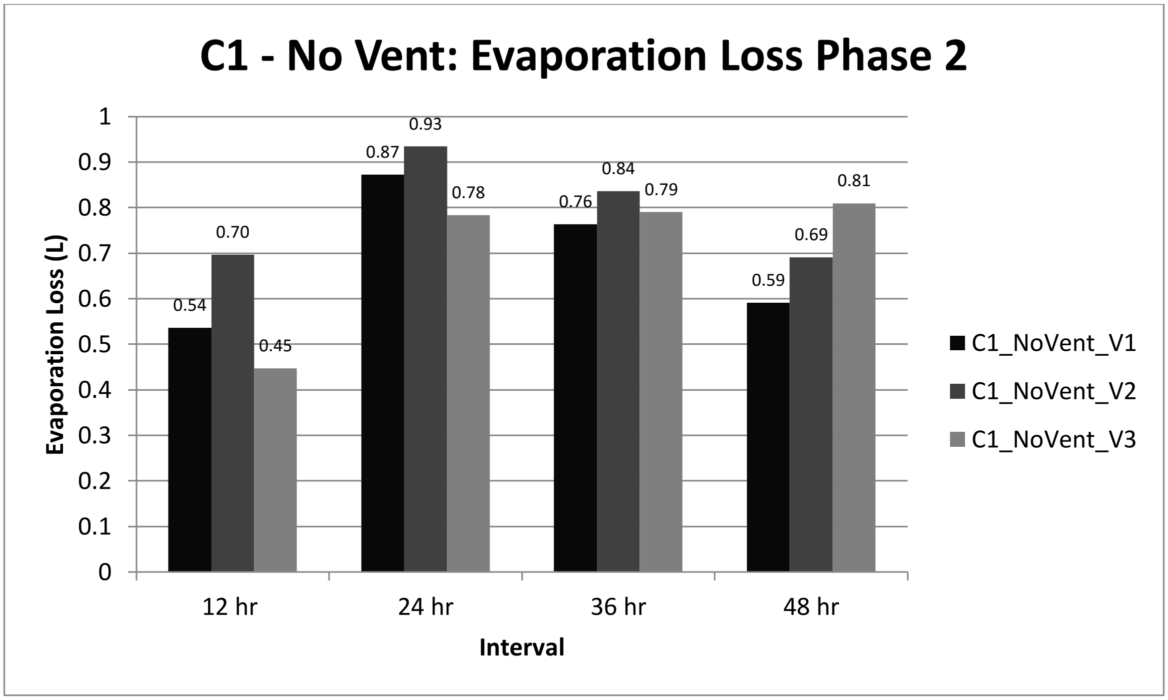


Figure 36 – C1, no ventilation, evaporation loss phase 2

Evaporation ranged from 0.45L to 0.93 L. Evaporation was highest between the 12 and 24 hour time points. Test V2 result showed the greatest amount of evaporation through all intervals, except at 48 hours.

4.4.1.3 Penetration

There was no measureable penetration through each wall in this series.

4.5.2 Moisture Content

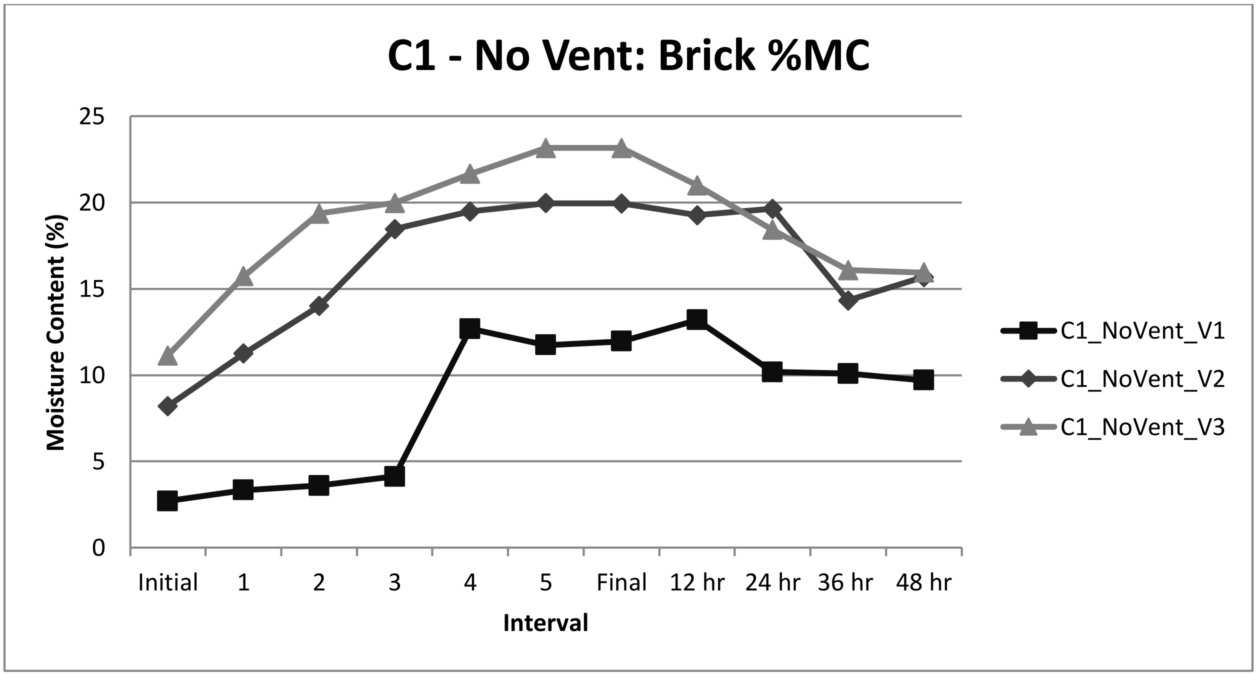


Figure 37 – C1, no ventilation, brick %MC

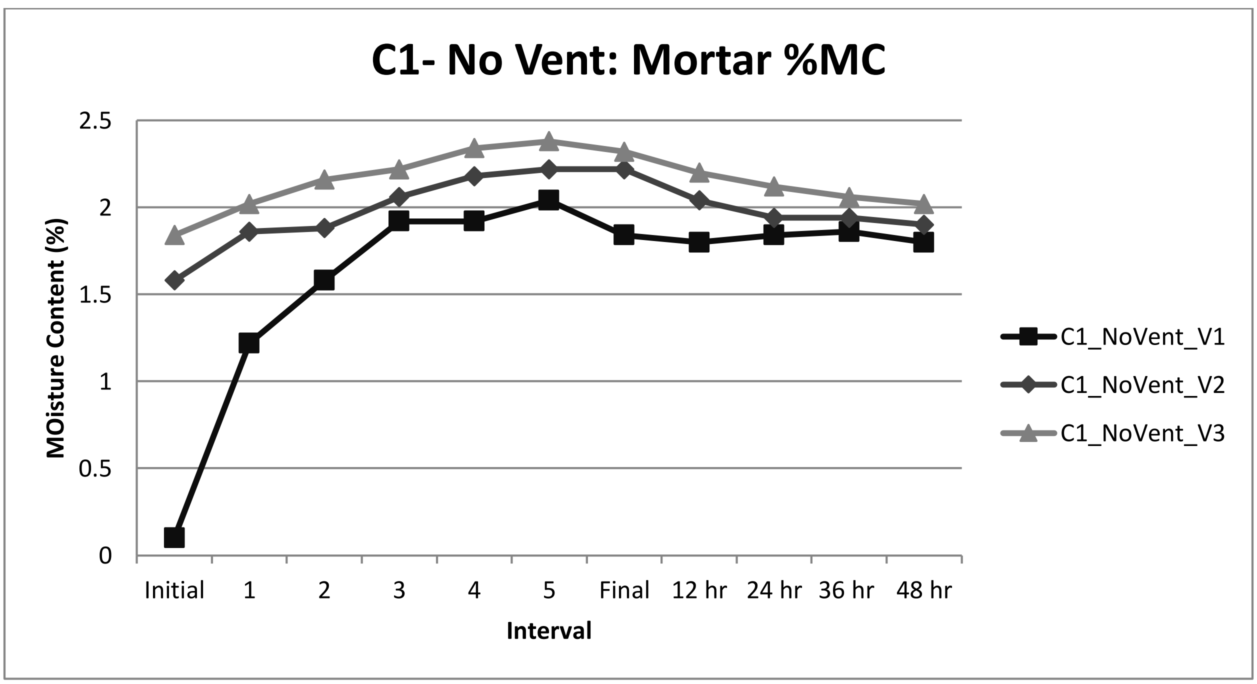


Figure 38 – C1, no ventilation, mortar %MC

Moisture content is generally higher in each subsequent test in both the brick and the mortar. The largest increase in moisture content readings is between test V1 and V2. The increase in moisture content between test V2 and V3 is comparatively small, which is predominantly seen in the brick. Mortar readings of %MC were closer together.

4.5.3 Air Temperature and Relative Humidity

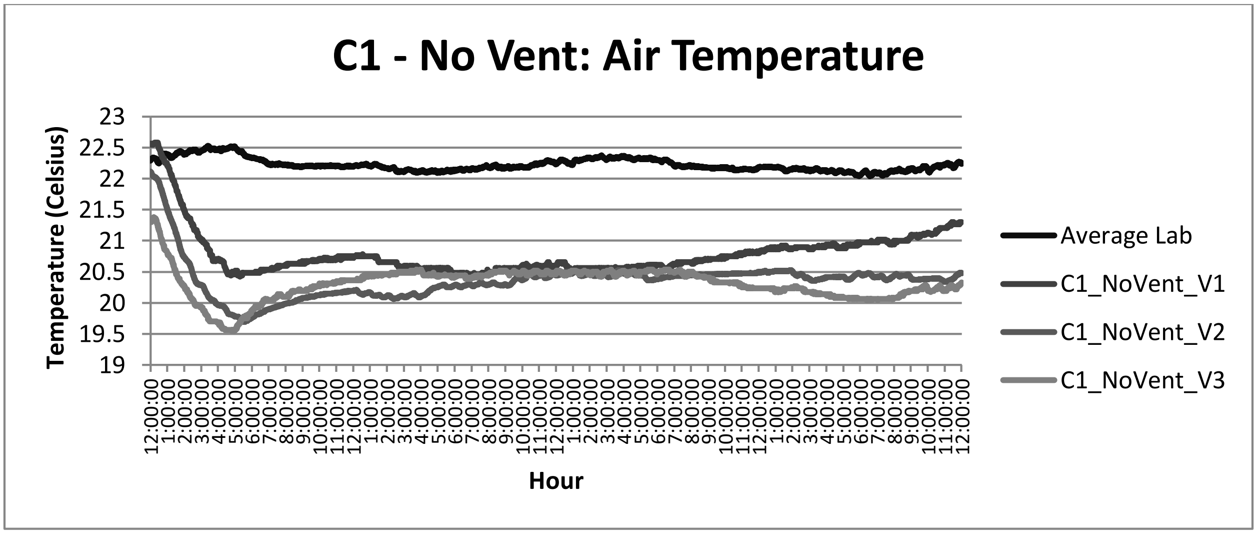


Figure 39 – C1, no ventilation, air temperature

Air temperature decrease during phase one of the experiment was approximately the same between all three tests. Cavity temperatures for all three tests converged to 20.5° C starting at the 24h hour of the test and remained at this temperature for approximately 6 hours. Each test was performed at different times, which means the convergence was unlikely caused by an external influence such as a mechanical system. The reason for the convergence is unknown. After the 30th hour, V1 measurements showed a temperature increase, V2 remains constant and V3 showed a temperature decrease.

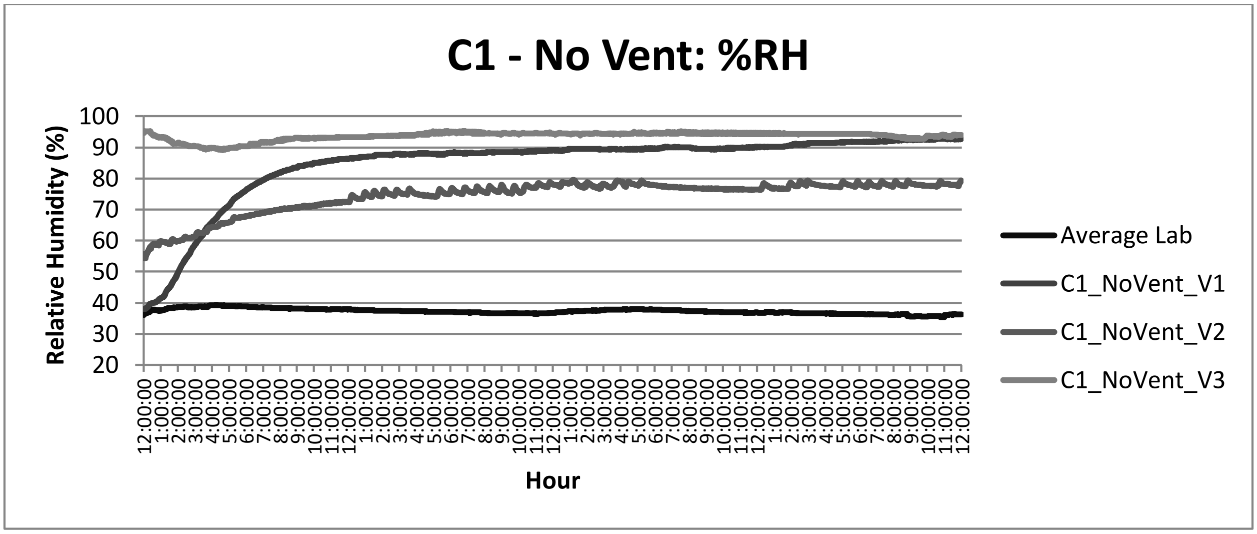


Figure 40 – C1, no ventilation, %RH

The relative humidity varied significantly between tests. V3 test data showed high initial RH because the cavity chamber was installed too early prior to the start of the test. Since the wall had already been subjected to two complete tests, it was considerably wet, thus moisture was allowed to accumulate in the cavity chamber. A similar issue occurred in test V2 albeit to a lesser extent, because the wall was drier than in test V3. In addition, the cavity chamber may have been attached later prior to starting the test.

Test V1 started near lab conditions which was the desired outcome for all tests.

4.6 C3 Series – 5ACH

4.6.1 Absorption, Evaporation and Penetration

4.6.1.1 Absorption

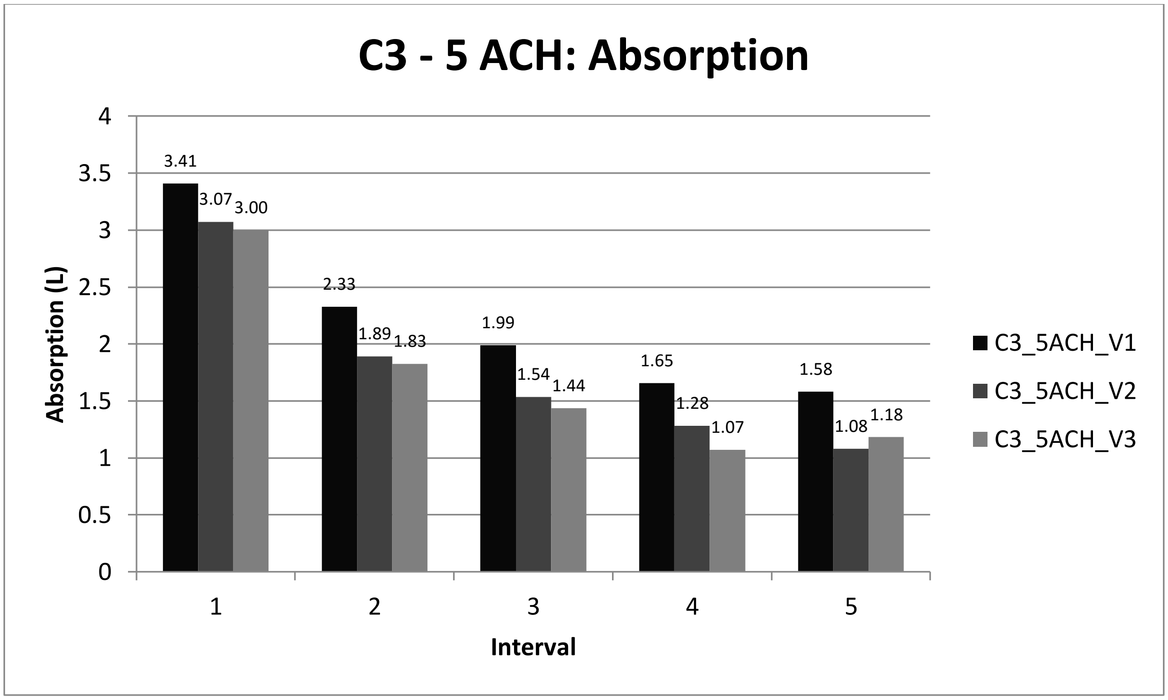


Figure 41 – C3, 5 ACH, absorption

Absorption follows a familiar "ski-slope" trend through successive wetting cycles. Absorbed water ranged from 1.08 L to 3.41 L. Test V1 absorbed the largest amount of water.

4.6.1.2 Evaporation

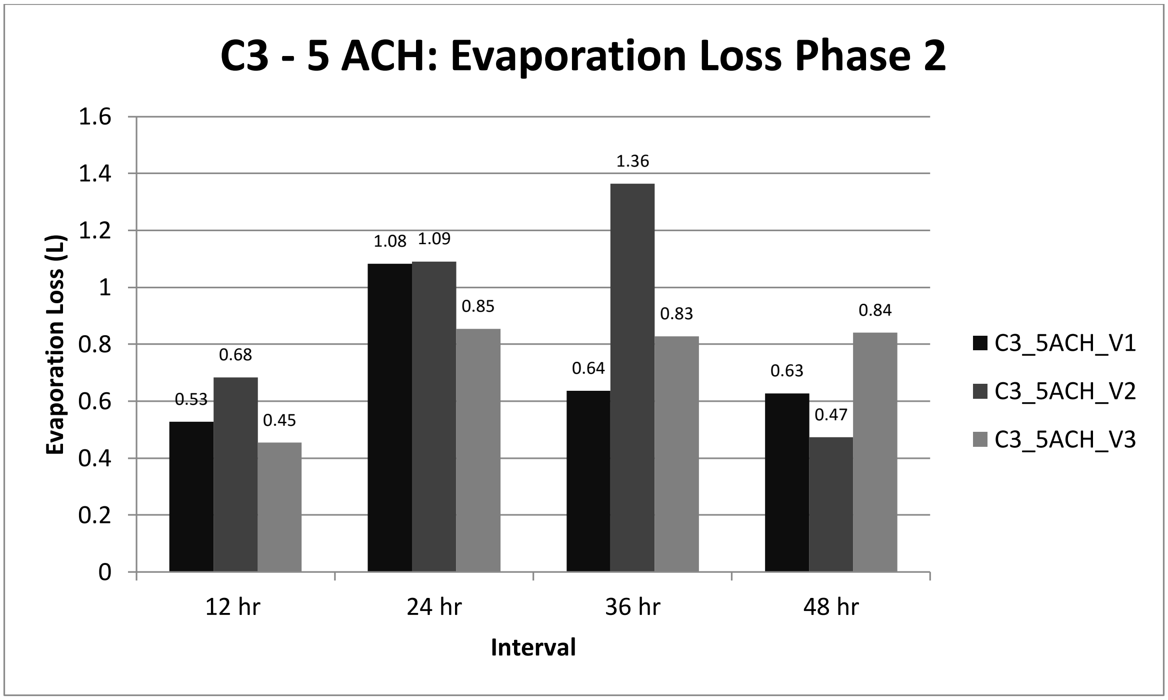


Figure 42 – C3, 5 ACH, evaporation loss phase 2

The drying rate was on average highest during 12 to 24 hours after the start of the test, which has become a typical observation through all series in this test. Test V2 showed a continually increasing rate of evaporation loss to the 36 hour time point before sharply dropping off afterwards. This did not conform to the typical profile observed in previous series.

4.6.1.3 Penetration

There was no measureable penetration through any C-Type wall.

4.6.2 Moisture Content

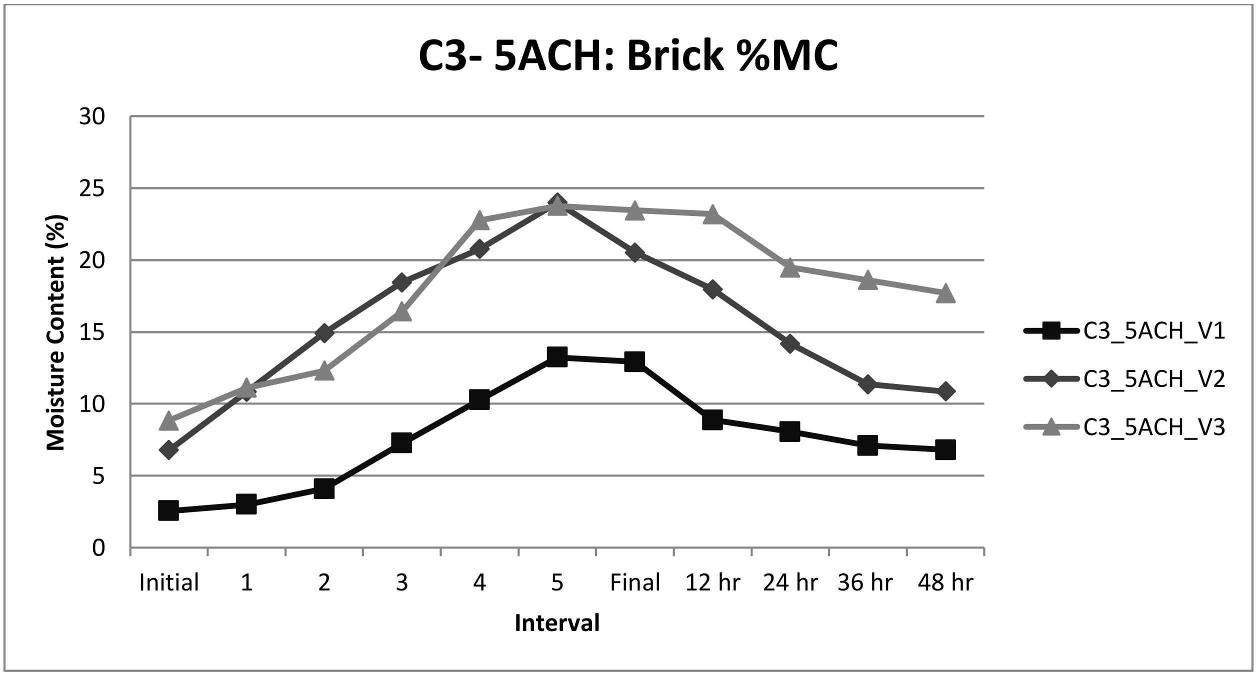


Figure 43 – C3, 5 ACH, brick %MC

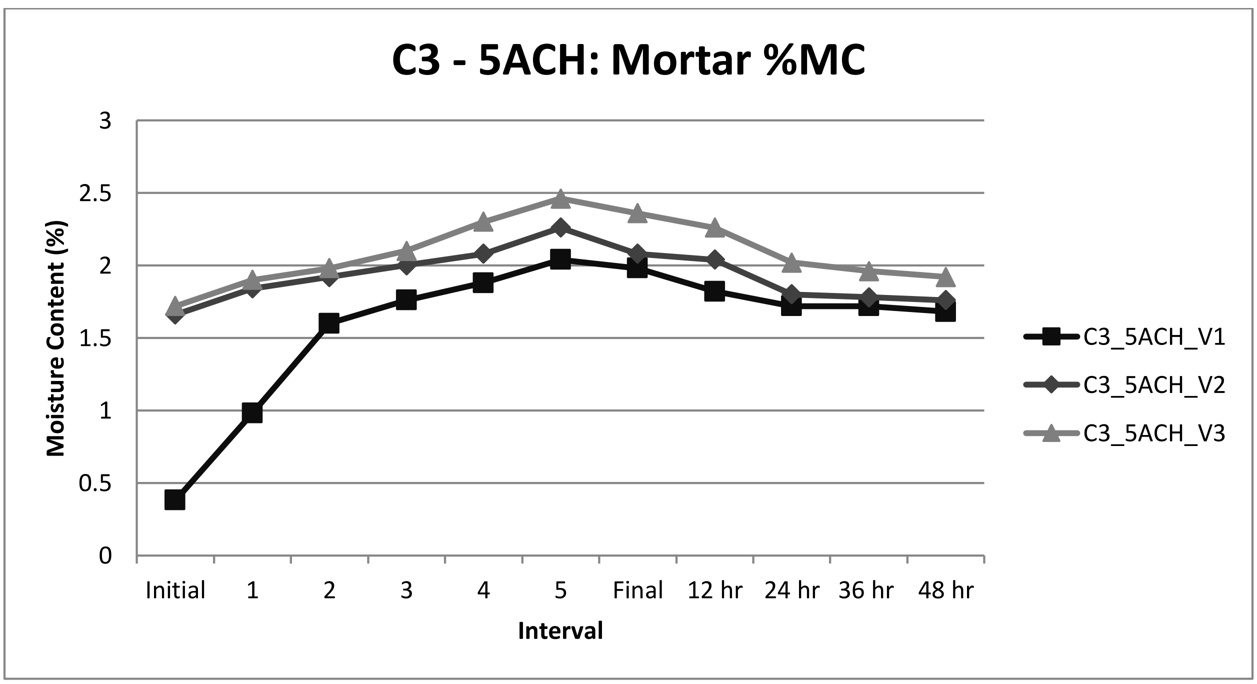


Figure 44 – C3, 5 ACH, mortar %MC

Moisture content readings were lowest in the first test, as expected due to the dry condition of the wall. Test V2 and V3 had similar MC profiles during phase one of the experiment, however test V2 had significantly lower MC readings in the brick during phase two of the experiment.

4.6.3 Air Temperature and Relative Humidity

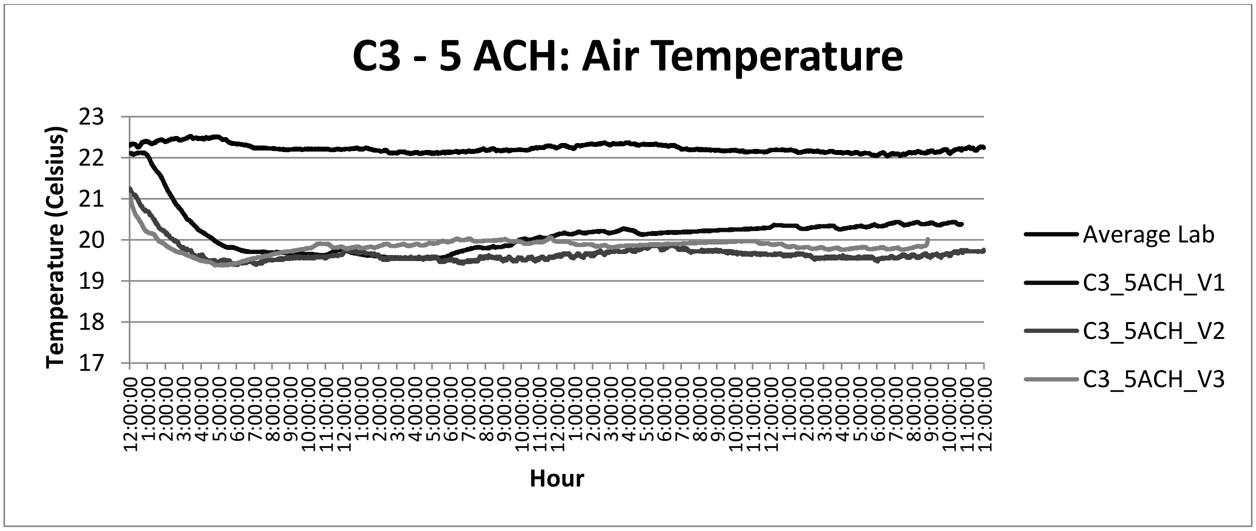


Figure 45 – C3, 5 ACH, air temperature

Temperatures after the initial temperature drop were similar in all three tests. During phase two of the experiment, test V2 and V3 had relatively constant temperatures while test V1 shows gradual heating of the cavity from the 18th hour onwards.

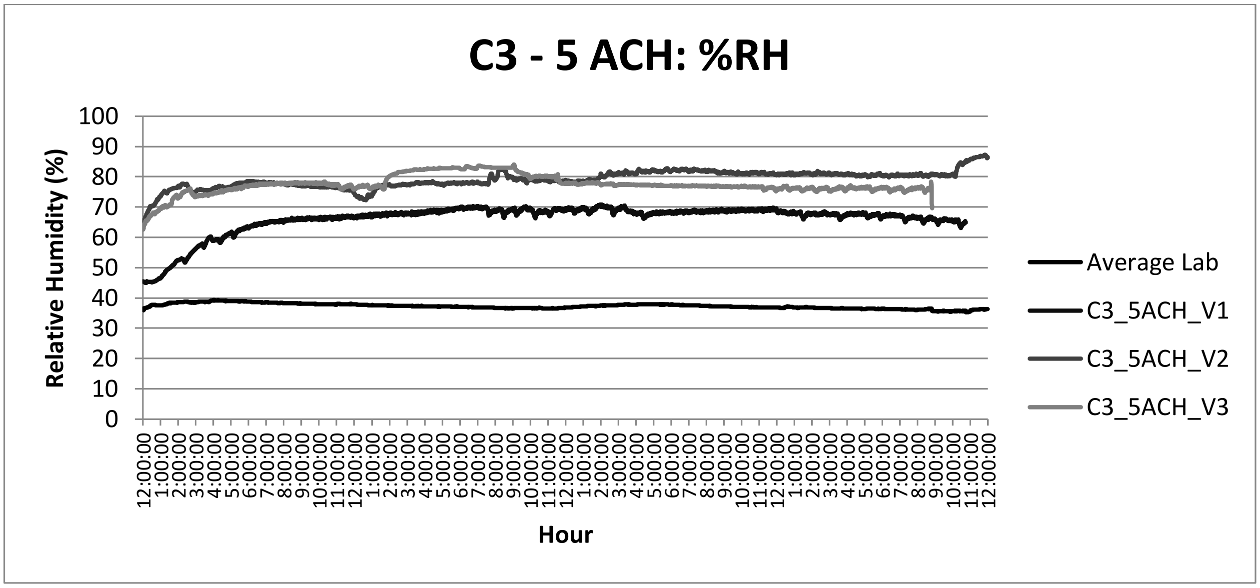


Figure 46 – C3, 5 ACH, %RH

Relative humidity was lowest during test V1, which also had a lower initial RH when compared to test V2 and V3. The initial conditions within the cavity appear to have a significant influence on RH levels through the remainder of the test. Test V1 likely had the chamber attached to the back of the wall for less time prior to the initial wetting, as it is closest to lab conditions.

There were a couple minor “dips” or “valleys” in the RH trend lines for test V2 and V3. This is caused by adjustments to the ventilation simulation equipment. This system is vulnerable to fluctuations in airflow rates and maintaining a constant suction rate is difficult. The fluctuations are caused by manual adjustments to the system.

4.7 C2 Series – 10 ACH

4.7.1 Absorption Evaporation and Penetration

4.7.1.1 Absorption

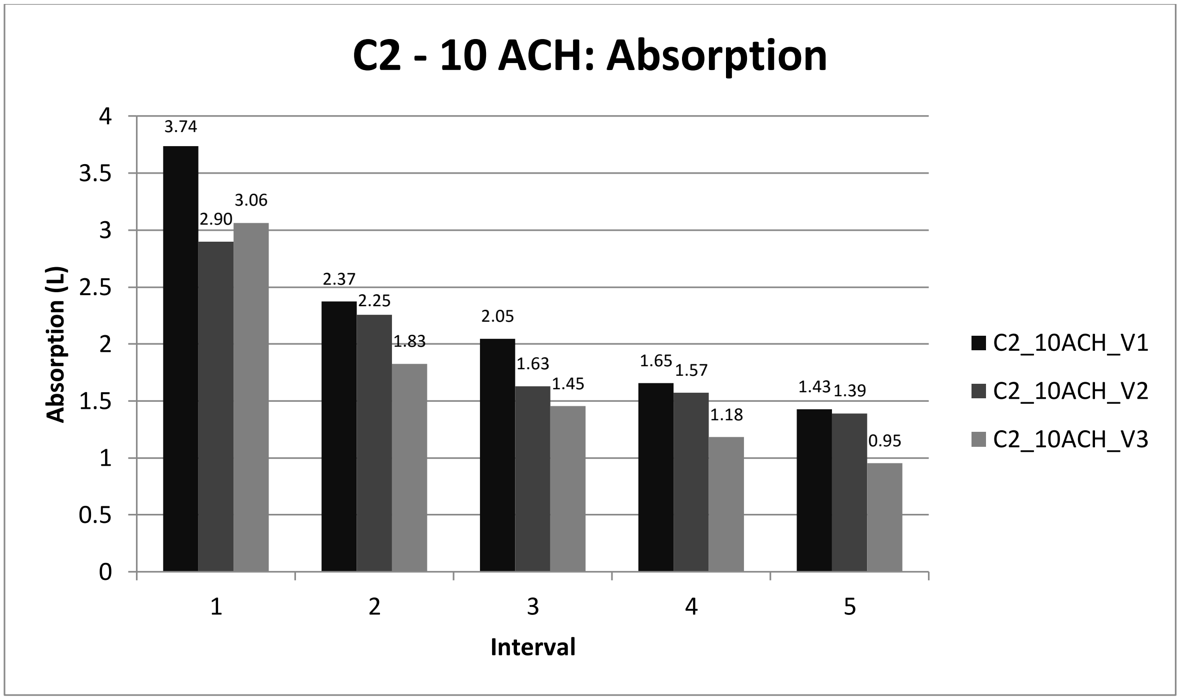


Figure 47 – C2, 10 ACH, absorption

Absorption quantities follow the familiar "ski-slope" trend seen in all previous test series. Absorption ranged from 0.95 L to 3.74 L. Each subsequent test absorbed less water than the previous test during each wetting cycle, except for the first interval.

4.7.1.2 Evaporation

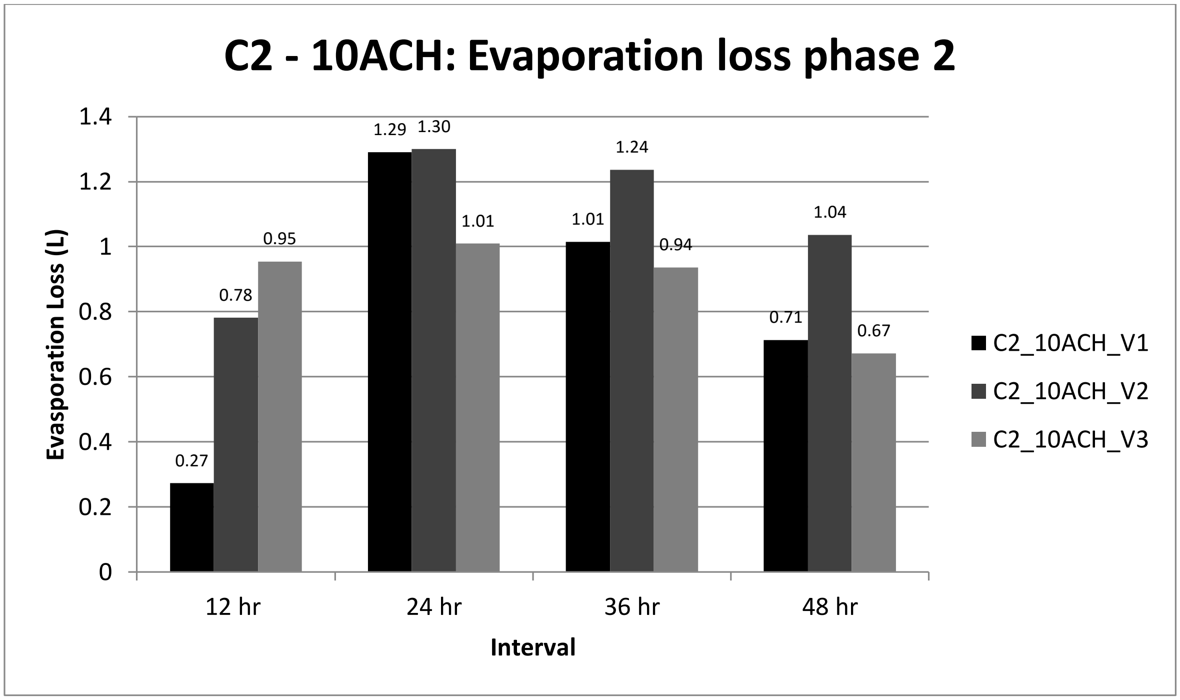


Figure 48 – C2, 10 ACH, evaporation loss phase 2

Highest evaporation rates were between the 12 and 24 hour time points. There was significantly more evaporation loss in test V2 compared to test V1.

4.7.1.3 Penetration

There was no measureable penetration in all three tests of this series.

4.7.2 Moisture Content

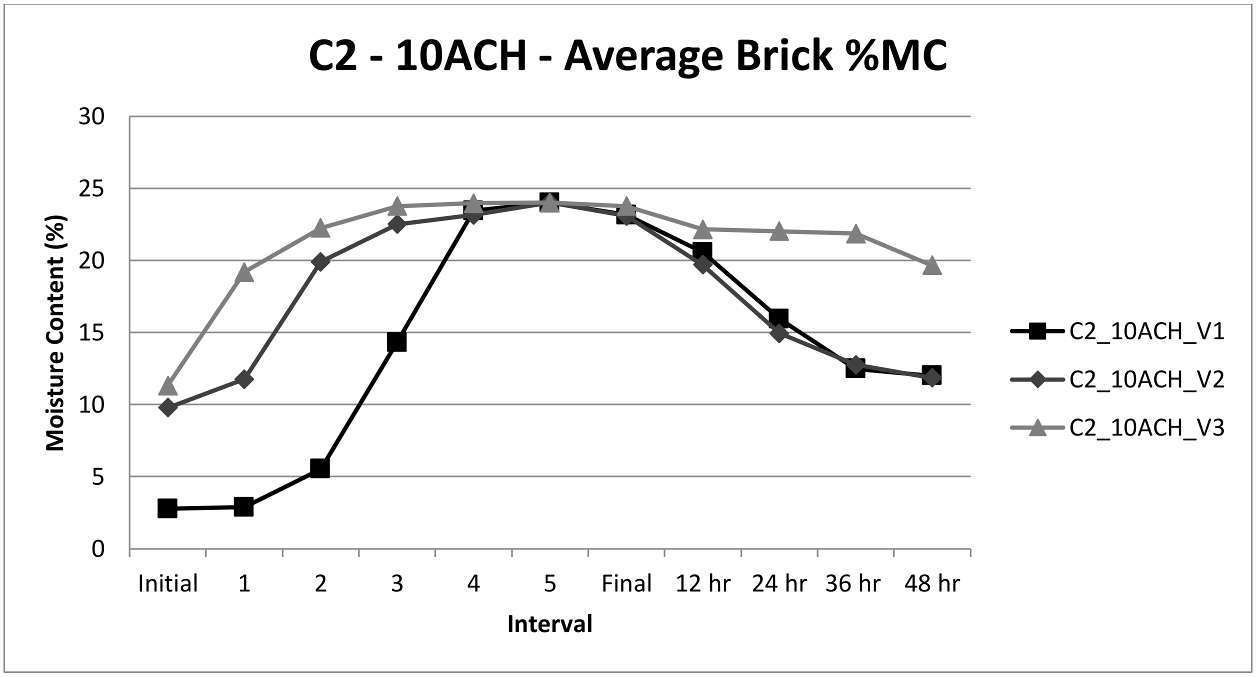


Figure 49 – C2, 10 ACH, brick %MC

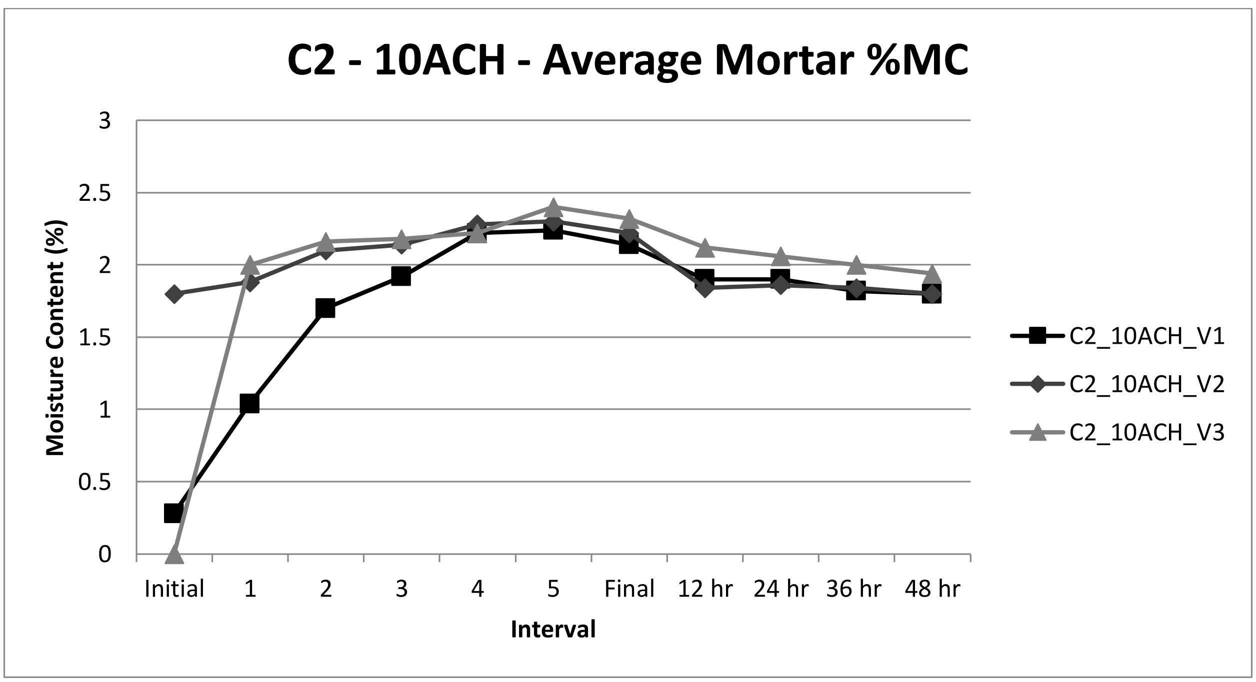


Figure 50 – C2, 10 ACH, mortar %MC

There is a significant difference in MC readings between test V1 and V2 during phase one of the experiment. This is seen in both the brick and mortar. During phase two, the MC profile in both tests are nearly identical. Part of this could be attributed to the limitations of the moisture content reader. The unit can read up to a maximum of 24% MC in masonry substrates. This maximum was reached during both tests (see appendix B), during the 4th and 5th wetting cycles. It is not known by how much over 24% each reading is. Assuming the wall in test V2 was damper during intervals 4 and 5, test V2 had more drying occur during phase 2 than test V1 based on the MC profile. Observing the measured evaporation loss confirms test V1 had 3.29 L of evaporation loss verses 4.35 L of evaporation loss in test V2. This confirms the suggestion of instrument limitation.

4.7.3 Air Temperature and Relative Humidity

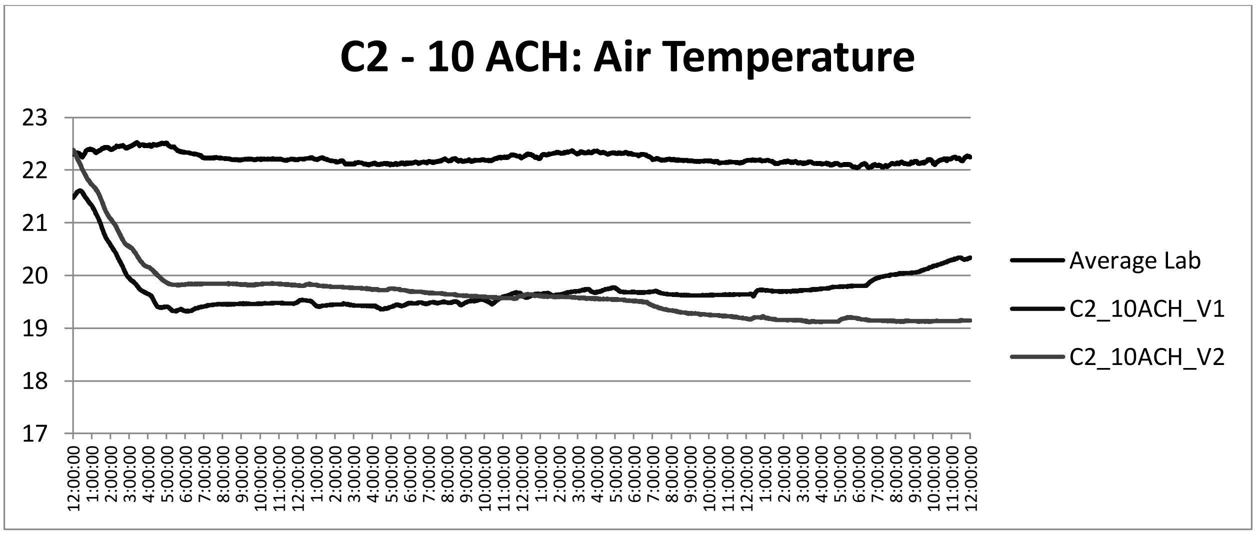


Figure 51 – C2, 10 ACH, air temperature

Air temperature decreases during phase one of the experiment by approximately 2 degrees Celsius. Test V1 showed initial temperatures considerably closer to lab conditions. This is likely because test V1 was the first test on this wall specimen which meant there was no evaporation off the wall occurring prior to the test. In addition, tap water had not yet cooled down the wall. This means regardless of the length of time the cavity chamber was installed prior to starting the test, temperatures were unaffected.

Test V1 and V2 mirror each other during phase two as V1 gradually increases in temperature and V2 decreases in temperature. The crossover occurs at the approximate midpoint of the test. This convergence occurs in other test series, specifically; C1 Series – No Ventilation and D2 Series – 10ACH. It has not been determined if this convergence is happening for a reason or if it is happenstance.

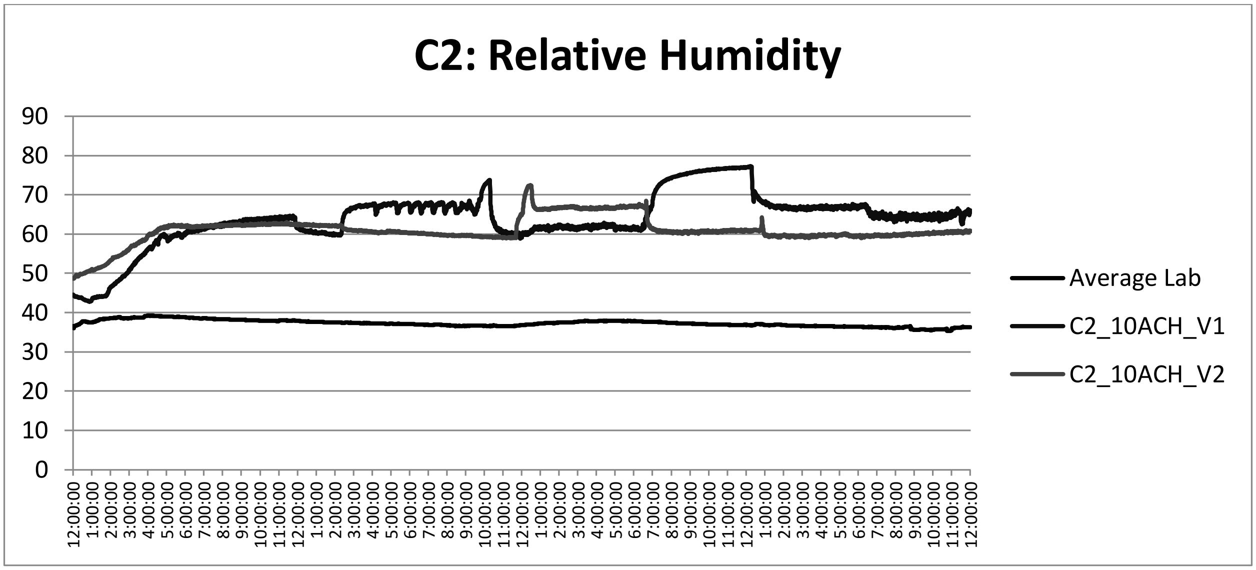


Figure 52 – C2, 10 ACH, %RH

Overall, RH levels in this series of tests are lower than those series with lower ventilation rates. However, the rate of ventilation does not remain constant throughout the test. This is a similar to the issue in D2 Series -10 ACH. There are stages in the tests where the ventilation fan appears to have suddenly dropped in speed thus decreasing the rate of ventilation and causing an increase in RH levels. Once the problem had been resolved manually, RH levels take a near vertical dive.

5.0 Comparative Analysis

5.1 Total Absorption

Total absorption, displayed below in Figure 53, is described as the total amount of water absorbed during phase one of the experiment.

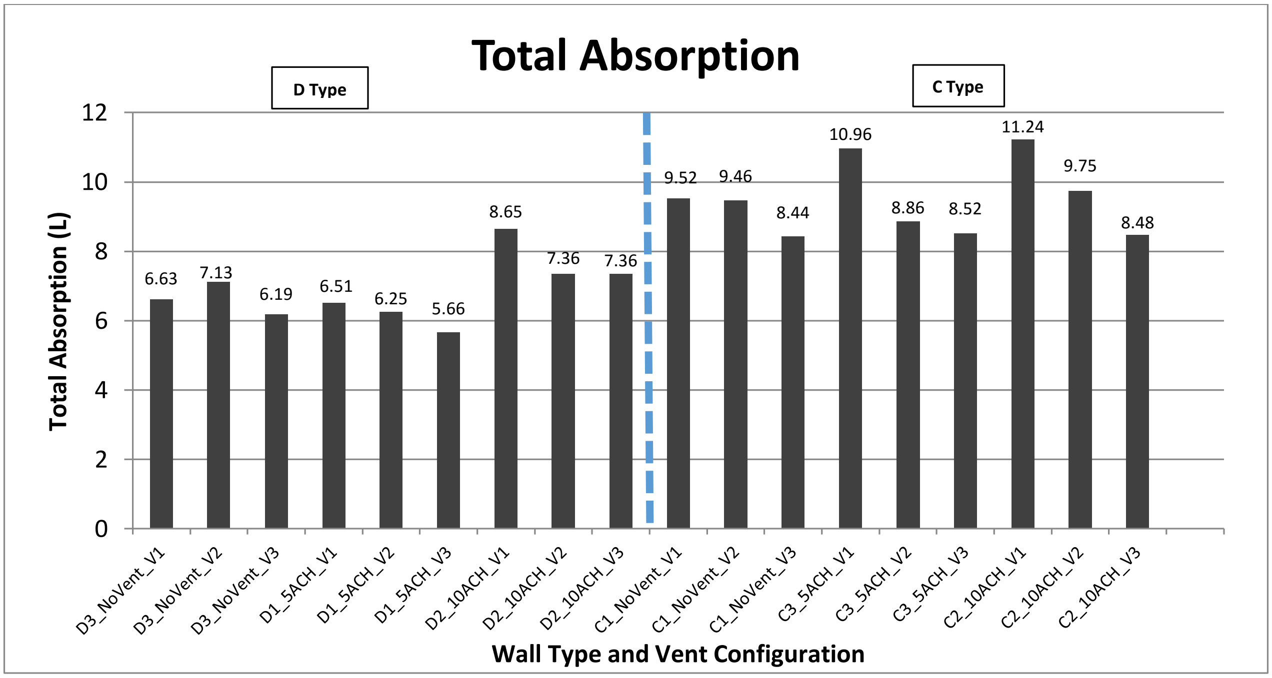


Figure 53 – Total absorption during phase one

Absorption is defined as the amount of water absorbed by each wall specimen during phase one of the experiment. The weight of the wall specimen was measured before and after each wetting cycle to determine the volume of water which had been absorbed.

The current investigation reports total absorption for wall type C in the range of 8.43 L to 11.23 L and 5.66 L to 8.65 L for wall type D. Overall, Type C wall absorbed more water than Type D, despite having a lower IRA. This is contradictory to Ou (2011), Straka (2013), who report absorption to be higher in wall type D after testing the same wall specimens using the ASTM E514 method. Ou (2011), Straka (2013) reported absorption in for each replicate of wall type C to be approximately 10 L and approximately 15 L for wall type D. Absorption values for wall type C appear to coincide with previous research, however values for wall type D show a significant difference. The reason for this difference could be due to the lack of a pressure gradient applied to the wall. Ou (2011), Straka and Gorkolewski (n.d), and Benjamin

(2011) all used pressure differentials to simulate WDR. The lack of pressure in the current study may have reduced the amount of water which was forced into the brick.

5.1.1 Wall Type D

The difference in total absorption between series D3 and D1 is minimal. Series D2 had the largest amount of absorption for wall type D. The debate is whether cavity ventilation has influenced the absorption rates of subsequent tests or if it is the material properties of the different walls themselves. To examine this, previous work by Ou (2011) will be used as baseline absorption values for wall type D. The table below summarizes the absorption values measured in Ou (2011) with those reported in the current investigation;

Wall Series D		
	Absorption (L)	
Specimen	Ou (2011) @ 500 Pa	Richards (2016) @ 0 Pa
D1	15.23	6.51 L
D2	17.05	8.65 L
D3	15.91	6.63 L

Table 7 – Absorption results from Ou (2011) and Richards (2016), performed ASTM E514

The initial test for each ventilation solution is used for the comparison as the walls were closest to the state they were in for testing in Ou (2011). D1 will be the reference point as it was had the lowest absorption. The percent increase in absorption from D1 to D3 and D3 to D2 in Ou (2011) is 4.27% and 6.69% respectively. The percent increase in absorption measured by the current study is 0.3% and 23.35%, respectively. There is almost no change in absorption from D1 to D3 despite the difference in ventilation rates. D2 had a significant jump in absorption but some of this can be explained by the material properties of the individual wall specimen. It is clear the individual characteristics of wall specimen D2 is a factor in the increased absorption values.

It is unlikely, based on the results of the current study and comparison to previous research, cavity ventilation increased the absorption capabilities of the wall type D.

5.1.2 Wall Type C

Absorption is higher in wall type C compared to wall type D. The only previous investigation at Ryerson which worked on wall type C and D was, Ou (2011). The initial test in each series was used for comparison. The absorption results are summarized below:

Wall Series C		
	Absorption (L)	
Specimen	Ou (2011) @ 500 Pa	Richards (2016) @ 0 Pa
C1	10.45	9.52 L
C2	10.23	10.96 L
C3	11.14	11.24 L

Table 8 – Absorption results from Ou (2011) and Richards (2016)

There is a similarity in the absorption results between the two investigations despite the differences in testing methodology. It appears the absorption characteristic of wall type C is relatively unaffected from increased exposure to water and increased pressure differentials across the wall.

The most significant difference in absorption is between the initial tests at each ventilation rate. Absorption values are closer together through subsequent tests which mean the ventilation rates do not impact the absorption characteristics of wall type C.

5.2 Total Evaporation

Total evaporation is described as the amount of water which has been lost due to evaporation during phase two of the experiment. Observing tests with the same repeat number, ie V1, V2 and V3, shows an increased amount of evaporation when higher ventilation rates are used.

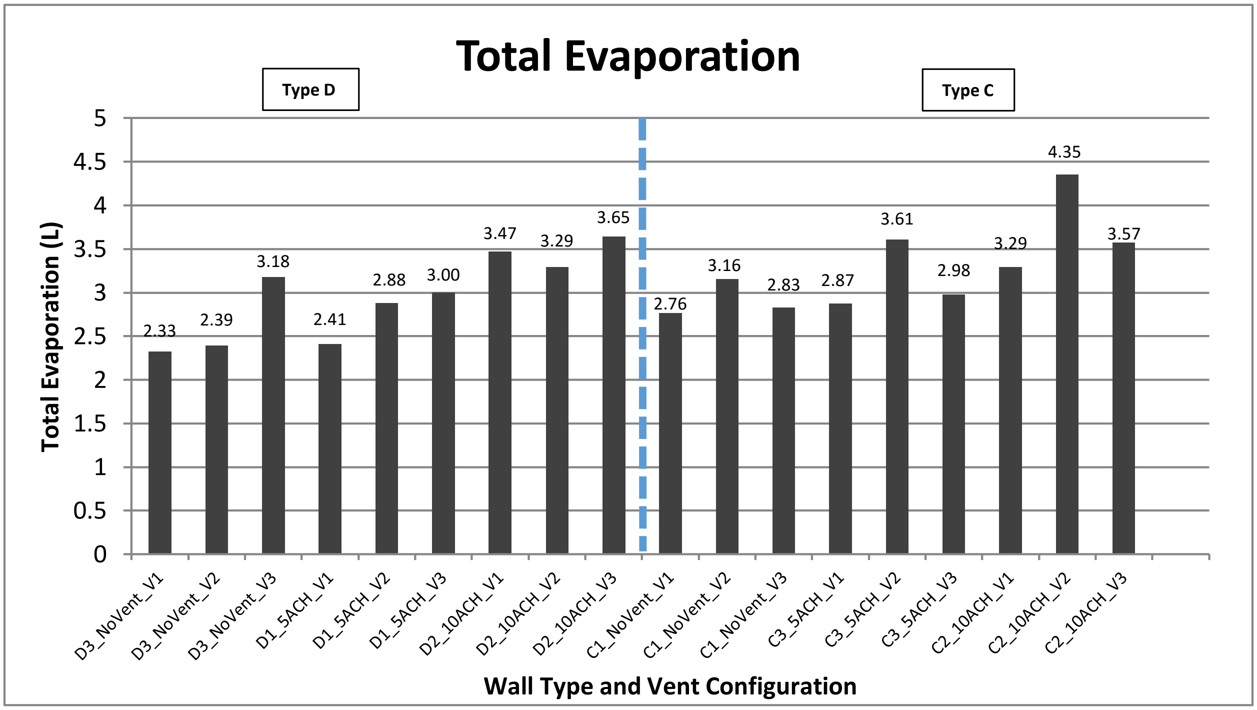


Figure 54 – Total evaporation during phase two

In two series of tests (D3_NoVent and D1_5ACH), wall specimens became damper through successive tests, more evaporation occurred. In all other series, this did not occur. The results from the two aforementioned series fit the logical assumption of; all else equal, wetter walls lose more water to evaporation over time. This was not observed in the other series which could be an indication of an inconsistent ventilation rate. However, this does indicate evaporation rates have been influenced by the rate of ventilation and are not just a function of the absorption properties of the walls.

The table below quantifies the change in total evaporation as the ventilation rate increases. Walls with same test repeat number are compared as they have received the same amount of water.

Test Repeat Number	Percent change in evaporation	
	No Vent to 5ACH	No Vent to 10 ACH
V1 – Wall D	3.32	32.85
V2 – Wall D	17.02	27.36
V3 – Wall D	-5.66	12.88
V1 – Wall C	2.47	16.11
V2 – Wall C	12.47	27.36
V3 – Wall C	5.03	20.73

Table 9 – Evaporation results analysis outlining percent change in evaporation rates with increased ventilation rates

Evaporation increased by 3.32% to 17.02% when the ventilation rate was set to 5ACH. When 10 ACH were used, evaporation increased by 12.88% to 32.85%. Apart from test D1_5ACH_V3, which had decreased evaporation, evaporation was significantly influenced by the rate of cavity ventilation. Higher ventilation rates resulted in more efficient drying of the wall. For example, each air change rate past 5 ACH resulted in more drying per unit increase of ACH compared to ACH 0 to 5.

5.3 Penetration

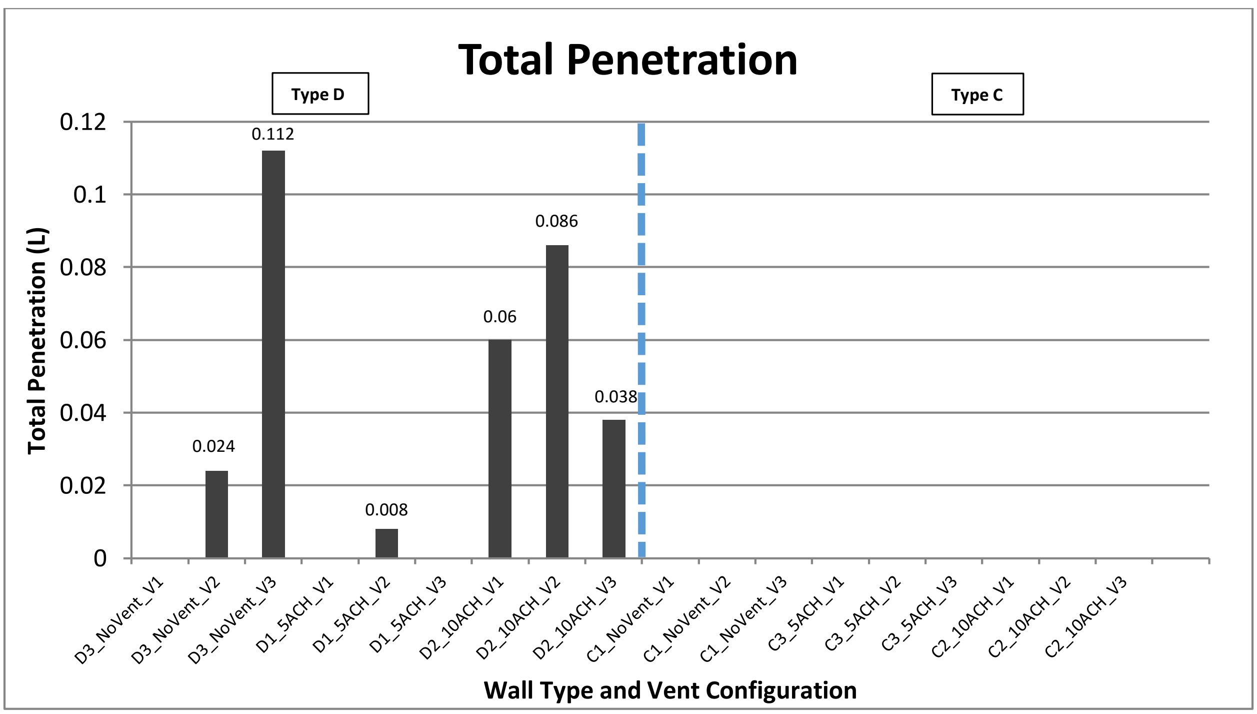


Figure 55 – Total penetration results for all tests

There was no measureable water leakage in all tests for wall type C. Test D3_NoVent_V3 had the largest amount of total penetration with 0.112 L. This was expected as the wall was unventilated and the wall was wettest during this test. The D1 series had measureable penetration on the second test (V2), at 0.008 L. Series D2, had the largest amount of water penetration through all three tests, despite receiving a treatment of 10 ACH. Previous research by Ou (2011) shows that penetration results for the three wall type D specimens are similar to each other (6.46 L, 5.90 L and 6.57 L), with specimen D2 having the least amount of penetration of the three at 5.90 L. However, the current investigation shows wall specimen D1 has the least amount of penetration through three successive tests.

The author proposed as ventilation rates increase, the amount of water which penetrated through the brick veneer wall would decrease. Using the methodology proposed in this investigation, the results are inconclusive with regards to the suggestion of a negative relationship between cavity ventilation rates and water penetration through brick veneer. At low pressure differentials and low volumes of WDR, water penetration appears to be heavily influenced by the different individual characteristics of the wall specimens. The set of three replicates for each wall type are built from the same materials, but the material properties themselves vary significantly from unit to unit. This makes WDR testing on brick veneer walls difficult when using lower volumes of water.

5.4 Relative Humidity

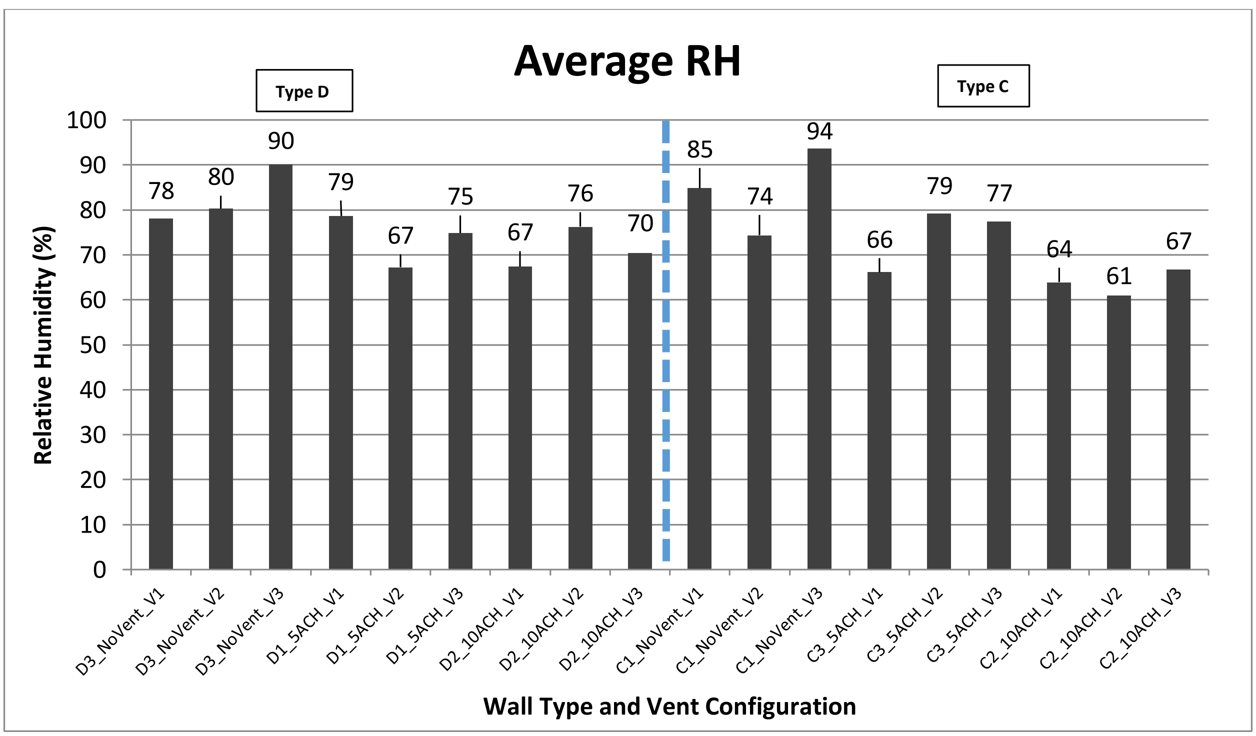


Figure 56: Average relative humidity during test

The relative humidity reported in the above graph has been averaged over 48 hours for each test. Overall, there is a decrease in RH in cavities exposed to higher ventilation rates. The highest average RH is found in cavities with no ventilation, while the lowest average RH occurs in cavities with ventilation.

5.5 Moisture Content

Moisture content was generally low for a typical brick veneer walls, in both the brick and mortar. Typical brick MC were between 2% – 3% while mortar MC was 0% - 0.5%. This caused a significant increase in the overall moisture content during the second repeat test of each series, while less of an increase during the third repeat of each test. MC content readings were generally higher in type C brick than type D towards the end of the test phase one. This suggests increased absorption occurring in type C, which was measured through weighing the wall specimens. These two results linked together to form a stronger assertion than absorption results are not a fluke. In most cases, subsequent tests with higher ventilation rates had lower MC readings in both the brick and mortar.

5.6 Conclusions

Upon completing this investigation, the major conclusions as they relate to the research objectives and questions are as follows:

1. Water penetration was higher in brick type D than brick type C, and absorption was higher in wall type C than wall type D. In general, cavity ventilation did not influence the absorption and penetration characteristics of the wall specimens. It was not determined if increased ventilation rates decrease the amount of penetrating water through the brick veneer because the results were inconclusive. Wall type C had no measured penetration regardless of the ventilation rate, making comparisons difficult. Investigating this matter further would require a redesign of the test to mitigate the impact of different physical properties between specimens of the same wall type. It is proposed, to test each wall specimen at three different cavity ventilation rates rather than one wall specimen at one specific ventilation rate. This method would allow the investigator to study the impact of cavity ventilation on one wall specimen, with the same physical properties. Increasing the duration of the wetting period to the point where penetration can be measured in wall type C may provide more insight however, this would stray away from the original intent of the study of simulating natural conditions.

2. Initial moisture content readings before testing were the same for both wall types. Cavity ventilation did not appear to influence the initial MC of subsequent tests. Through successive wetting cycles, MC readings reached higher peaks in wall type C. This was attributed to the physical characteristics of the brick rather than cavity ventilation. This is an indication of higher absorption occurring in wall type C. Final MC in the mortar in both wall types was unaffected by cavity ventilation. In some tests, final MC was lower in the brick with high cavity ventilation rates. This did not always occur as some tests with lower cavity ventilation also had lower final MC. The properties of the bricks and mortar themselves have a strong influence on moisture content readings.

3. There is a negative relationship between ventilation rates and cavity RH. Increased ventilation results in decreased cavity RH. Increasing the cavity ventilation rate results in higher rates of evaporation, thus there is a positive relationship. The difference in evaporation between a non-ventilated cavity and 5 ACH is small, however there is a significant difference in evaporation when 10 ACH is used. Higher cavity ventilation rates are more efficient drying than lower rates.

4. The effectiveness of the study method can be evaluated in three parts; absorption/penetration, moisture content, and cavity conditions. Absorption measurements were successful and came with a low margin of error. Penetration was not adequately studied because an effective method of retrieving trapped water inside the cavity was not devised. Moisture content readings were unreliable due to complications with instrumentation. The cavity chamber was proven to have created a microclimate which was independent from the lab environment, however the simulated cavity ventilation was problematic. Changes to the experiment are expressed in more detail in section 6.4. The lessons learned are the most significant academic benefits of this research study. A foundation has been created to build upon for future researchers.

6.0 Discussion

6.1 Sources of Error and Limitations

6.1.1 Penetration Measurement

Water penetration through the brick veneer panels was measured by collecting said water at the base of the cavity chamber with a moisture absorbent cloth. This method made the assumption all water which penetrated through the brick veneer would travel down the back of the wall, drain past the insulation and onto the cloth. In practice, this did not occur. Once moisture had penetrated through the brick wall specimen, there were a number of events which occurred.

i) Water accumulated on the mortar droppings or in raked mortar joints instead of draining to the bottom of the wall.

ii) Water drained downward, outside the test area and collected on raked mortar joints where the water was re-absorbed into the bricks which were not exposure to the simulated WDR. This is exemplified in Figure 57.

Figure 57 – Photograph showing water accumulating on a raked mortar joint, outside the test area.

iii) If there was enough accumulation of water on the mortar dropping, sometimes the water would drain and fall off the wall, landing on the bar of insulation at the bottom of cavity chamber. This moisture could not be measured without removing the cavity chamber. An example of the accumulation can be seen in Figure 58.

Figure 58 – Photograph showing moisture accumulation on mortar droppings.

Due to the three factors outlined above, the reported values for water penetration are lower than what was expected on the base of visual observation.

6.1.2 Water Delivery Grid

The original design of the water distribution grid was to use twelve misting heads positioned 30 cm from the wall to provide sufficient coverage. The spread of the misting heads is dependent on the amount of available water flow. Initial mock tests showed this was not possible with the equipment because too much water was being delivered to the wall specimen for the desired spread pattern. As a result, the flow had reduced, therefore reducing the diameter of the spread pattern. This resulted in an uneven distribution of water should the delivery grid stay stationary. Figure 59 shows the actual spread pattern which was used in the investigation.

Figure 59 – Photograph showing the actual spread pattern used in the investigation

This spread pattern required the investigator to shift the water delivery grid throughout the 15 minute wetting cycles to provide an even distribution. The grid was shifted twice, moving left to right, during each wetting interval for a total of five minutes in each position. Without this technique, a significant portion of the wall would not be exposed to the simulated WDR. The only test which did not receive this treatment was D3_NoVent_V1. The effect of this can be seen in the absorption results as the subsequent test in that series (V2) absorbed more water.

6.1.3 Water Supply System

The flow meter which aided in controlling the rate of water flow to the distribution grid was examined for functionality by comparing the total flow measured by the device during a wetting cycle, to the amount of water which was absorbed, shed or penetrated through the brick wall specimen. Assuming there are no losses and the flow meter has been calibrated, the two values should be same. In practice, the flow meter measured 3 L to 4 L more water than what was accounted for by deflection, absorption and penetration. It was initially thought the length of hose between the flow meter and the distribution grid could be causing the problem, but shortening the length of this hose did not affect the results. The bench scale used to measure the deflected water was investigated and a basic calibration procedure showed 1 L of water measured 996 grams on the scale. This instrument was ruled out a major source of error. The only logical conclusion was the flow meter had not been calibrated properly or was malfunctioning.

During the course of the investigation, the flow meter had a catastrophic failure and was rendered useless. The unit was not repaired in time to be used in subsequent tests. The water distribution grid was designed to emit water at rate of 125L/hr when the tap valve was fully open. This is the maximum flow which could be applied to the wall specimens. Small adjustments to an inline value were made to decrease the flow to the desired value. With no working flow meter, the increments had to be made with visual ques. The investigator had some experience with the general position of the inline valve to reach 100 L/hr however, the real rate of water delivery was not precisely known.

6.2 Measuring Evaporation During Phase 1

Part of the original intent of the study was to measure evaporation during phase one of the experiment. This would be done by measuring the wall specimen weight before and after each drying cycle to determine the difference in weight. The difference would then be equated to a volume of water. Upon calibration of the scale used to measure the wall specimen weight, it became clear it was not possible to report these values with any degree of certainty. Calibrated weights were used to measure the sensitivity of the scale. For instance, a 1 Kg weight would read 2.20 Lbs on the scale, and a 0.2 kg weight measured approximately 0.44 Lbs on the scale. However, when using a calibrated weight of less than 0.1 Kg, the error became +- 50 grams. Measuring specimen weight during phase one of the experiment was performed regardless because absorption values were needed, this required specimen weights. The results show quantities ranging from 0 to 100 ml of water loss during the drying cycles.

6.3 Water Balance

The total volume of water was originally calculated via an electromagnetic flow meter. However, this instrument proved to be unreliable and eventually malfunctioned completely. In order to determine the water balance during each test, the total amount of water delivered during each test was calculated by adding together the water which was shed from the wall, water which was absorbed into the wall, and penetrated water. The amount of losses due to dripping from the misting heads, a leakage off the draining trough was insignificant. The water balance gives an idea about the uniformity of water delivery through each test in the investigation.

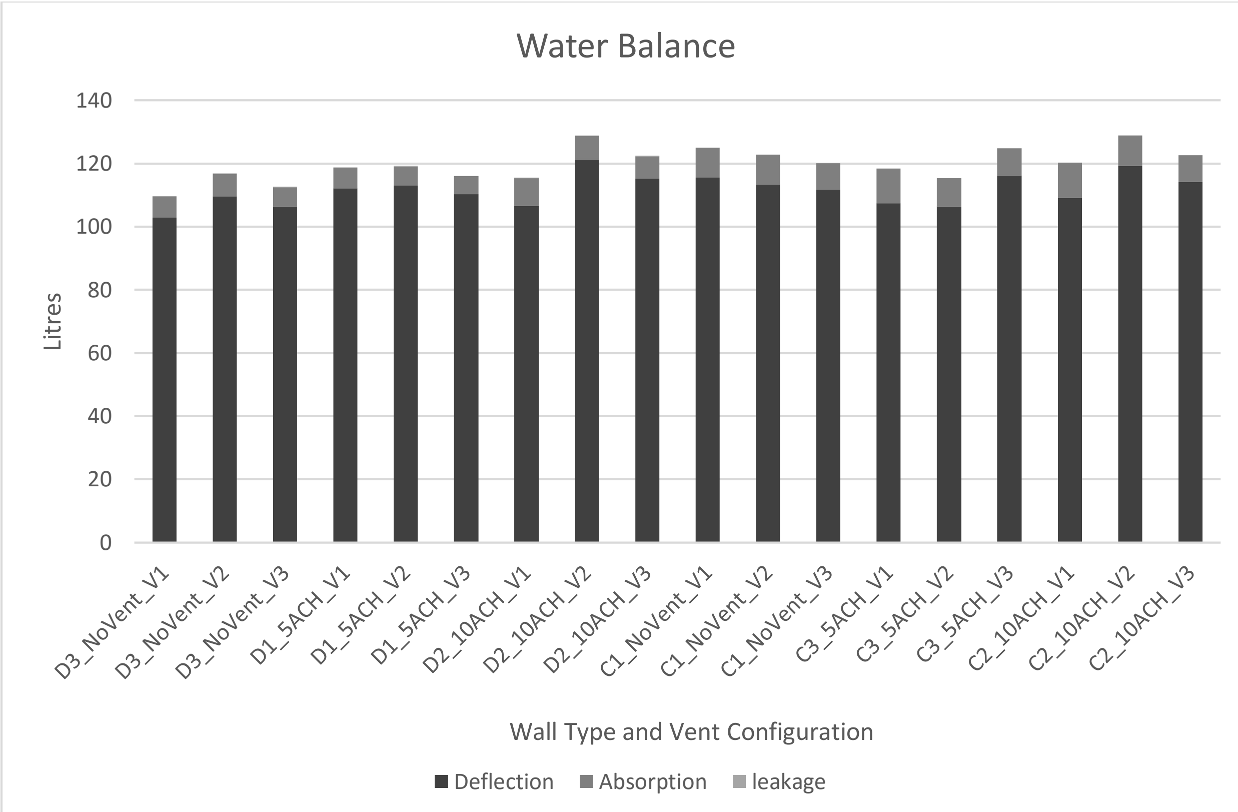


Figure 60 – Water balance showing deflection, absorption and leakage

6.4 Recommendations for Future Work

1. The length of test should be increased to further examine the drying process. 48 hours limited the amount of time available to measure evaporation differences among wall samples. It was clear that relative humidity was still increasing by the end of the test, indicating that evaporation was still occurring. A longer test may further delineate tests with varying evaporation rates and allow for more change in moisture content.

2. The ventilation strategy should be redesigned to provide consistent suction, particularly at high ventilation rates. Ideally, separate cavities for each wall specimen should be built and installed with airtight seals. The cavity side of bricks are uneven resulting in rigid insulation board passing over various grooves and inconsistencies rather than filling them in. These gaps were not sealed effectively because repeated removal of the cavity chamber was favoured. The suction apparatus itself should also be redesigned with a permanent solution. It was originally designed for modularity, but at the cost of air tightness. Cavity ventilation calculations were based on the

assumption that all air which removed at the top of the cavity chamber via suction, is replaced by air which enters the through the bottom vent. Due to the air tightness issues, the theoretically designed ACH was likely higher than the actual ACH in the cavity chamber because air was pulled through other areas. It was not possible to measure the magnitude of this error.

The fan providing suction was not rated for variable speeds, so any intentional blockage of intake air to change cavity ACH resulted in stress on the fan motor which consistently caused the fan to fail. A variable speed motor would help this problem. In addition, a lower CFM fan would reduce the amount of adjustments required to lower the active suction

3. Increased amounts of absorption results in increased amounts of evaporation. This issue caused some uncertainty for interpreting the impact of cavity ventilation. It was found that certain wall specimens of the same wall type absorbed different volumes of water. The design of the study tested one ventilation rate per wall specimen which made it difficult to determine if changes in evaporation rates were a result of the cavity ventilation, or due to the difference in water absorbed by the wall specimen. Future investigations should apply different ventilation rates to the same wall specimens to properly measure the influence of cavity ventilation on penetration and absorption. Such an experiment for example, would take wall specimen C1, C2, C3, and test each specimen three times, once at 0 ACH, 5 ACH and 10 ACH. The researcher would now have results for cavity ventilation rates across three different wall specimens rather than one, adding more rigor to the research.

4. The method of moisture content measurement in this study did not yield reliable results. The researcher found it difficult to read specific percentages on the instrument readout display because the readings would jump up and down significantly within a short time span of less than a couple seconds. This issue became increasingly more difficult as the walls became more damp through successive tests. It is theorized that the drill points for the moisture pins had been compromised by some sort of water entry. Either the silicone seal became compromised, or water migrated from internal brick or mortar layers into the drill hole. Upon inspection, there was no visible evidence such as rust or liquid water that pointed to water migration. However, it was determined through trial, even a small amount of water on the surface of the pin was able to influence the reading on the instrument.

Other trials were performed to determine if the same issues occurred in different building materials. SPF (Spruce Pine Fur) timber was tested by nailing two pins with a hammer to a 2x4 stud. The stud was submerged in water for several hours. In general, the live readout on the instrument was significantly more stable when measuring wood MC. Measuring MC in wood did not require a pre drilled hole to insert the nails, resulting in a much smaller gap between the nail and the wood inside the hole. It is possible this influenced the readings.

Electrical resistance has been proven to provide accurate moisture content readings in mineral materials (Sachse et al. 2015). It is the implementation of this phenomenon which affects the accuracy of these measurements. An alternative to the method used in this study could involve the embedding of physical instrumentation into the wall. Williams (2015) installed moisture calibrated wood hemlock dowels into brick walls to measure the wood moisture content equivalent. As the brick walls became damper, the dowel absorbs more water and the electrical resistance changes, which can be measured by the device. Actual measurements are recorded by a data logger rather than manually by hand which can provide increased resolution. Using this method, the researcher did not report significant issues with the measurement process.

5. All instrumentation should receive proper calibration and testing to measure accuracy and durability, particularly if lengthy test durations are performed. Manufacturers should be contacted and used as valuable resources to troubleshoot problems with instrumentation. Adequate lead-time prior to initiating tests is important to reduce problems and sources of error.

Appendix A – Raw Data: Absorption, Blockage, Penetration

C1_NoVent_C1_Dec2

Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	4:00	15	15						
1	off	4:15	40	55	1130.455	1157.035	992.56	998.86	998.46	no water whatsoever
	on	4:50	15	70						
2	off	5:05	40	110	1157.035	1182.167	998.46	1003.2	1003.02	
	on	5:45	15	125						
3	off	6:00	40	165	1182.167	1208.605	1003.02	1006.8	1006.6	
	on	6:40	15	180						noticed 5 minutes were lost around this time
4	off	6:55	40	220	1208.605	1234.993	1006.6	1009.84	1009.64	
	on	7:35	15	235						
5	off	7:50	40	275	1234.993	1262.866	1009.64	1012.52	1012.32	
Finished		8:30								
@12 hours	hours								1011.14	
@24 hours									1009.22	
@29 hours										
@36 hours									1007.54	
@48 hours									1006.24	

Interval	Absorl	Water Evaporated du	Blockage	Total water delivered	Leakage	Difference
1	2.864		20.524	26.58	0	3.192
		0.181818182				
2	2.155		20	25.132	0	2.977
		0.081818182				
3	1.718		20.938	26.438	0	3.782
		0.090909091				
4	1.473		21.146	26.388	0	3.769
		0.090909091				
5	1.309		23.398	27.873	0	3.166
		0.090909091				
6						
12 hr		0.536363636				
24 hr		0.872727273				
36 hr		0.763636364				
48 hr		0.590909091				

C1_NoVent_V2_Dec10

Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	5:00	15	15						
1	off	5:15	40	55	1527.517	1552.969	1003.08	1010.36	1010.34	no penetration, but mortar has become noticeably more damp.
	on	5:55	15	70						
2	off	6:10	40	110	1552.969	1579.168	1010.34	1014.4	1014.4	
	on	6:50	15	125						
3	off	7:05	40	165	1579.168	1605.86	1014.4	1018	1018	still no penetration
	on	7:45	15	180						
4	off	8:00	40	220	1605.86	1632.582	1018	1021.12	1021	small leakage at location 1 and 4
	on	8:40	15	235						
5	off	8:55	40	275	1632.582	1658.765	1021	1023.76	1023.7	
		9:35								
Finished										
@12 hours									1023.397	
@24 hours									1020.477	
@36 hours									1018.637	
@48 hours									1017.117	

significantly more absorption is likely due to the new technique of moving the water grid over every 5 minutes to provide more even distribution. More dry bricks are being exposed to the water.

Interval	r Absorb	Water Evaporated du	Blockag	Total water del	Leakage	Difference
1	3.309		18.14	25.452	0	4.003
		0.009090909				
2	1.845		20.714	26.199	0	3.640
		0				
3	1.636		21.834	26.692	0	3.222
		0				
4	1.418		21.774	26.722	0	3.530
		0.054545455				
5	1.255		21.474	26.183	0	3.454
		0.027272727				
6						
12 hr		0.137727273				
24 hr		1.327272727				
36 hr		0.836363636				
48 hr		0.690909091				

C1_NoVent_V3			no flow meter							
Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	1:45	15	15						
1	off	2:00	40	55	x	x	1007.6	1014.72	1014.52	
	on	2:40	15	70						
2	off	2:55	40	110	x	x	1014.52	1018.42	1018.34	
	on	3:35	15	125						
3	off	3:50	40	165	x	x	1018.34	1021.16	1021.1	
	on	4:30	15	180						
4	off	4:45	40	220	x	x	1021.1	1023.54	1023.5	leakage starting to appear at location 1 ,2 and 6
	on	5:25	15	235						
5	off	5:40	40	275	x	x	1023.5	1025.78	1025.74	
		6:20								
Finished										
@12 hours									1024.757	
@24 hours									1023.03479	
@36 hours									1021.297	
@48 hours									1019.517	

Interval	ter Absorbed	Water Evaporated	Blockage	Total water delivere	Leakage
1	3.236		19.662	#VALUE!	0
		0.090909091			
2	1.773		20.7	#VALUE!	0
		0.036363636			
3	1.282		19.028	#VALUE!	0
		0.027272727			
4	1.109		22.33	#VALUE!	0
		0.018181818			
5	1.036		21.624	#VALUE!	0
		0.018181818			
6					
12 hr		0.446818182			
24 hr		0.782822727			
36 hr		0.789904545			
48 hr		0.809090909			

C3_5ACH_V1_Dec15			no flow meter							
Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	4:30	15	15						
1	off	4:45	40	55	x	x	1001.2	1008.7	1008.48	
	on	5:25	15	70						
2	off	5:40	40	110	x	x	1008.48	1013.6	1013.52	
	on	6:20	15	125						
3	off	6:35	40	165	x	x	1013.52	1017.9	1017.88	mortar has become noticeably darker indication it has become damp
	on	7:15	15	180						
4	off	7:30	40	220	x	x	1017.88	1021.52	1021.12	
	on	8:10	15	235						
5	off	8:25	40	275	x	x	1021.12	1024.6	1024.32	small penetration at locations 3 and 4
		9:05								
Finished										
@12 hours									1023.157576	
@24 hours									1020.777	
@36 hours									1019.377	
@48 hours									1017.997	

Interval	r Absorbe	Water Evaporated	Blockage	Total water del	Leakage
1	3.409		16.83	#VALUE!	0
		0.1			
2	2.327		21.208	#VALUE!	0
		0.036363636			
3	1.991		21.248	#VALUE!	0
		0.009090909			
4	1.655		20.64	#VALUE!	0
		0.181818182			
5	1.582		16.534	#VALUE!	0
		0.127272727			
6					
12 hr		0.528374655			
24 hr		1.082079891			
36 hr		0.636363636			
48 hr		0.627272727			

C3_5ACH_V2_Dec18			no flow meter							
Interval	**Water**	**Time of Day**	**Interval**	**Elapsed Time**	**Previous Flow Reading**	**Current Flow Reading**	**Weight Before Wetting**	**Weight after wetting**	**Weight After Drying Period**	
	on	3:45	15	15						
1	off	4:00	40	55	x	x	1010.94	1017.7	1017.64	
	on	4:40	15	70						
2	off	4:55	40	110	x	x	1017.64	1021.8	1021.74	
	on	5:35	15	125						
3	off	5:50	40	165	x	x	1021.74	1025.12	1025.02	
	on	6:30	15	180						
4	off	6:45	40	220	x	x	1025.02	1027.84	1027.78	small lekage at location 7, not much
	on	7:25	15	235						
5	off	7:40	40	275	x	x	1027.78	1030.16	1030.04	
		8:20								
Finished										
@12 hours									1028.537	
@24 hour:									1026.137	
@36 hours									1023.137	
@48 hours									1022.097	
									1021.097	

Interval	er Absorbe	Water Evaporated	Blockage	Total water del	Leakage
1	3.073		19.034	#VALUE!	0
		0.027272727			
2	1.891		18.938	#VALUE!	0
		0.027272727			
3	1.536		19.852	#VALUE!	0
		0.045454545			
4	1.282		17.97	#VALUE!	0
		0.027272727			
5	1.082		21.864	#VALUE!	0
		0.054545455			
6					
12 hr		0.683181818			
24 hr		1.090909091			
36 hr		1.363636364			
48 hr		0.472727273			

C3_5ACH_V3_Dec21			no flow meter							
Interval	**Water**	**Time of Day**	**Interval**	**Elapsed Time**	**Previous Flow Reading**	**Current Flow Reading**	**Weight Before Wetting**	**Weight after wetting**	**Weight After Drying Period**	
	on	6:15	15	15						
1	off	6:30	40	55	x	x	1020.92	1027.52	1027.42	
	on	7:10	15	70						
2	off	7:25	40	110	x	x	1027.42	1031.44	1031.4	entire back mortar is damp
	on	8:05	15	125						
3	off	8:20	40	165	x	x	1031.4	1034.56	1034.5	
	on	9:00	15	180						
4	off	9:15	40	220	x	x	1034.5	1036.86	1036.74	very minor leakage at point 1
	on	9:55	15	235						
5	off	10:10	40	275	x	x	1036.74	1039.34	1039.2	
		10:50								
Finished										
@12 hours									1038.2	
@24 hour:									1036.32	
@36 hours									1034.5	
@48 hours									1032.65	

Interval	er Absorbe	Water Evaporated	Blockage	Total water del	Leakage
1	3.000		22.254	#VALUE!	0
		0.045454545			
2	1.827		20.567	#VALUE!	0
		0.018181818			
3	1.436		20.348	#VALUE!	0
		0.027272727			
4	1.073		22.152	#VALUE!	0
		0.054545455			
5	1.182		22.47	#VALUE!	0
		0.063636364			
6					
12 hr		0.454545455			
24 hr		0.854545455			
36 hr		0.827272727			
48 hr		0.840909091			

C2_10ACH_V1_Dec19			no flow meter							
Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	5:15	15	15						
1	off	5:30	40	55	x	x	999.44	1007.66	1007.58	
	on	6:10	15	70						
2	off	6:25	40	110	x	x	1007.58	1012.8	1012.66	small leakage at point 7
	on	7:05	15	125						
3	off	7:20	40	165	x	x	1012.66	1017.16	1017.08	interesting white coloration on the tips of the mortar droppings.
	on	8:00	15	180						
4	off	8:15	40	220	x	x	1017.08	1020.72	1020.52	
	on	8:55	15	235						
5	off	9:10	40	275	x	x	1020.52	1023.66	1023.437	
		9:50								
Finished										
@12 hours									1022.837	
@24 hour:									1020	
@36 hours									1017.767	
@48 hours									1016.197	

Interval	r Absorb	Water Evaporated	Blockage	Total water del	Leakage				
1	3.736		19.498	#VALUE!	0				
		0.036363636							
2	2.373		21.808	#VALUE!	0				
		0.063636364							
3	2.045		21.28	#VALUE!	0				s
		0.036363636							
4	1.655		20.768	#VALUE!	0				
		0.090909091							
5	1.427		14.486	#VALUE!	0				
		0.100894477							
6									
12 hr		0.272727273							
24 hr		1.289545455							
36 hr		1.015							
48 hr		0.713636364							

C2_10ACH_V2_Dec27			no flow meter						
Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	eight Before Wetting	Weight after wetting	Weight After Drying Period
	on	1:35	15	15					
1	off	1:50	40	55	x	x	1012.02	1018.4	1018.22
	on	2:30	15	70					
2	off	2:45	40	110	x	x	1018.22	1023.18	1023.06
	on	3:25	15	125					
3	off	3:40	40	165	x	x	1023.06	1026.64	1026.46
	on	4:20	15	180					
4	off	4:35	40	220	x	x	1026.46	1029.92	1029.74
	on	5:15	15	235					
5	off	5:30	40	275	x	x	1029.74	1032.8	1032.72
		6:10							
Finished									
@12 hours									1031
@24 hour:									1028.14
@36 hours									1025.42
@48 hours									1023.14

Interval	r Absorb	Water Evaporated du	Blockag	Total water del	Leakage				
1	2.900		19.463	#VALUE!	0				
		0.081818182							
2	2.255		24.016	#VALUE!	0				
		0.054545455							
3	1.627		22.046	#VALUE!	0				s
		0.081818182							
4	1.573		22.48	#VALUE!	0				
		0.081818182							
5	1.391		21.492	#VALUE!	0				
		0.036195328							
6									
12 hr		0.781818182							
24 hr		1.3							
36 hr		1.236363636							
48 hr		1.036363636							

			no flow meter							
Interval	**Water**	**Time of Day**	**Interval**	**Elapsed Time**	**Previous Flow Reading**	**Current Flow Reading**	**Weight Before Wetting**	**Weight after wetting**	**Weight After Drying Period**	
	on	1:20	15	15						
1	off	1:35	40	55	x	x	1020.92	1027.66	1027.52	
	on	2:15	15	70						
2	off	2:30	40	110	x	x	1027.52	1031.54	1031.22	
	on	3:10	15	125						
3	off	3:25	40	165	x	x	1031.22	1034.42	1034.3	
	on	4:05	15	180						
4	off	4:20	40	220	x	x	1034.3	1036.9	1036.7	small amount of water transmittance, unable to quantify
	on	5:00	15	235						
5	off	5:15	40	275	x	x	1036.7	1038.8	1038.6	
		5:55								
Finished										
@12 hours									1036.5	
@24 hour:									1034.28	
@36 hours									1032.22	
@48 hours									1030.74	

Interval	**r Absorb**	**Water Evaporated**	**Blockage**	**Total water del**	**Leakage**	
1	3.064		18.172	#VALUE!	0	
		0.063636364				
2	1.827		20.91	#VALUE!	0	
		0.145454545				
3	1.455		22.516	#VALUE!	0	s
		0.054545455				
4	1.182		21.21	#VALUE!	0	
		0.090909091				
5	0.955		22.868	#VALUE!	0	
		0.09048832				
6						
12 hr		0.954545455				
24 hr		1.009090909				
36 hr		0.936363636				
48 hr		0.672727273				

D3_NoVent_Nov30

Interval	**Water**	**Time of Day**	**Interval**	**Elapsed Time**	**Previous Flow Reading**	**Current Flow Reading**	**Weight Before Wetting**	**Weight after wetting**	**Weight After Drying Period**	
	on	12:00	15	15						
1	off	12:15	40	55	999.273	1023.571	919.14	923.66	923.54	watter dribbing down back at 12:03 @ location 4, water appears to be dripping down being absorbed by brick on the lower portion of the wall
	on	12:55	15	70						
2	off	1:10	40	110	1023.571	1049.225	923.54	926.6	926.44	water is coming down past the bottom, wetting bricks and mortar underneath the test area
	on	1:50	15	125						
3	off	2:05	40	165	1049.225	1073.972	926.44	929.04	928.98	
	on	2:45	15	180						
4	off	3:00	40	220	1073.972	1099.066	928.98	931.18	931	
	on	3:40	15	235						
5	off	3:55	40	275	1099.066	1124.137	931	933.2	933.06	water is clearly migrating down the wall but not pooling at the bottom. Water at bottom outside test area. Location 8 and
Finished		4:35								
@12 hours hours									931.54	
@24 hours									930.16	
@29 hours									929.5	
@36 hours									928.84	
@48 hours									927.94	

Interval	**Absorb**	**Water Evaporated**	**Blockag**	**Total water del**	**Leakage**	
1	2.055		19.418	24.298	0	s
		0.054545455				
2	1.391		21.112	25.654	0	
		0.072727273				
3	1.182		20.712	24.747	0	
		0.027272727				
4	1.000		21.238	25.094	0	
		0.081818182				
5	1.000		20.493	25.071	0	
		0.063636364				
6						
12 hr		0.690909091				
24 hr		0.627272727				
36 hr		0.6				
48 hr		0.409090909				

D3_NoVent_V2_Dec8

Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	7:10	15	15						
1	off	7:25	40	55	1392.598	1419.069	923.26	928.14	927.88	penetration immediately within one minute at location 4
	on	8:05	15	70						
2	off	8:20	40	110	1419.069	1446.426	927.88	931.3	931.1	
	on	9:00	15	125						
3	off	9:15	40	165	1446.426	1473.903	931.1	933.8	933.58	
	on	9:55	15	180						most of mortar is visible damp
4	off	10:10	40	220	1473.903	1501.297	933.58	936.1	936.02	
	on	10:50	15	235						
5	off	11:05	40	275	1501.297	1527.517	936.02	938.18	938.08	
		11:45								
Finished										
@12 hours									936.26	
@24 hour:	wall specimen was moved from original location because mechnical system was interferring and causeing ventilation air to circulate in the cavity. Air spe								934.177	
@36 hours									932.937	
@48 hours									932.817	

Interval	r Absorb	Water Evaporated	Blockage	Deflected	Leakage
1	2.218		21.06	26.471	0
		0.118181818			
2	1.555		22.662	27.357	0
		0.090909091			
3	1.227		22.602	27.477	0
		0.1			
4	1.145		21.544	27.394	0.008
		0.036363636			
5	0.982		21.826	26.22	0.016
		0.045454545			
6					
12 hr		0.827272727			
24 hr		0.946818182			
36 hr		0.563636364			
48 hr		0.054545455			

D3_NoVent_V3_Dec11

Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	5:00	15	15						
1	off	5:15	40	55	1658.765	1685.265	929.44	934.22	934.14	water coming through immediately
	on	5:55	15	70						
2	off	6:10	40	110	1685.265	1711.241	934.14	937.12	936.84	
	on	6:50	15	125						
3	off	7:05	40	165	1711.241	1737.447	936.84	939.18	938.86	
	on	7:45	15	180						
4	off	8:00	40	220	1737.447	1763.816	938.86	940.88	940.78	water coming in at all locations
	on	8:40	15	235						
5	off	8:55	40	275	1763.816	1790.454	940.78	942.28	942.28	
		9:35								
Finished										
@12 hours									940.577	
@24 hours									938.437	
@36 hours									936.637	
@48 hours									935.277	

Interval	r Absorb	Water Evaporated	Blockag	Deflected	Leakage	Difference
1	2.173		20.384	26.5	0	3.943
		0.036363636				
2	1.355		19.851	25.976	0.004	4.770
		0.127272727				
3	1.064		21.778	26.206	0.02	3.364
		0.145454545				
4	0.918		22.004	26.369	0.034	3.447
		0.045454545				
5	0.682		22.378	26.638	0.054	3.578
		0				
6						
12 hr		0.774090909				
24 hr		0.972727273				
36 hr		0.818181818				
48 hr		0.618181818				

D1_5ACH_V1_Dec6

Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	2:25	15	15						
1	off	2:40	40	55	1262.866	1288.138	924.36	928.18	928.04	
	on	3:20	15	70						
2	off	3:35	40	110	1288.138	1313.465	928.04	931.3	931.16	
	on	4:15	15	125						
3	off	4:30	40	165	1313.465	1340.657	931.16	933.9	933.74	water leakage at location 2. very minimal
	on	5:10	15	180						
4	off	5:25	40	220	1340.657	1366.307	933.74	936.04	936	leakage at locatin 5 and 6 now
	on	6:05	15	235						
5	off	6:20	40	275	1366.307	1392.598	936	938.2	938	
		7:00								
Finished										
@12 hours									936.36	adjustment made to fan at 12 hour mark because it was not providing enough suction
@24 hours									934.64	
@36 hours									933.28	
@48 hours									932.7	

Interval	Absorb	Water Evaporated	Blockage	Total water delivered		Difference
1	1.736		20.296	25.272		3.240
		0.063636364				
2	1.482		21.828	25.327		2.017
		0.063636364				
3	1.245		21.246	27.192		4.701
		0.072727273				
4	1.045		21.08	25.65		3.525
		0.018181818				
5	1.000		21.282	26.291		4.009
		0.090909091				
6						
12 hr		0.745454545				
24 hr		0.781818182				
36 hr		0.618181818				
48 hr		0.263636364				

D1_5ACH_V2_Dec12

Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	5:55	15	15						
1	off	6:10	40	55	1790.454	1816.265	933.8	938.42	938.4	
	on	6:50	15	70						
2	off	7:05	40	110	1816.265	1842.21	938.4	941.06	940.82	small leakage at location 2 and near to location 1 and at location 10 and 4
	on	7:45	15	125						
3	off	8:00	40	165	1842.21	1868.403	940.82	943.12	943.02	
	on	8:40	15	180						
4	off	8:55	40	220	1868.403	1894.111	943.02	945.18	944.98	
	on	9:10	15	235						
5	off	9:25	40	275	1894.111	1919.7978	944.98	946.98	946.96	
		10:05								
Finished										
@12 hours									945.44	
@24 hours									943.54	
@36 hours									941.577	
@48 hours									940.617	

Interval	er Absorbe	Water Evaporated	Blockage	Total water del	Leakage	Difference
1	2.100		20.406	25.811	0	3.305
		0.009090909				
2	1.209		21.176	25.945	0	3.560
		0.109090909				
3	1.045		21.962	26.193	0.002	3.186
		0.045454545				
4	0.982		21.45	25.708	0.002	3.276
		0.090909091				
5	0.909		21.696	25.6868	0.004	3.082
		0.009090909				
6						
12 hr		0.690909091				
24 hr		0.863636364				
36 hr		0.892272727				
48 hr		0.436363636				

D3_5ACH_V3_Dec16			no flow meter							
Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	eight After Drying Period	
	on	2:45	15	15						
1	off	3:00	40	55	x	x	932.82	937.22	937.2	
	on	3:40	15	70						
2	off	3:55	40	110	x	x	937.2	940.14	939.98	very small amounts of leakage
	on	4:35	15	125						
3	off	4:50	40	165	x	x	939.98	941.94	941.9	bit more, mortar droppings are becoming visibly damp
	on	5:30	15	180						
4	off	5:45	40	220	x	x	941.9	943.54	943.44	dripping water now coming through
	on	6:25	15	235						
5	off	6:40	40	275	x	x	943.44	944.96	944.92	
		7:20								
Finished										
@12 hours									943.86	
@24 hour:									941.537	
@36 hours									939.657	
@48 hours									938.317	

Interval	r Absorb	Water Evaporated	Blockage	Deflected	Leakage
1	2.000		20.858	#VALUE!	0
		0.009090909			
2	1.336		20.3	#VALUE!	0
		0.072727273			
3	0.891		21.838	#VALUE!	0
		0.018181818			
4	0.745		20.836	#VALUE!	0
		0.045454545			
5	0.691		20.902	#VALUE!	0
		0.018181818			
6					
12 hr		0.481818182			
24 hr		1.055909091			
36 hr		0.854545455			
48 hr		0.609090909			

D2_10ACH_V1_Dec17			no flow meter							
Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	3:45	15	15						
1	off	4:00	40	55	x	x	917.8	924.26	924.26	leak at location one during 3:55 mark
	on	4:40	15	70				c		
2	off	4:55	40	110	x	x	924.26	927.9	927.8	small leakage and locations 3, 4, 5, 6
	on	5:35	15	125						
3	off	5:50	40	165	x	x	927.8	931	930.96	substantial leakage now coming through
	on	6:30	15	180						
4	off	6:45	40	220	x	x	930.96	934.06	933.96	
	on	7:25	15	235						
5	off	7:40	40	275	x	x	933.96	936.58	936.58	
		8:20								
Finished										
@12 hours									934.76	
@24 hour:									932.637	
@36 hours									930.597	
@48 hours									928.957	

Interval	r Absorb	Water Evaporated	Blcokage	Total water del	Leakage
1	2.936		20.666	#VALUE!	0
		0			
2	1.655		18.228	#VALUE!	0
		0.045454545			
3	1.455		18.55	#VALUE!	0.012
		0.018181818			
4	1.409		21.532	#VALUE!	0.022
		0.045454545			
5	1.191		18.934	#VALUE!	0.026
		0			
6					
12 hr		0.827272727			
24 hr		0.965			
36 hr		0.927272727			
48 hr		0.745454545			

D2_10ACH_V2_Dec20 no flow meter

Interval	Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
	on	4:45	15	15						
1	off	5:00	40	55	x	x	922.94	928.34	928.14	
	on	5:40	15	70						
2	off	5:55	40	110	x	x	928.14	931.6	931.52	leakage at 5:43 mark, location 6, 3,
	on	6:35	15	125						
3	off	6:50	40	165	x	x	931.52	934.46	934.24	
	on	7:30	15	180						
4	off	7:45	40	220	x	x	934.24	936.8	936.6	
	on	8:25	15	235						
5	off	8:40	40	275	x	x	936.6	938.44	938.34	
		9:20								
Finished										
@12 hours									936.297	
@24 hour:									934.057	
@36 hours									932.817	
@48 hours									931.097	

Interval	er Absorb	Water Evaporated	Blockage	Total water del	Leakage
1	2.455		21.224	#VALUE!	0
		0.090909091			
2	1.573		23.625	#VALUE!	0
		0.036363636			
3	1.336		24.114	#VALUE!	0.008
		0.1			
4	1.164		21.388	#VALUE!	0.028
		0.090909091			
5	0.836		23.51	#VALUE!	0.05
		0.045454545			
6					
12 hr		0.928636364			
24 hr		1.018181818			
36 hr		0.563636364			
48 hr		0.781818182			

D2_10ACH_V3_Dec26 no flow meter

Water	Time of Day	Interval	Elapsed Time	Previous Flow Reading	Current Flow Reading	Weight Before Wetting	Weight after wetting	Weight After Drying Period	
on	6:15	15	15						
off	6:30	40	55	x	x	923.78	928.58	928.38	penetration at 4, 5 and 6, penetration was within the first 10 minutes of wetting
on	7:10	15	70						
off	7:25	40	110	x	x	928.38	931.86	931.76	leakage water is starting to run down below test chamber in recessed mortar joint
on	8:05	15	125						
off	8:20	40	165	x	x	931.76	934.62	934.54	
on	9:00	15	180						
off	9:15	40	220	x	x	934.54	937.06	936.94	
on	9:55	15	235						
off	10:10	40	275	x	x	936.94	938.86	938.72	cavity has become very wet, water dripping constantly at most locations
	10:50								
								937.297	
								935.217	
s								933.097	
s								930.697	

er Absorb	Water Evaporated	Blockage	Total water del	Leakage
2.182		19.452	#VALUE!	0
	0.090909091			
1.582		20.4	#VALUE!	0
	0.045454545			
1.300		21.3	#VALUE!	0
	0.036363636			
1.145		22.556	#VALUE!	0.016
	0.054545455			
0.873		24.372	#VALUE!	0.022
	0.063636364			
	0.646818182			
	0.945454545			
	0.963636364			
	1.090909091			

Appendix B – Raw Data: Moisture Content

C1_NoVent_C1_Dec2

Brick B1 Mode

	Date	Dec 2nd		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	2.7	2.7	2.7	2.7	2.7	2.7
		1	After	2.7	2.8	3	2.7	5.5	3.34
			Before						
		2	After	2.7	3.3	3.6	2.8	5.6	3.6
			Before						
		3	After	2.7	4.1	5.5	2.6	5.7	4.12
			Before						
		4	After	2.7	8.3	12.6	20	19.8	12.68
			Before						
		5	After	2.7	9.1	21.4	5.5	20	11.74
			Before						
		6	After						
			Before						
		7	After						
Final				2.7	7.6	20.9	6.1	22.5	11.96
@12 hours				2.8	6.3	21	12.9	23	13.2
@24 hours				2.9	5.6	11.2	11.4	19.8	10.18
@ 29 hours									#DIV/0!
@36 hours				3	5.5	10.5	11.6	19.8	10.08
@48 hours				3.1	6.4	6.5	12.7	19.8	9.7

Mortar B3 Mode

Date	Dec 2nd		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	0	0	0.1	0.3	0.1	0.1
0:00	1	After	0	0.4	2.2	1.6	1.9	1.22
		Before						
0:00	2	After	0.2	1.9	1.9	2	1.9	1.58
		Before						
0:00	3	After	1.4	2.1	2.1	1.7	2.3	1.92
		Before						
0:00	4	After	1.1	2.1	2.1	1.8	2.5	1.92
		Before						
0:00	5	After	0.6	2.2	2.1	2.9	2.4	2.04
		Before						
	6	After						
		Before						
	7	After						
0:00	Final		1.3	2	1.9	2	2	1.84
			1.1	2	2	1.9	2	1.8
			1.4	2.1	1.9	1.8	2	1.84
								#DIV/0!
			1.5	2	2.1	1.8	1.9	1.86
			1.5	2	1.9	1.8	1.8	1.8

C1_NoVent_V2_Dec10

Brick B1 Mode

	Date	10-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	3.1	11	6.5	7.6	12.8	8.2
		1	After	3.1	13	8.5	11.4	20.2	11.24
			Before						
		2	After	3.1	15.4	15.3	12.2	24	14
			Before						
		3	After	3.2	23.3	20.3	21.5	24	18.46
			Before						
		4	After	3.2	22.3	24	23.9	24	19.48
			Before						
		5	After	3.8	24	24	24	24	19.96
			Before						
		6	After						
			Before						
		7	After						
Final				3.7	24	24	24	24	19.94
@12 hours				4.5	24	24	19.8	24	19.26
@24 hours				6.4	24	24	19.8	24	19.64
@36 hours				4.5	24	14.2	14.6	24	14.325
@48 hours				4.7	24	12.8	12.9	24	15.68

Mortar B3 Mode

Date	10-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	1.4	1.7	1.5	1.6	1.7	1.58
0:00	1	After	1.5	2.2	1.8	1.8	2	1.86
		Before						
0:00	2	After	1.5	2.1	1.9	1.8	2.1	1.88
		Before						
0:00	3	After	1.8	2.2	2.1	1.8	2.4	2.06
		Before						
0:00	4	After	1.8	2.5	2	2	2.6	2.18
		Before						
0:00	5	After	1.8	2.5	2	2	2.8	2.22
		Before						
	6	After						
		Before						
	7	After						
0:00	Final		1.8	2.5	2	2	2.8	2.22
			1.7	2.3	1.9	1.9	2.4	2.04
	=outside range		1.6	2.1	1.8	1.9	2.3	1.94
			1.5	2.1	2.1	1.7	2.3	1.94
			1.6	2	1.9	1.8	2.2	1.9

C1_NoVent_V3_Dec 14

Brick B1 Mode

	Date	14-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	6.8	15	7.2	13.3	13.4	11.14
		1	After	7.3	20.3	12	15	24	15.72
			Before						
		2	After	7.3	24	21.1	20.4	24	19.36
			Before						
		3	After	6.5	24	22.5	22.9	24	19.98
			Before						
		4	After	12.3	24	24	24	24	21.66
			Before						
		5	After	19.8	24	24	24	24	23.16
			Before						
		6	After						
			Before						
		7	After						
Final				19.8	24	24	24	24	23.16
@12 hours				9	24	24	24	24	21
@24 hours				9.2	24	19.8	15.1	24	18.42
@36 hours				5.6	24	13.4	13.4	24	16.08
@ 48 hours				5.6	24	12.8	13.3	24	15.94

Mortar B3 Mode

Date	14-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	1.6	2	1.7	1.8	2.1	1.84
0:00	1	After	1.7	2.3	1.9	1.9	2.3	2.02
		Before						
0:00	2	After	1.8	2.4	2.1	1.9	2.6	2.16
		Before						
0:00	3	After	1.8	2.5	2.1	2	2.7	2.22
		Before						
0:00	4	After	1.8	2.7	2.3	2.1	2.8	2.34
		Before						
0:00	5	After	1.8	2.7	2.3	2.2	2.9	2.38
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		1.8	2.7	2.1	2.1	2.9	2.32
			1.7	2.6	1.9	2	2.8	2.2
			1.6	2.5	1.9	2	2.6	2.12
	=outside range							
	=compromised		1.6	2.4	2	1.9	2.4	2.06
			1.6	2.4	1.9	1.8	2.4	2.02

C3_5ACH_V1_Dec15

Brick B1 Mode

	Date	15-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	2.8	2.8	1.7	2.7	2.8	2.56
		1	After	2.9	3	2.2	4	2.9	3
			Before						
		2	After	4.3	4.7	3.4	4.7	3.4	4.1
			Before						
		3	After	10	6.2	9.1	6.5	4.5	7.26
			Before						
		4	After	13	9.7	9.2	9.1	10.3	10.26
			Before						
		5	After	14	16.1	14	10.4	11.7	13.24
			Before						
		6	After						
			Before						
		7	After						
Final				14	16	13	10.3	11.3	12.92
@12 hours				7.3	10.1	6.1	10.7	10.2	8.88
@24 hours				6.4	9.2	7.2	8.3	9.2	8.06
@36 hours				6.1	7.3	6.8	8.2	9.2	7.1
@48 hours				6.1	7.2	5.5	7.9	7.3	6.8

Mortar B3 Mode

Date	15-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	0.4	0.3	0.4	0.4	0.4	0.38
0:00	1	After	0.5	1.2	1.2	1.5	0.5	0.98
		Before						
0:00	2	After	1.3	1.5	1.5	1.7	2	1.6
		Before						
0:00	3	After	1.6	1.7	1.6	1.8	2.1	1.76
		Before						
0:00	4	After	1.8	1.8	1.9	1.8	2.1	1.88
		Before						
0:00	5	After	1.8	2.2	2	1.9	2.3	2.04
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		1.8	2.1	2	1.8	2.2	1.98
			1.8	1.8	1.8	1.8	1.9	1.82
			1.6	1.8	1.8	1.7	1.7	1.72
	=outside range							
	=compromised		1.7	1.7	1.9	1.6	1.7	1.72
			1.5	1.7	1.8	1.6	1.8	1.68

C3_5ACH_V2_Dec18

Brick B1 Mode

	Date	18-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	7.7	7	5.2	6.5	7.5	6.78
		1	After	15.1	11.5	7.7	7.8	12.1	10.84
			Before						
		2	After	19.8	20.5	8.7	10.5	15.1	14.92
			Before						
		3	After	23	21.3	10.3	15.6	22	18.44
			Before						
		4	After	24	22.5	13.4	20.1	23.8	20.76
			Before						
		5	After	24	24	24	24	24	24
			Before						
		6	After						
			Before						
		7	After						
Final				12.3	21.8	20.5	24	24	20.52
@12 hours				10.2	12.8	19.8	23	24	17.96
@24 hours				9.8	10.5	14.7	15.4	20.5	14.18
@36 hours				9.8	9.2	12.3	9.5	16	11.36
@48 hours				9.8	10.3	10.2	11	13	10.86

Mortar B3 Mode

Date	18-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	1.5	1.7	1.8	1.5	1.8	1.66
0:00	1	After	1.5	1.9	1.9	1.6	2.3	1.84
		Before						
0:00	2	After	1.6	1.9	2.1	1.6	2.4	1.92
		Before						
0:00	3	After	1.7	2.1	2.1	1.7	2.4	2
		Before						
0:00	4	After	1.7	2.1	2.2	1.8	2.6	2.08
		Before						
0:00	5	After	1.8	2.1	2.5	1.9	3	2.26
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		1.7	1.9	2.4	1.7	2.7	2.08
			1.7	1.9	2.2	1.8	2.6	2.04
			1.7	1.7	1.8	1.7	2.1	1.8
	=outside range							
	=compromised		1.7	1.7	1.8	1.7	2	1.78
			1.7	1.7	1.9	1.7	1.8	1.76

Brick B1 Mode

	Date	20-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	7.7	8.9	7.5	11	9.1	8.84
		1	After	9.3	10.4	10.9	10	15	11.12
			Before						
		2	After	9.7	11.4	9.3	11.3	19.8	12.3
			Before						
		3	After	16.2	19.8	11.8	11.7	22.6	16.42
			Before						
		4	After	19.8	22	24	24	24	22.76
			Before						
		5	After	22.8	24	24	24	24	23.76
			Before						
		6	After						
			Before						
		7	After						
Final				21.3	24	24	24	24	23.46
@12 hours				20	24	24	24	24	23.2
@24 hours				22	15.8	15.8	19.8	24	19.48
@36 hours				21	15.3	15.8	17.6	23.4	18.62
@48 hours				19.8	14.7	15.8	15.4	22.8	17.7

Mortar B3 Mode

Date	20-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	1.7	1.7	1.8	1.6	1.8	1.72
0:00	1	After	1.7	1.9	2	1.9	2	1.9
		Before						
0:00	2	After	1.8	2	2.1	1.9	2.1	1.98
		Before						
0:00	3	After	1.7	2.2	2.4	2.1	2.1	2.1
		Before						
0:00	4	After	1.8	2.1	2.6	2.1	2.9	2.3
		Before						
0:00	5	After	1.9	2.4	2.7	2.3	3	2.46
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		1.9	2	2.7	2.2	3	2.36
			1.8	2.1	2.5	2	2.9	2.26
			1.7	1.9	2.4	1.7	2.4	2.02
	=outside range							
	=compromised		1.7	1.7	2.3	1.7	2.4	1.96
			1.7	1.7	2.2	1.7	2.3	1.92

C2_10ACH_V1_Dec19

Brick B1 Mode

	Date	19-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	2.8	2.8	2.7	2.7	2.8	2.76
		1	After	3.1	2.8	2.8	2.8	2.9	2.88
			Before						
		2	After	4.2	5.5	7.1	3.1	7.7	5.52
			Before						
		3	After	19.8	15	16	6.5	14.3	14.32
			Before						
		4	After	24	24	21.3	24	24	23.46
			Before						
		5	After	24	24	24	24	24	24
			Before						
		6	After						
			Before						
		7	After						
Final				24	24	24	19.8	24	23.16
@12 hours				24	19.8	23	21	15	20.56
@24 hours				22	15	16.7	13	13	15.94
@36 hours				19.8	11.6	9.6	10.8	10.6	12.48
@48 hours				15.8	12	10.5	12.2	9.5	12

Mortar B3 Mode

Date	19-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	0.1	0.3	0.4	0.3	0.3	0.28
0:00	1	After	0.4	1.2	0.4	1.9	1.3	1.04
		Before						
0:00	2	After	1.1	2.1	1.5	1.5	2.3	1.7
		Before						
0:00	3	After	1.3	2.2	2.1	1.6	2.4	1.92
		Before						
0:00	4	After	2.1	2.2	2.2	2.3	2.3	2.22
		Before						
0:00	5	After	2.1	2.2	2.2	2.3	2.4	2.24
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		2.1	2.2	2.1	2	2.3	2.14
			1.7	1.7	2	1.9	2.2	1.9
			1.7	1.7	2	1.9	2.2	1.9
(red)	=outside range		1.7	1.7	2	1.9	1.8	1.82
(yellow)	=compromised		1.8	1.9	1.8	1.8	1.7	1.8

C2_10ACH_V3_Dec27

Brick B1 Mode

	Date	27-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	11.9	11.1	8.5	6.4	11	9.78
		1	After	14	15.3	12	6.5	11	11.76
			Before						
		2	After	21.4	19.8	16.6	21.5	20.2	19.9
			Before						
		3	After	24	24	20.5	23	21	22.5
			Before						
		4	After	24	24	19.8	24	24	23.16
			Before						
		5	After	24	24	24	24	24	24
			Before						
		6	After						
			Before						
		7	After						
Final				23	24	20.4	24	24	23.08
@12 hours				22.5	20.2	16	20	19.8	19.7
@24 hours				14.5	13.7	14	19.8	12.7	14.94
@36 hours				14.1	13.2	11.1	13.8	11.6	12.76
@48 hours				12.5	12.7	10.8	12	11.3	11.86

Mortar B3 Mode

Date	27-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	1.7	1.8	1.9	1.7	1.9	1.8
0:00	1	After	1.9	1.8	1.9	1.7	2.1	1.88
		Before						
0:00	2	After	2	2.1	1.9	2.1	2.4	2.1
		Before						
0:00	3	After	2.1	2.2	2.2	1.7	2.5	2.14
		Before						
0:00	4	After	2.1	2.2	2.3	2.2	2.6	2.28
		Before						
0:00	5	After	2.2	2.2	2.3	2.2	2.6	2.3
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		2.2	1.9	2.3	2.1	2.6	2.22
					2	1.6	2	1.8667
(red)	=outside range				2	1.7	1.9	1.8667
(yellow)	=compromised							
					1.9	1.7	1.8	1.8
					1.7	1.7	1.8	1.7333

C2_10ACH_V3_Dec29

Brick B1 Mode

	Date	29-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	12.5	12.3	10.5	11.2	10.1	11.32
		1	After	14.2	20.2	19.8	19.8	22	19.2
			Before						
		2	After	20.5	20.3	22.7	23.7	24	22.24
			Before						
		3	After	24	23	23.8	24	24	23.76
			Before						
		4	After	24	23.8	24	24	24	23.96
			Before						
		5	After	24		24	24	24	24
			Before						
		6	After						
			Before						
		7	After						
Final				24	22.8	24	24	24	23.76
@12 hours				24	19.8	21.4	21.6	24	22.16
@24 hours				24	19.8	21.2	21.1	24	22.02
@36 hours				24	19.8	21.1	20.4	24	21.86
@48 hours				21.2	15.6	19.8	20.2	21.5	19.66

Mortar B3 Mode

Date	29-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	1.7	1.8	1.9	1.9	1.8	1.82
0:00	1	After	1.8	2.1	2	1.7	2.4	2
		Before						
0:00	2	After	1.8	2.2	1.9	2.3	2.6	2.16
		Before						
0:00	3	After	1.8	2.3	2.2	2	2.6	2.18
		Before						
0:00	4	After	1.8	2.3	2.2	2	2.8	2.22
		Before						
0:00	5	After	2.1	2.3	2.4	2.2	3	2.4
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		1.9	2.1	2.3	2.3	3	2.32
			1.8	2.1	2.2	1.9	2.6	2.12
(red)	=outside range		1.8	2	2.1	1.9	2.5	2.06
(yellow)	=compromised							
			1.8	1.9	2	1.9	2.4	2
			1.8	1.9	2	1.8	2.2	1.94

D3_NoVent_V1_Nov30

Brick B1 Mode

	Date	Nov 30th		Location MC %					
	Time	Interval	Wetting	1	2	3	4	5	Avg
Initial	12:00		Before	2.8	2.8	2.9	1.9	2.9	2.66
	12:15	1	After	2.8	2.8	2.9	2.7	3	2.84
			Before						
	1:10	2	After	2.8	3.3	3.1	2.7	5.9	3.56
			Before						
	2:05	3	After	2.8	9.3	3.7	2.9	7.9	5.32
			Before						
	3:00	4	After	2.8	9.5	19.8	2.9	21.4	11.28
			Before						
	3:55	5	After	3.2	10.2	22.6	3	23.9	12.58
			Before						
	H	6	After						
			Before						
		7	After						
Final	4:35			3.3	12.5	19.8	3.1	21.3	12
@12 hours				2.9	10.3	20.2	3.5	21.3	11.64
@24 hours				2.9	9.9	19.8	3.7	20.3	11.32
@ 29 hours				4.1	8.1	19.8	3.8	19.8	11.12
@36 hours				4.3	7.7	19.8	4	20.5	11.26
@48 hours				4.2	7.3	19.8	4.1	19.8	11.04

Mortar B3 Mode

Date	Nov 30th		Location MC %					
Time	Interval	Wetting	1	2	3	4	5	Avg
12:00		Before	0	0.1	0.2	0.2	0.1	0.12
12:15	1	After	1.6	0.3	2	0.5	2	1.28
		Before						
1:10	2	After	1.7	0.5	2.6	0.5	2.2	1.5
		Before						
2:05	3	After	1.6	1.7	2.6	1.1	2.3	1.86
		Before						
3:00	4	After	1.8	1.9	2.6	1.7	2.2	2.04
		Before						
3:55	5	After	1.8	2.1	2.6	2.2	2.4	2.22
		Before						
	6	After						
		Before						
	7	After						
4:35	Final		1.9	2.4	2.6	2.3	2.1	2.26
			1.7	2.4	2.5	2.3	2.1	2.2
			1.8	2.4	2.5	2.3	2	2.2
			1.8	2.3	2.5	2.1	1	1.94
			1.8	2.4	2.5	2.2	1.9	2.16
			1.7	2.3	2.5	2.1	1.9	2.1

D3_NoVent_V2_Dec8

Brick B1 Mode

	Date	8-Dec		Location MC %					
	Time	Interval	Wetting	1	2	3	4	5	Avg
Initial			Before	4	7.2	9.9	4	8.5	6.72
		1	After	4.1	7	14.2	4	12.3	8.32
			Before						
		2	After	4.1	8.9	19.8	4	19.8	11.32
			Before						
		3	After	4	19.8	21.5	4	20.6	13.98
			Before						
		4	After	4.4	20.2	20.8	4.1	21.7	14.24
			Before						
		5	After	10.3	20.7	24	4.1	24	16.62
			Before						
		6	After						
			Before						
		7	After						
Final				9.4	19.88	24	4.1	24	16.276
@12 hours				4.9	15.6	20.7	4.2	24	13.88
@24 hours				4.9	12.4	19.8	4.2	24	13.06
@36 hours				4.9	10.9	20.7	4.2	22.2	12.58
@48 hours				5.3	7.4	20.1	4.3	20.1	11.44

Mortar B3 Mode

Date	8-Dec		Location MC %					
Time	Interval	Wetting	1	2	3	4	5	Avg
0:00		Before	1.4	1.8	2	1.5	1.6	1.66
0:00	1	After	1.7	2	2.3	1.6	1.9	1.9
		Before						
0:00	2	After	1.6	2.1	2.5	1.8	2.1	2.02
		Before						
0:00	3	After	1.8	2.3	2.5	2.4	2.1	2.22
		Before						
0:00	4	After	1.8	2.4	2.7	2.5	2.1	2.3
		Before						
0:00	5	After	2.1	2.6	2.8	2.6	2.4	2.5
		Before						
	6	After						
		Before						
	7	After						
0:00	Final		1.8	2.6	2.8	2.5	2.2	2.38
			1.8	2.5	2.6	2.4	2.1	2.28
			1.8	2.3	2.6	2.4	2	2.22
			1.8	2.2	2.5	2.3	1.8	2.12
			1.8	2.4	2.3	2.2	1.8	2.1

=outside range

D3_NoVent_V3_Dec11

Brick B1 Mode

	Date	10-Dec		Location MC %					
	Time	Interval	Wetting	1	2	3	4	5	Avg
Initial			Before	7.9	13.9	19.8	4.5	22.8	13.78
		1	After	11.9	15.2	24	4.6	23.2	15.78
			Before						
		2	After	13.3	19.8	24	4.7	24	17.16
			Before						
		3	After	20	19.8	24	4.7	24	18.5
			Before						
		4	After	19.8	20.5	24	4.7	24	18.6
			Before						
		5	After	19.8	20.5	24	4.7	24	18.6
			Before						
		6	After						
			Before						
		7	After						
Final				19.8	20.5	24	4.7	24	18.6
@12 hours				14.4	19.8	24	4.7	24	17.38
@24 hours				10	12.9	24	4.7	24	15.12
@36 hours				7.5	9.6	24	4.5	20.3	11.4
@48 hours				4.9	9.5	24	4.7	20.5	12.72

Mortar B3 Mode

Date	10-Dec		Location MC %					
Time	Interval	Wetting	1	2	3	4	5	Avg
0:00		Before	1.7	2.2	2.3	2.2	1.9	2.06
0:00	1	After	1.8	2.4	2.5	2.4	2	2.22
		Before						
0:00	2	After	2.1	2.4	2.7	2.2	2.6	2.4
		Before						
0:00	3	After	2	2.5	2.8	2.5	2.6	2.48
		Before						
0:00	4	After	2	2.5	2.8	2.7	2.6	2.52
		Before						
0:00	5	After	2.1	2.5	2.9	2.6	2.9	2.6
		Before						
	6	After						
		Before						
	7	After						
0:00	Final		2.1	2.5	2.9	2.5	2.8	2.56
			1.9	2.5	2.8	2.6	2.1	2.38
			1.9	2.4	2.8	2.6	2.1	2.36
			1.8	2.2	2.7	2.4	2.5	2.32
			1.9	2.2	2.7	2.5	2.4	2.34

=outside range
=compromised

D1_5ACH_V1_Dec6

	Brick B1 Mode								
	Date	Dec 6th		Location MC %					
	Time	Interval	Wetting	1	2	3	4	5	Avg
Initial			Before	3.2	2.7	2.8	2.8	2.9	2.88
		1	After	3.2	2.7	2.9	2.9	3	2.94
			Before						
		2	After	3.3	2.7	3.2	3	3.3	3.1
			Before						
		3	After	3.4	2.9	9.2	3.1	13.2	6.36
			Before						
		4	After	3.6	3.1	9.8	3.2	19.8	7.9
			Before						
		5	After	3.9	3.2	15.5	3.2	20.3	9.22
			Before						
		6	After						
			Before						
		7	After						
Final				4.1	3.2	7.2	4.9	15.7	7.02
@12 hours				3.1	4	6.3	4.1	13.5	6.2
@24 hours				3	6.4	6.7	4.3	10.8	6.24
@ 29 hours									
@36 hours				3	6	6.5	4.5	9.8	5.96
@48 hours				3	5.4	6	4.5	9.4	5.66

Mortar B3 Mode								
Date	Dec 6th		Location MC %					
Time	Interval	Wetting	1	2	3	4	5	Avg
0:00		Before	0.5	0.3	0.3	0.3	0.5	0.38
0:00	1	After	0.7	1.4	1.9	0.5	1.8	1.26
		Before						
0:00	2	After	1.6	1.3	2.3	0.7	2.5	1.68
		Before						
0:00	3	After	2.1	1.6	2.5	1.6	2.4	2.04
		Before						
0:00	4	After	2.4	1.7	2.6	1.6	2.6	2.18
		Before						
0:00	5	After	2.6	2	2.6	1.6	2.7	2.3
		Before						
	6	After						
		Before						
	7	After						
0:00	Final		2.4	1.9	2.5	1.4	2.5	2.14
			2.4	1.9	2.2	1.8	2.4	2.14
			2.3	1.7	2	1.9	2.5	2.08
			2.2	1.7	1.8	1.9	2.4	2
			2.1	1.6	1.8	1.9	2.3	1.94

D1_5ACH_V2_Dec12

	Brick B1 Mode								
	Date	10-Dec		Location MC %					
	Time	Interval	Wetting	1	2	3	4	5	Avg
Initial			Before	21.9	5.6	4.5	4.9	4.9	8.36
		1	After	23	6.2	6.2	5	5.5	9.18
			Before						
		2	After	24	6.4	11.5	6.5	19.8	13.64
			Before						
		3	After	24	6.4	12.3	6.5	20	13.84
			Before						
		4	After	24	7.2	19.7	6.9	22.5	16.06
			Before						
		5	After	24	7.3	21.3	7	24	16.72
			Before						
		6	After						
			Before						
		7	After						
Final				24	7.4	21	22.2	24	19.72
@12 hours				24	8.5	7.9	8.6	12.3	12.26
@24 hours				24	7.1	6.9	7.3	10.1	11.08
@36 hours				24	6.1	6.1	6.8	7	10
@48 hours				24	6.1	6	6.8	6.9	9.96

Mortar B3 Mode								
Date	10-Dec		Location MC %					
Time	Interval	Wetting	1	2	3	4	5	Avg
0:00		Before	2	1.5	1.8	1.8	2.2	1.86
0:00	1	After	2.1	1.7	2.1	1.9	2.6	2.08
		Before						
0:00	2	After	2.4	1.7	2.3	1.9	2.6	2.18
		Before						
0:00	3	After	2.6	1.8	2.6	1.9	2.7	2.32
		Before						
0:00	4	After	2.5	2	2.6	2	2.7	2.36
		Before						
0:00	5	After	2.6	2	2.6	2.1	2.8	2.42
		Before						
	6	After						
		Before						
	7	After						
0:00	Final		2.6	2	2.6	2.3	2.8	2.46
			2.5	1.9	2.5	2.2	2.4	2.3
(red)	=outside range		2.4	1.8	2.4	2.2	2.3	2.22
(yellow)	=compromised							
			2.4	1.8	1.9	2.2	2.5	2.16
			2.3	1.8	1.9	2.1	2.5	2.12

D1_5ACH_V3_Dec16

	Brick B1 Mode								
	Date	15-Dec		Location MC %					
	Time	Interval	Wetting	1	2	3	4	5	Avg
Initial			Before	21.8	5.8	6	6	7.8	9.48
		1	After	23.3	6.7	7.3	6.5	9.5	10.66
			Before						
		2	After	24	6.5	11.4	6.7	14.1	12.54
			Before						
		3	After	24	6.7	14.3	6.9	15.8	13.54
			Before						
		4	After	24	6.7	19.8	8.5	20.4	15.88
			Before						
		5	After	24	7.3	20.4	10.2	24	17.18
			Before						
		6	After						
			Before						
		7	After						
Final				24	7.3	20.4	9.6	24	17.06
@12 hours				24	7.7	19.8	8.1	20	15.92
@24 hours				22	7.3	16.7	8.1	16.3	14.08
@36 hours				21	7	15.5	8.2	11.1	12.56
@48 hours				20.4	6.6	5.5	6.5	10	9.8

Mortar B3 Mode								
Date	15-Dec		Location MC %					
Time	Interval	Wetting	1	2	3	4	5	Avg
0:00		Before	2.2	1.6	1.8	1.9	2.3	1.96
0:00	1	After	2.2	1.8	2.1	2.2	2.3	2.12
		Before						
0:00	2	After	2.4	1.8	2.3	2.2	2.5	2.24
		Before						
0:00	3	After	2.5	1.9	2.5	2.3	2.5	2.34
		Before						
0:00	4	After	2.5	2	2.5	2.2	2.7	2.38
		Before						
0:00	5	After	2.6	2.1	2.7	2.3	2.8	2.5
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		2.5	2.1	2.7	2.3	2.8	2.48
			2.5	2.1	2.6	2.1	2.7	2.4
			2.4	2.1	2.4	2.2	2.6	2.34
(red)	=outside range		2.4	2	2.4	2.2	2.5	2.3
(yellow)	=compromised		2.2	1.9	2.3	2.2	2.4	2.2

D2_10ACH_V1_Dec17

Brick B1 Mode

	Date	15-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	2.7	2.8	3.1	3.1	3.1	2.96
		1	After	2.8	3.1	14.5	3.1	7.6	6.22
			Before						
		2	After	2.8	10.5	20.7	4	15.6	10.72
			Before						
		3	After	3.3	12.2	23.4	20	19.8	15.74
			Before						
		4	After	4.6	19.8	20.5	19.8	20.1	16.96
			Before						
		5	After	5.7	19.8	24	19.8	24	18.66
			Before						
		6	After						
			Before						
		7	After						
Final				4.1	11.1	20.7	19.8	24	15.94
@12 hours				15.4	8.8	11.5	19.8	20	15.1
@24 hours				10.5	7	8.5	12.5	15.2	10.74
@36 hours				11.8	7.1	7.2	12.7	12.5	10.26
@48 hours				11.2	7	8	9.4	11.6	9.44

Mortar B3 Mode

Date	15-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	0.3	0.3	0.4	0.4	0.5	0.38
0:00	1	After	1.7	1.4	1.5	1.4	1.7	1.54
		Before						
0:00	2	After	1.9	1.6	1.7	1.6	1.8	1.72
		Before						
0:00	3	After	2	1.7	1.9	1.6	2.1	1.86
		Before						
0:00	4	After	2	1.7	1.9	1.6	2.3	1.9
		Before						
0:00	5	After	2.1	1.9	1.9	2.1	2.8	2.16
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		2	1.8	1.9	1.7	2.1	1.9
			1.7	1.7	1.9	1.7	1.7	1.74
			1.7	1.7	1.9	1.8	1.7	1.76
			1.6	1.6	1.9	1.7	1.7	1.7
			1.6	1.6	1.9	1.7	1.7	1.7

=outside range

=compromised

D2_10ACH_V2_Dec20

Brick B1 Mode

	Date	20-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	12	7	7.1	7	7.7	8.16
		1	After	11.9	12.3	11.4	10.8	15.2	12.32
			Before						
		2	After	10.5	20.5	20.2	19.8	22.5	18.7
			Before						
		3	After	15.3	20.6	20.3	19.8	24	20
			Before						
		4	After	15.2	21	21.7	24	24	21.18
			Before						
		5	After	16.2	20.1	24	24	24	21.66
			Before						
		6	After						
			Before						
		7	After						
Final				14.3	15.8	24	20.8	24	19.78
@12 hours				8.8	8.8	22.9	16.3	20.5	15.46
@24 hours				9.9	9.1	20.4	10	19.8	13.84
@36 hours				10.8	8.7	19.8	11.6	12.5	12.68
@48 hours				10.5	7.5	12.3	8.5	12	10.16

Mortar B3 Mode

Date	20-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
0:00		Before	1.6	1.6	1.7	1.8	1.5	1.64
0:00	1	After	1.7	1.8	1.7	1.6	1.8	1.72
		Before						
0:00	2	After	1.7	1.7	2.1	1.6	2.6	1.94
		Before						
0:00	3	After	1.7	1.8	2.1	1.8	2.8	2.04
		Before						
0:00	4	After	1.7	2.1	2.2	2	2.9	2.18
		Before						
0:00	5	After	1.7	2	2.6	2	2.9	2.24
		Before						
	6	After						
		Before						
	7	After						#DIV/0!
0:00	Final		1.7	1.9	2.6	1.9	2.9	2.2
			1.7	1.8	2.3	1.8	2.4	2
			1.7	1.7	2.2	1.7	2	1.86
			1.6	1.6	2	1.8	1.9	1.78
			1.6	1.6	2	1.8	1	1.6

=outside range

=compromised

D2_10ACH_V3_Dec26

Brick B1 Mode

	Date	26-Dec		Location MC %					
	Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
Initial			Before	8.4	8.5	10	7.8	7.8	8.5
		1	After	10.2	19.8	15.5	9.5	13	13.6
			Before						
		2	After	10.5	22.9	22.5	15	24	18.98
			Before						
		3	After	11.3	23.6	23	19.8	24	20.34
			Before						
		4	After	13	23.6	24	24	24	21.72
			Before						
		5	After	20.8	24	24	24	24	23.36
			Before						
		6	After						
			Before						
		7	After						
Final				19.8	22.8	24	21.8	24	22.48
@12 hours				13.5	16	20.2	19.8	24	18.7
@24 hours				10.9	11.4	16.3	16	20	14.92
@36 hours				9.1	9.6	12.2	11.5	14.4	11.36
@48 hours				8.6	8.9	12.3	9.2	9.5	9.7

=outside range

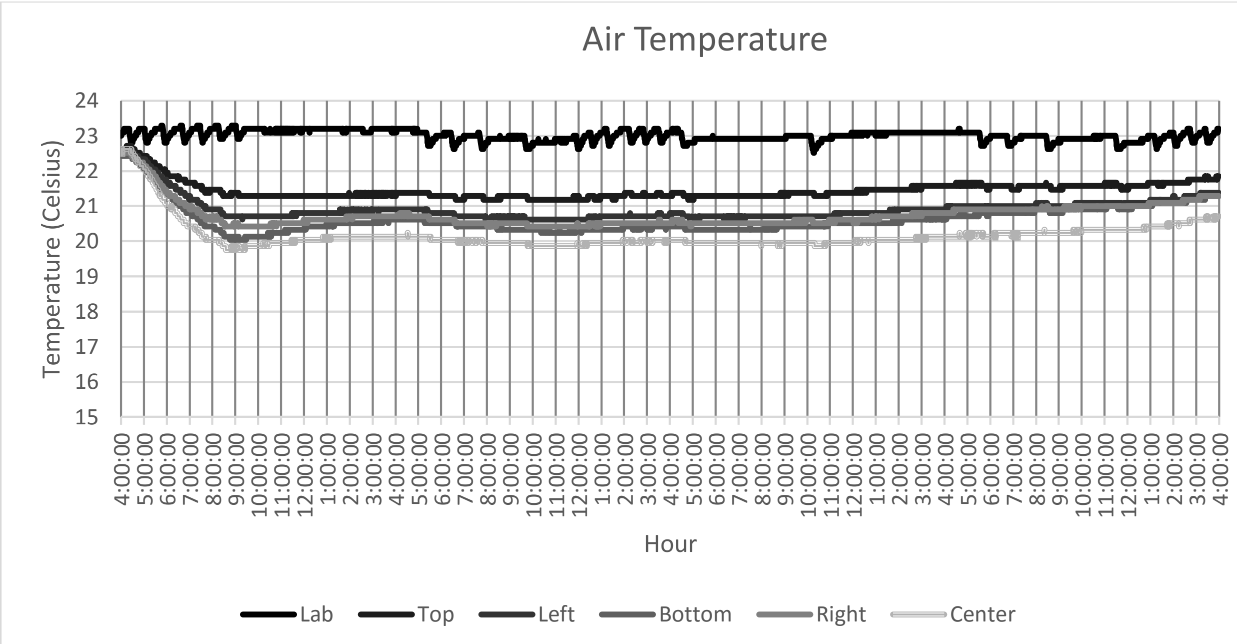
=compromised

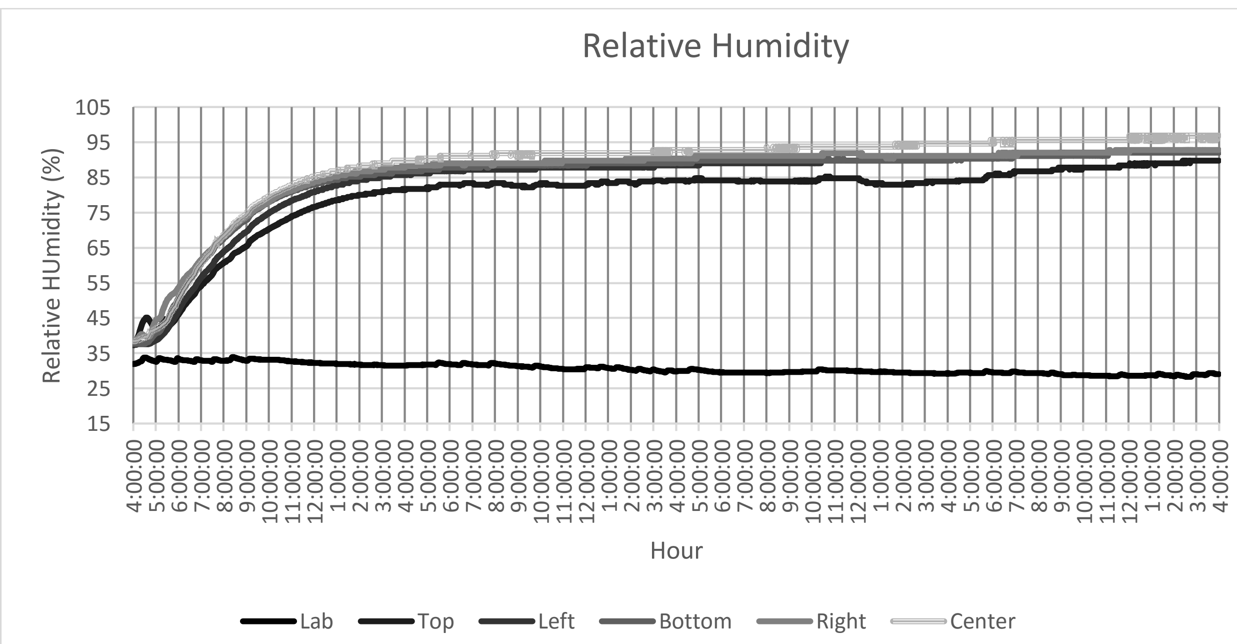
Mortar B3 Mode

Date	26-Dec		Location MC %					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
			1.6	1.8	1.8	1.7	1.9	1.76
	1		1.7	1.8	1.9	1.7	2	1.82
	2		1.8	2	2.1	1.7	2.8	2.08
	3		1.8	2	2.2	1.9	2.8	2.14
	4		2.9	2.1	2.2	2.7	2.9	2.56
	5		1.7	2.3	2.6	2.8	2.9	2.46
	6							
	7							#DIV/0!
			1.9	2.1	2.5	2.5	2.8	2.36
			1.6	1.8	2.1	2	2.6	2.02
			1.6	1.8	2	2	2.1	1.9
			1.6	1.7	2	2	2	1.86
			1.6	1.7	1.9	2	2	1.84

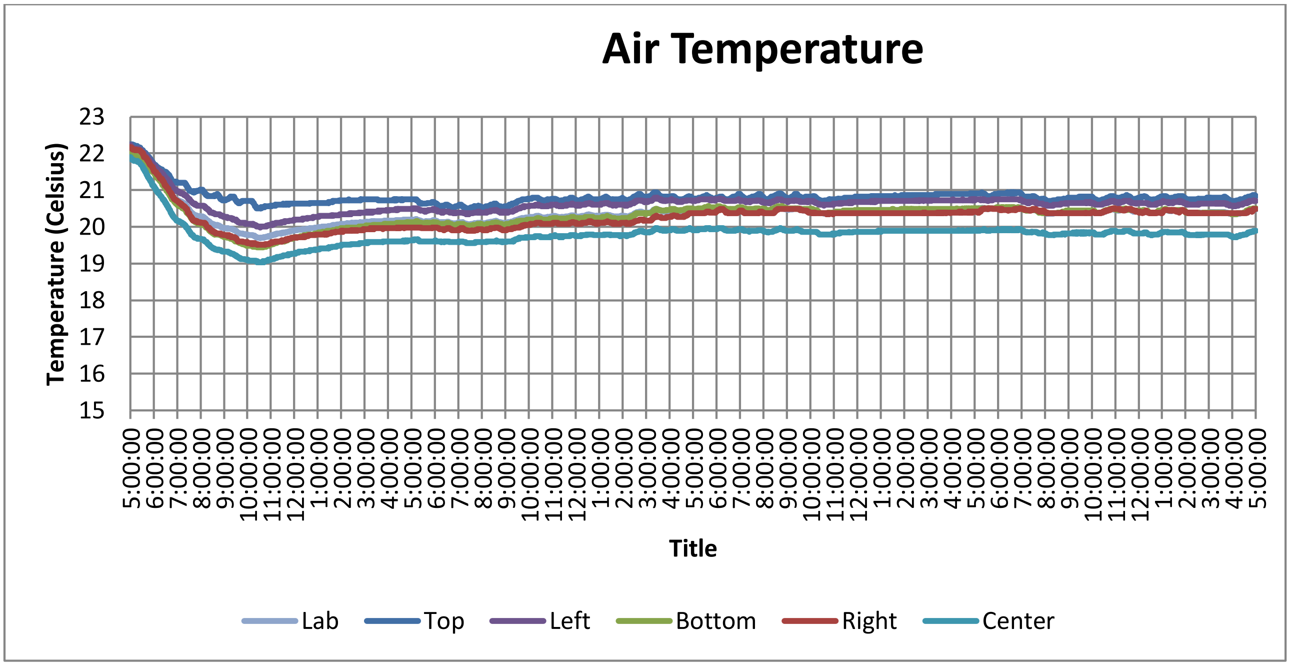
Appendix C – Raw Data: Temperature and Relative Humidity Curves

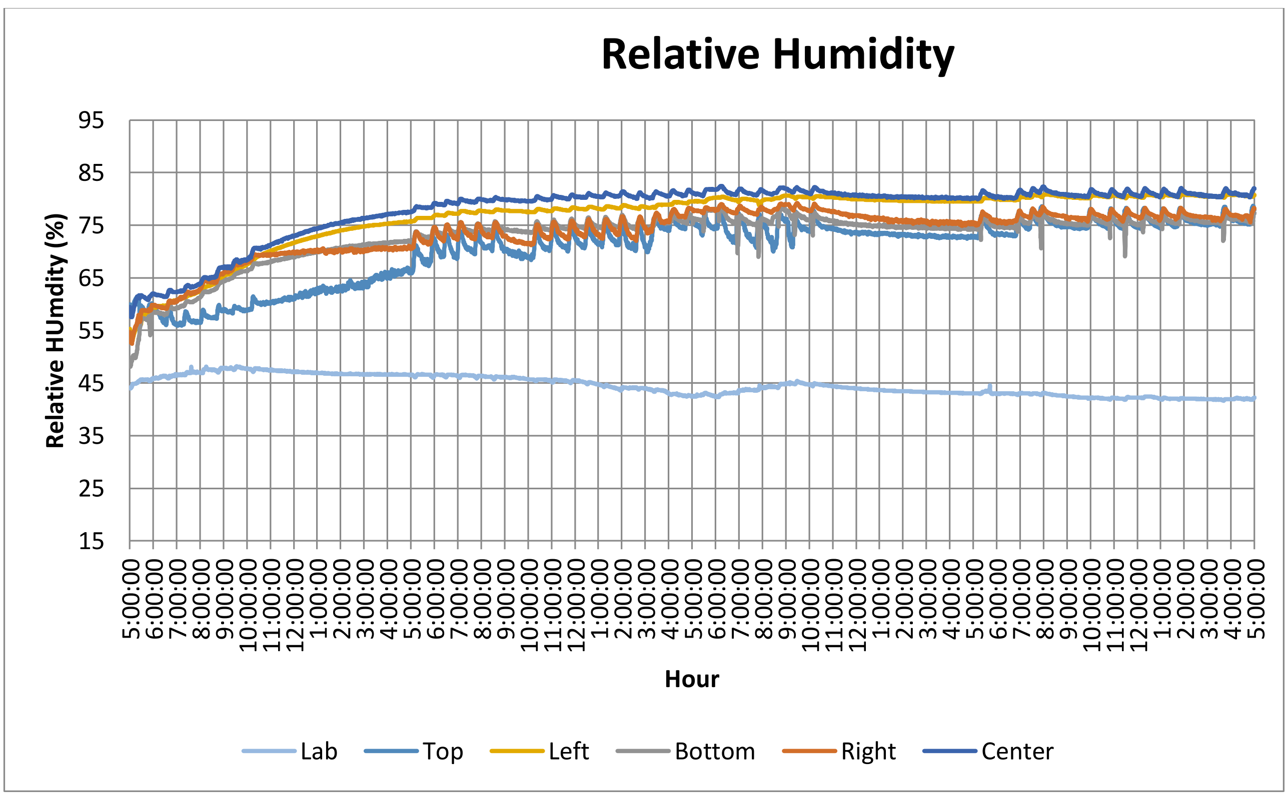
C1_NoVent_V1



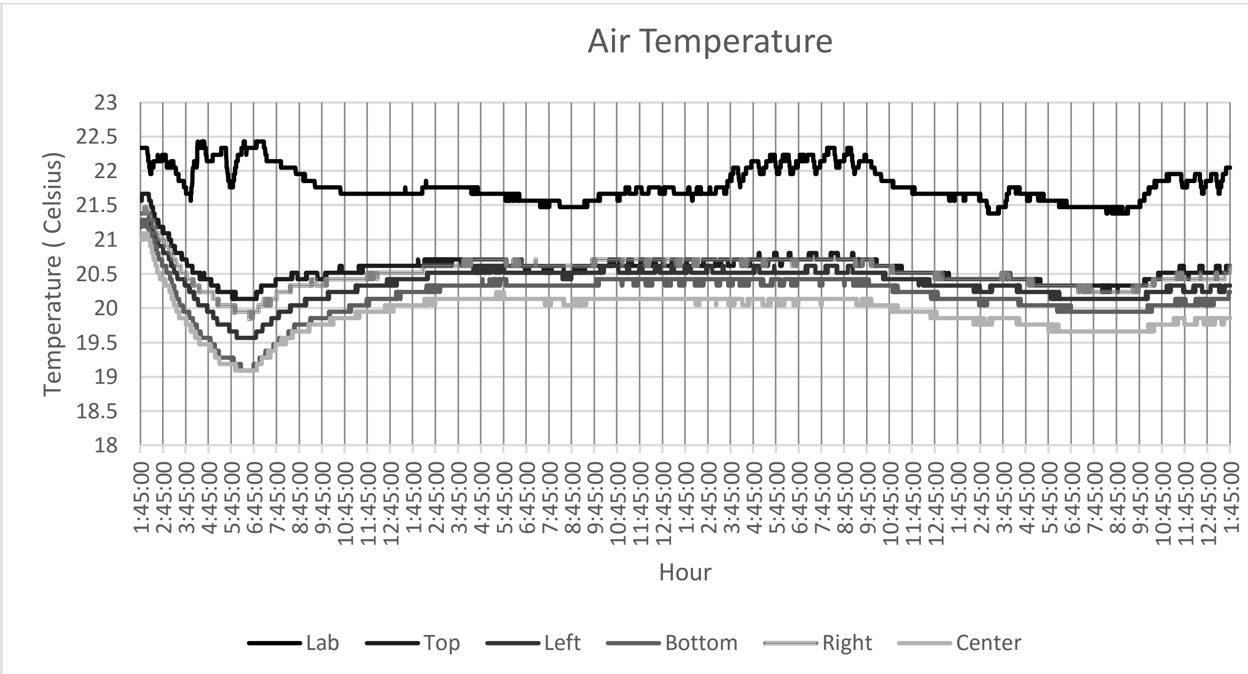


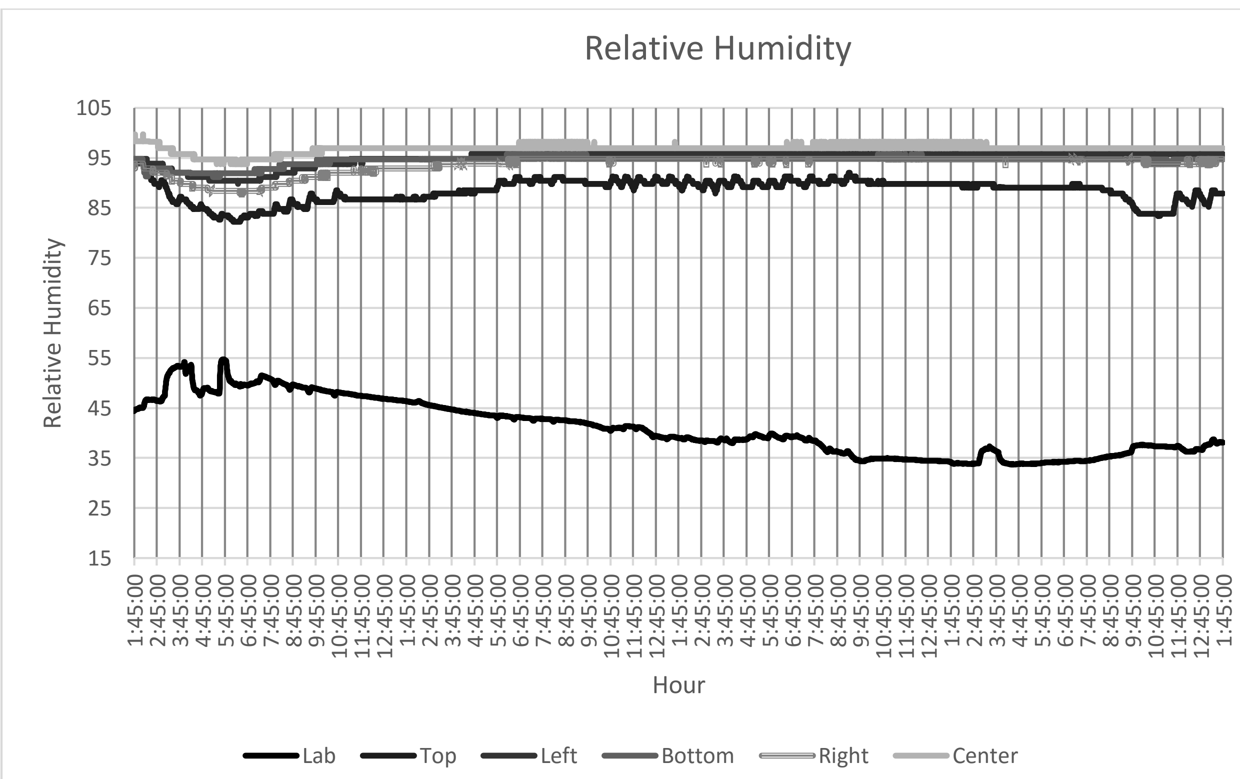
C1_NoVent_V2


Air Temperature
Temperature (Celsius)
Title
Lab
Top
Left
Bottom
Right
Center

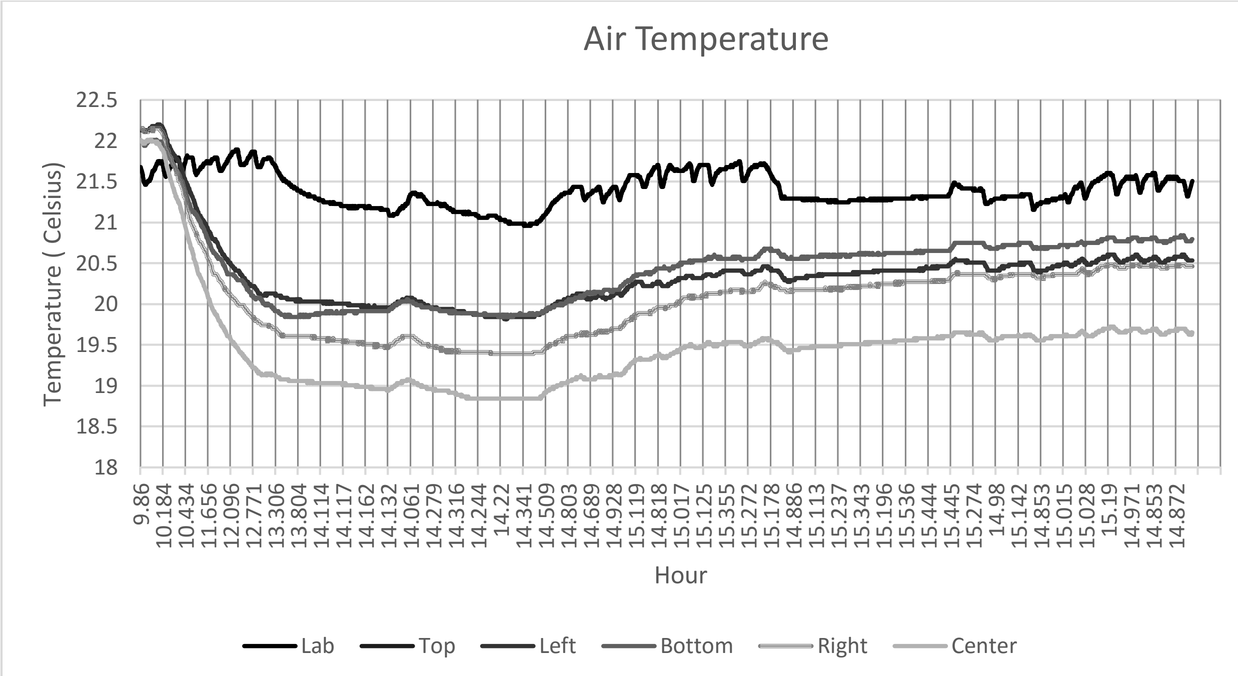

Relative Humidity
Relative HUmdity (%)
Hour
Lab
Top
Left
Bottom
Right
Center

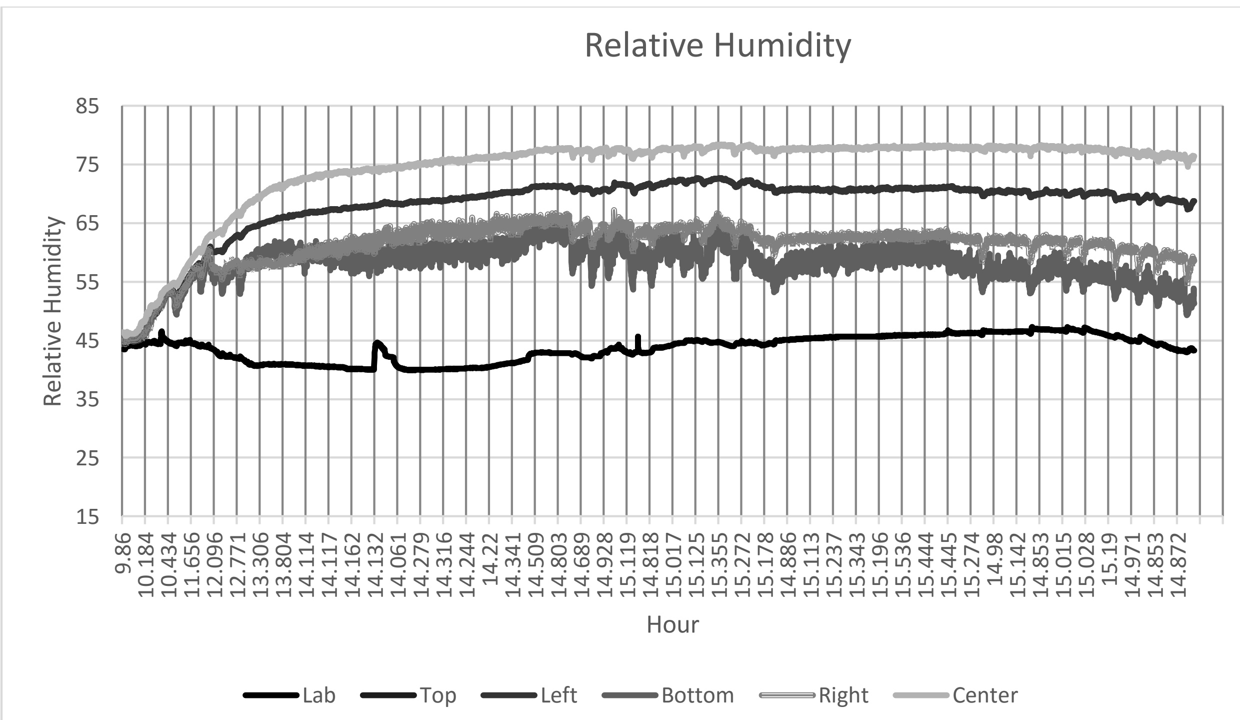
C1_NoVent_V3


Air Temperature
Temperature (Celsius)
Hour
Lab
Top
Left
Bottom
Right
Center

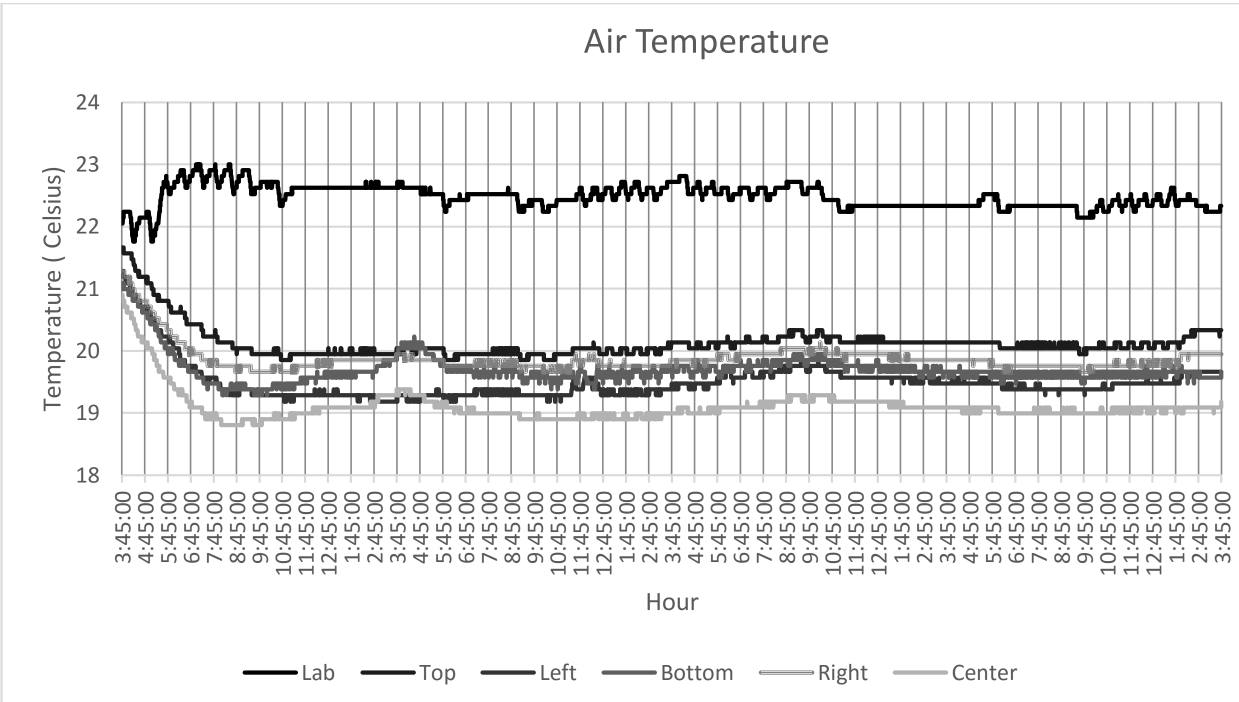

Relative Humidity
Relative Humidity
Hour
Lab
Top
Left
Bottom
Right
Center

C3_5ACH_V1

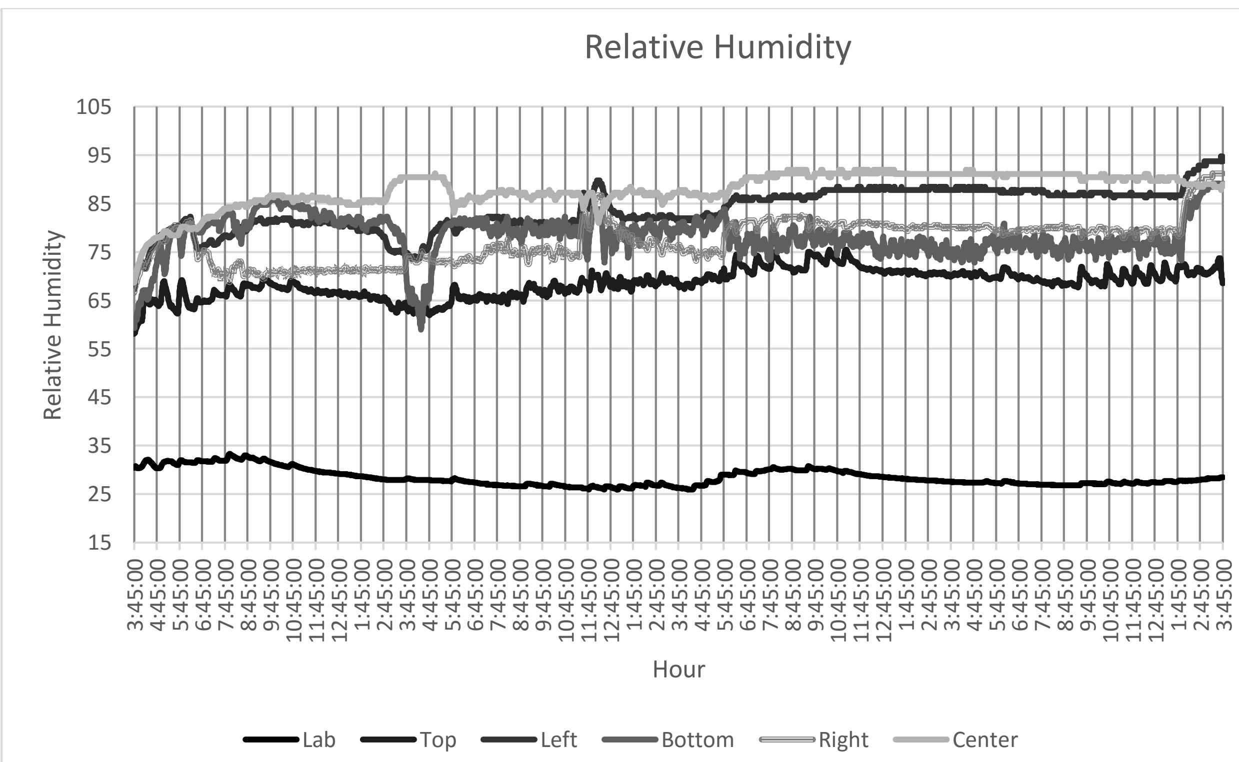

Air Temperature
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
Temperature (Celsius)
Hour
Lab
Top
Left
Bottom
Right
Center


Relative Humidity
85
75
65
55
45
35
25
15
Relative Humidity
Hour
Lab
Top
Left
Bottom
Right
Center

C3_5ACH_V2

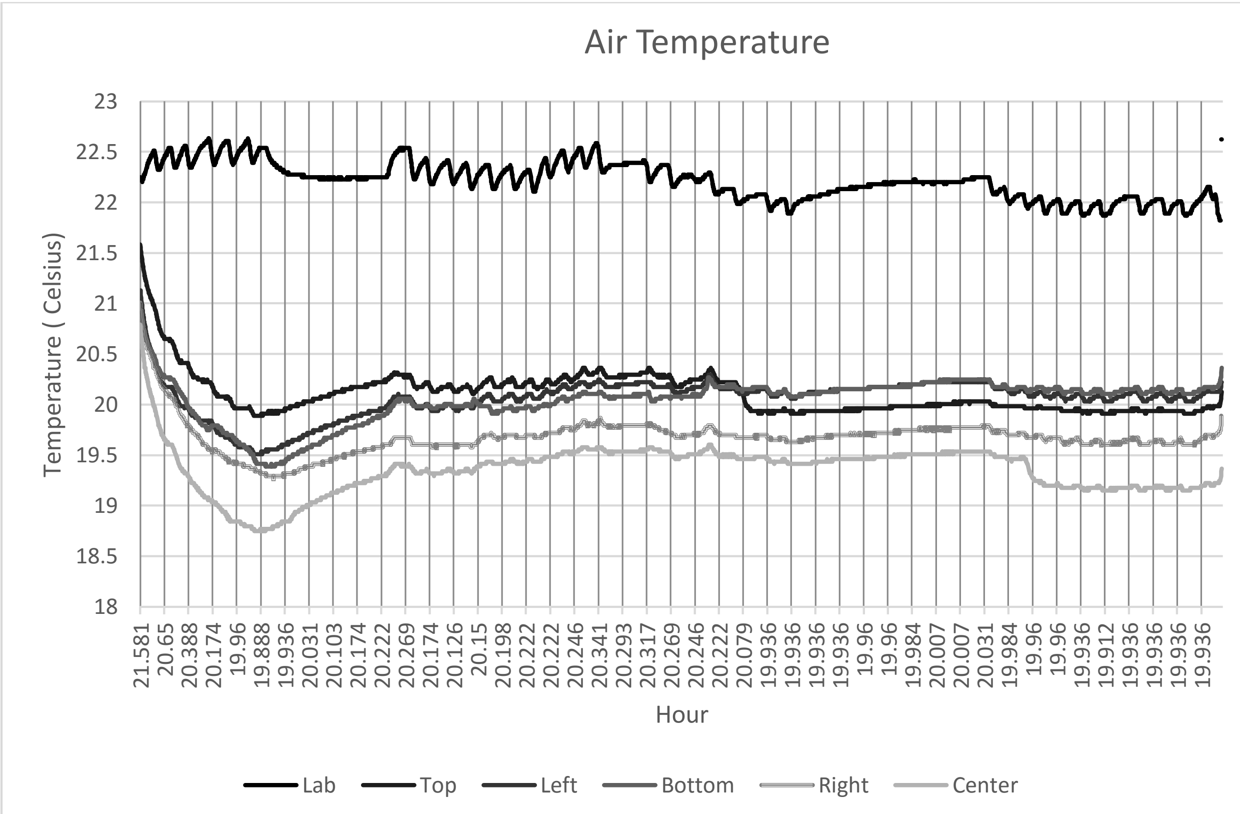


Air Temperature
24
23
22
21
20
19
18
Temperature (Celsius)
3:45:00
4:45:00
5:45:00
6:45:00
7:45:00
8:45:00
9:45:00
10:45:00
11:45:00
12:45:00
1:45:00
2:45:00
Hour
Lab
Top
Left
Bottom
Right
Center

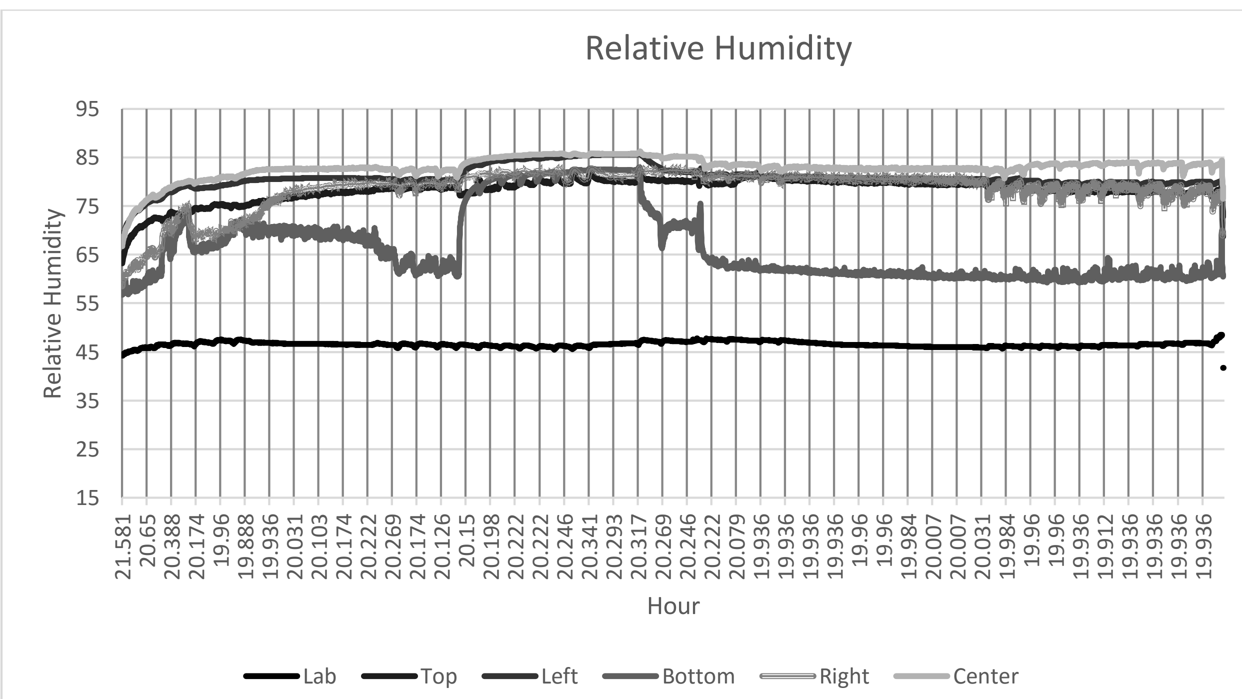


Relative Humidity
105
95
85
75
65
55
45
35
25
15
Relative Humidity
3:45:00
4:45:00
5:45:00
6:45:00
7:45:00
8:45:00
9:45:00
10:45:00
11:45:00
12:45:00
1:45:00
2:45:00
Hour
Lab
Top
Left
Bottom
Right
Center

C3_5ACH_V3

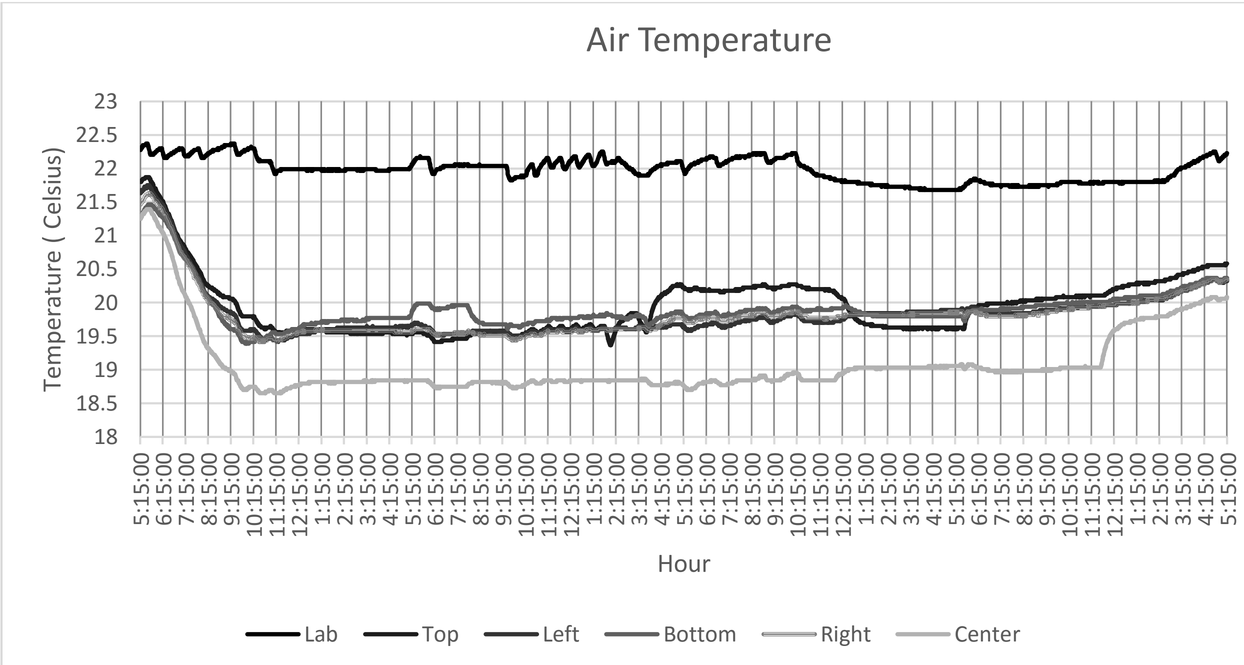


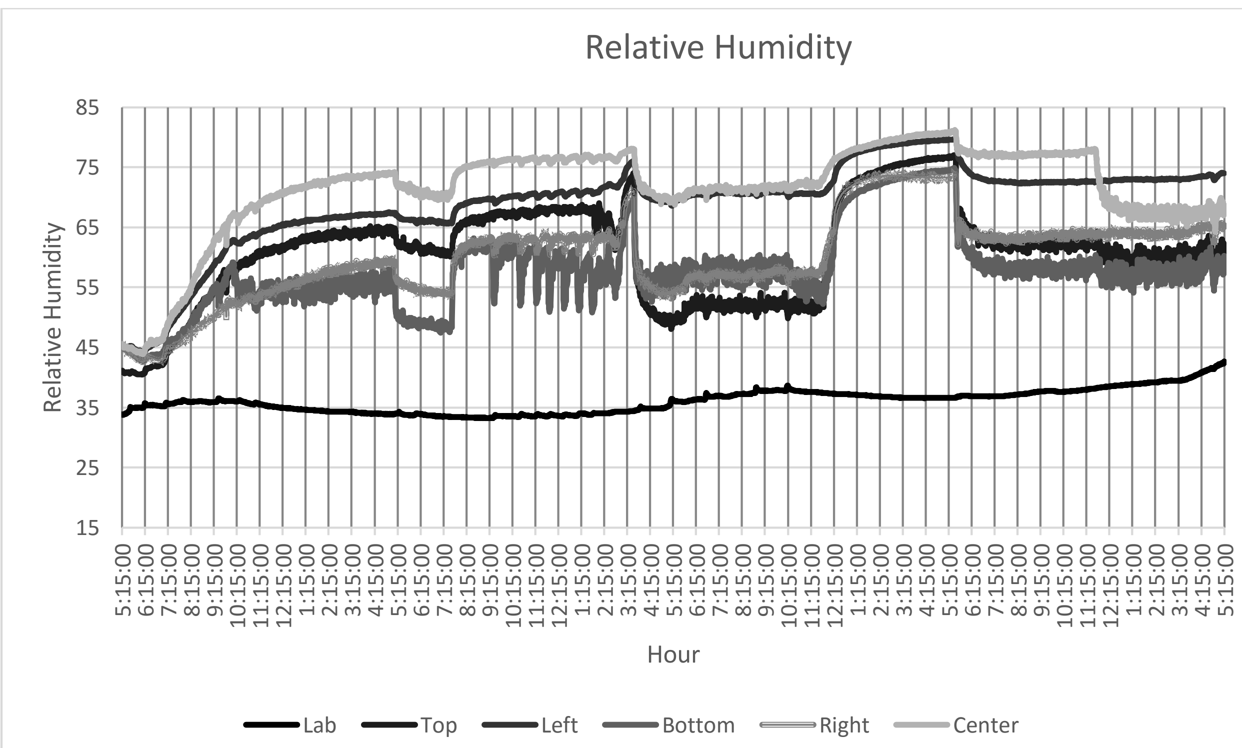
Air Temperature
23
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
Temperature (Celsius)
21.581
20.65
20.388
20.174
19.96
19.888
19.936
20.031
20.103
20.174
20.222
20.269
20.174
20.126
20.15
20.198
20.222
20.222
20.246
20.341
20.293
20.317
20.269
20.246
20.222
20.079
19.936
19.936
19.936
19.936
19.96
19.96
19.984
20.007
20.007
20.031
19.984
19.96
19.96
19.936
19.912
19.936
19.936
19.936
19.936
Hour
Lab
Top
Left
Bottom
Right
Center



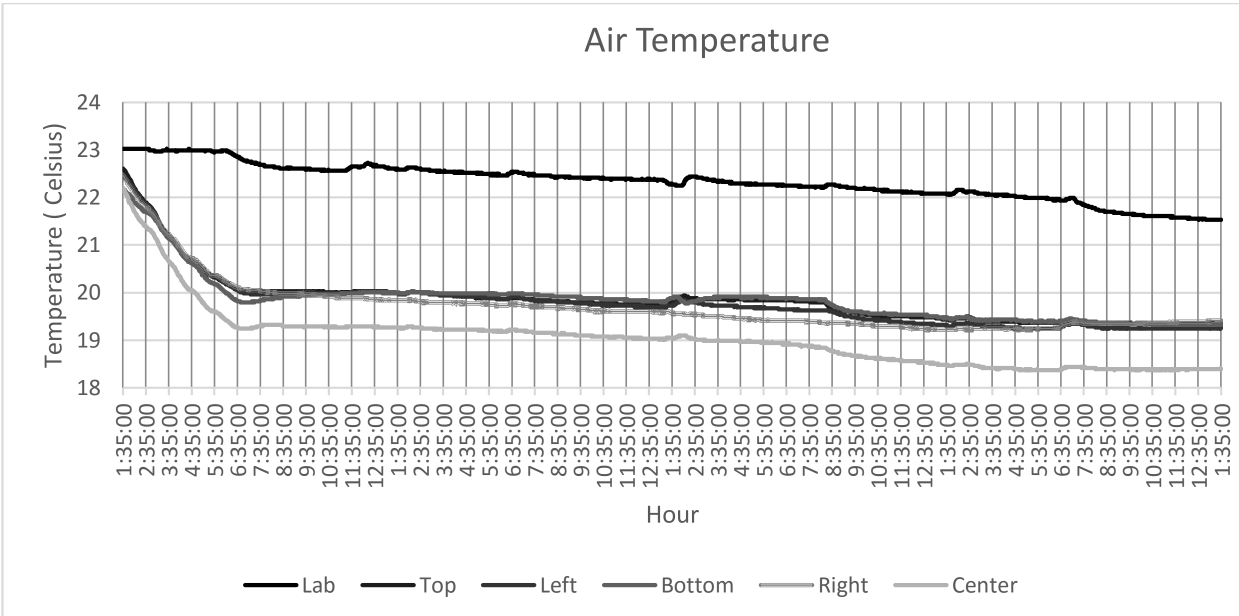
Relative Humidity
95
85
75
65
55
45
35
25
15
Relative Humidity
21.581
20.65
20.388
20.174
19.96
19.888
19.936
20.031
20.103
20.174
20.222
20.269
20.174
20.126
20.15
20.198
20.222
20.222
20.246
20.341
20.293
20.317
20.269
20.246
20.222
20.079
19.936
19.936
19.936
19.936
19.96
19.96
19.984
20.007
20.007
20.031
19.984
19.96
19.96
19.936
19.912
19.936
19.936
19.936
19.936
Hour
Lab
Top
Left
Bottom
Right
Center

C2_10ACH_V1

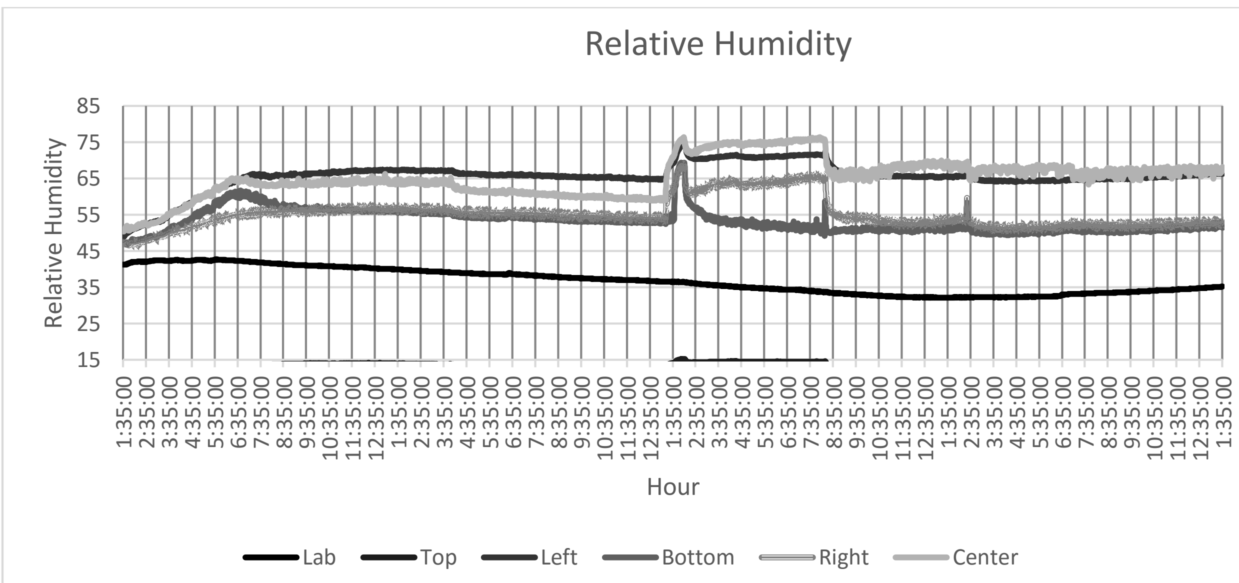

Air Temperature
Temperature (Celsius)
23
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
3:15:00
4:15:00
Hour
Lab
Top
Left
Bottom
Right
Center


Relative Humidity
Relative Humidity
85
75
65
55
45
35
25
15
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
3:15:00
4:15:00
Hour
Lab
Top
Left
Bottom
Right
Center

C2_10ACH_V2

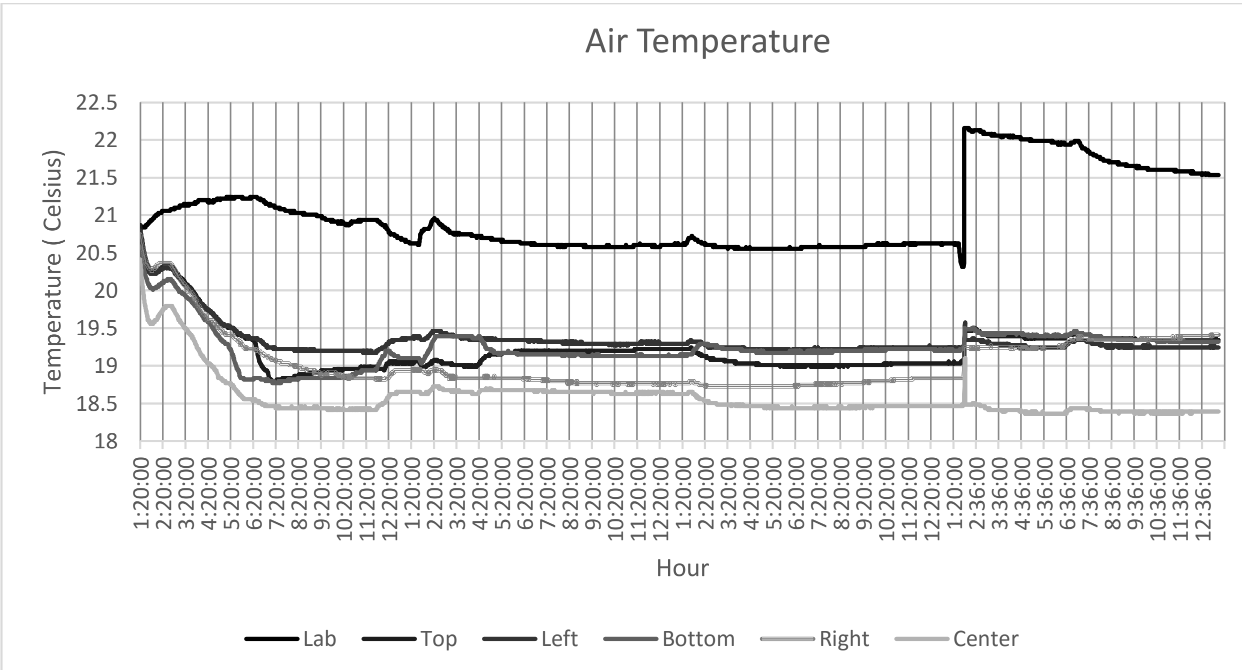


Air Temperature
Temperature (Celsius)
24
23
22
21
20
19
18
Hour
Lab
Top
Left
Bottom
Right
Center

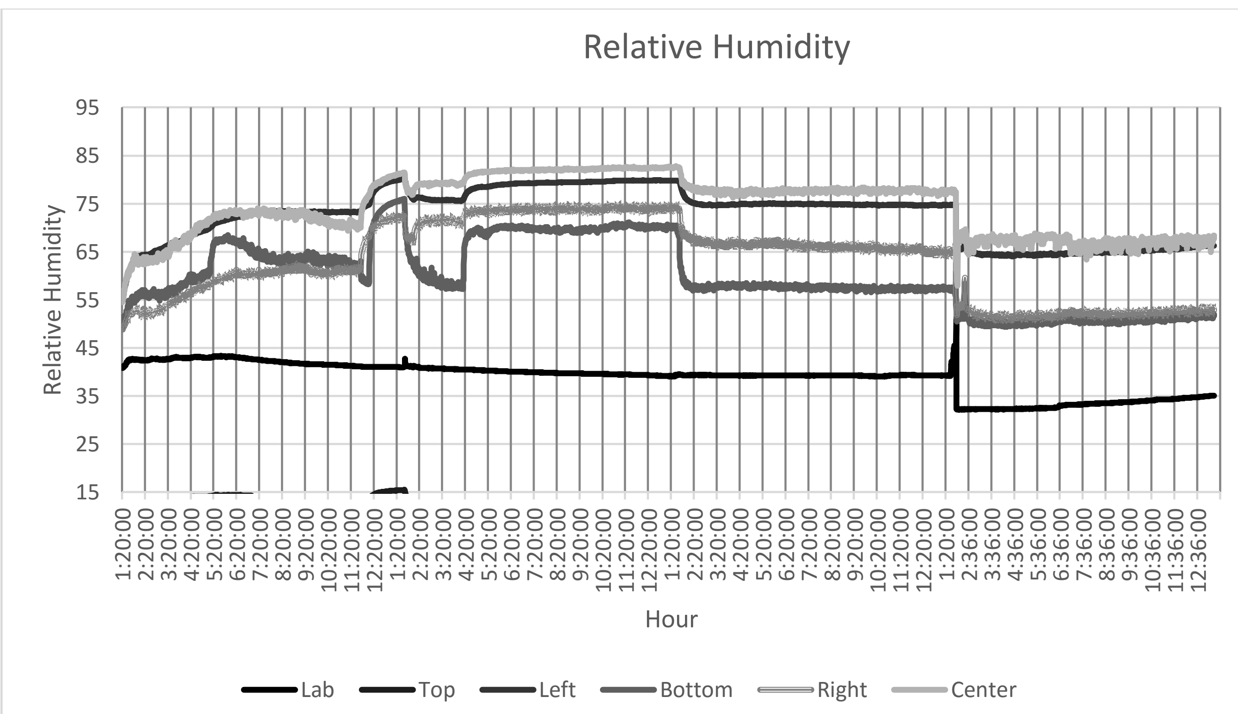


Relative Humidity
Relative Humidity
85
75
65
55
45
35
25
15
Hour
Lab
Top
Left
Bottom
Right
Center

C2_10ACH_V3

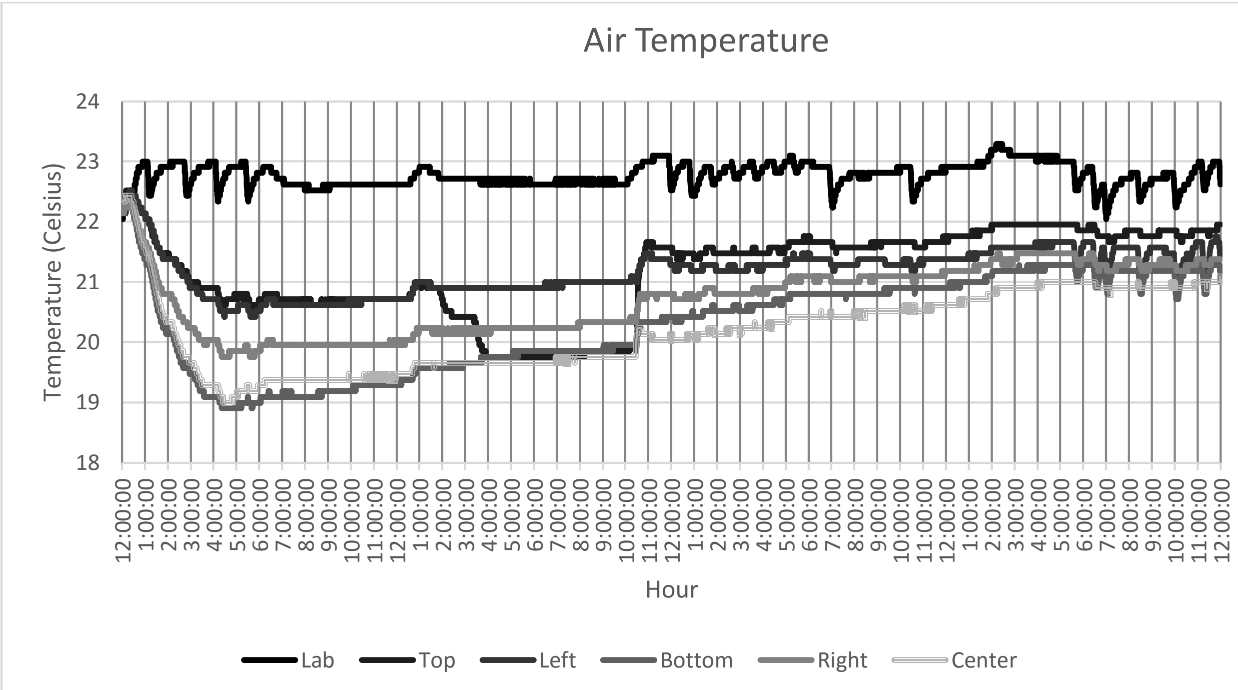


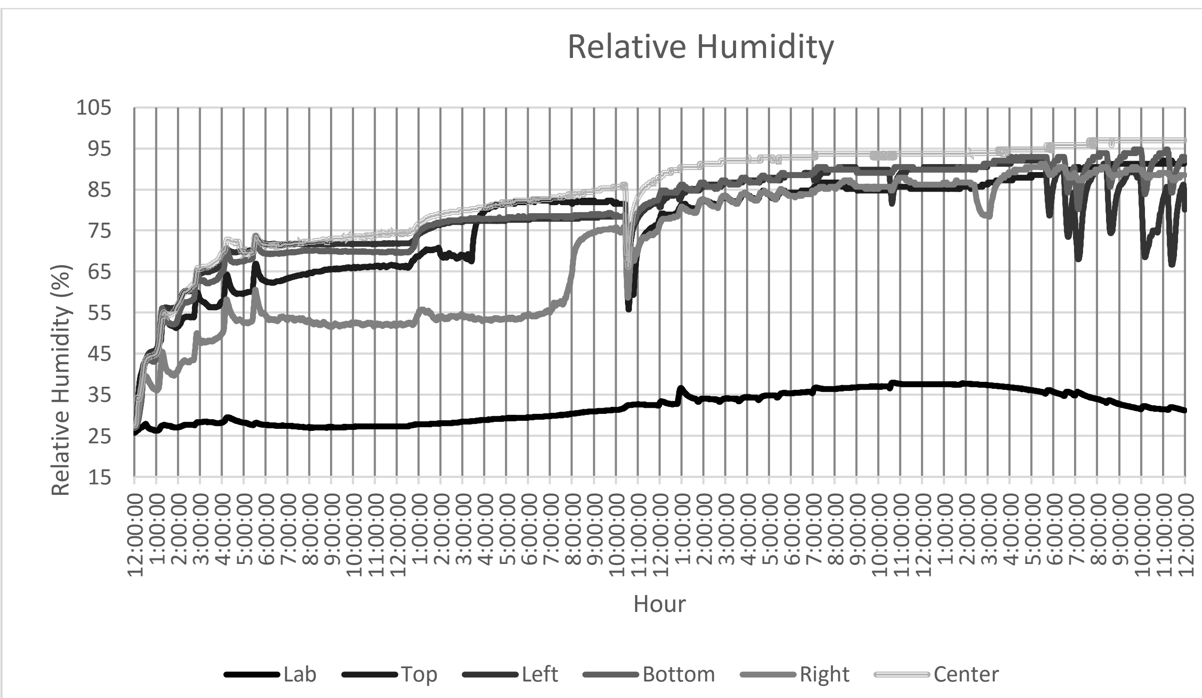
Air Temperature
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
Temperature (Celsius)
1:20:00
2:20:00
3:20:00
4:20:00
5:20:00
6:20:00
7:20:00
8:20:00
9:20:00
10:20:00
11:20:00
12:20:00
1:20:00
2:20:00
3:20:00
4:20:00
5:20:00
6:20:00
7:20:00
8:20:00
9:20:00
10:20:00
11:20:00
12:20:00
1:20:00
2:20:00
3:20:00
4:20:00
5:20:00
6:20:00
7:20:00
8:20:00
9:20:00
10:20:00
11:20:00
12:20:00
1:20:00
2:36:00
3:36:00
4:36:00
5:36:00
6:36:00
7:36:00
8:36:00
9:36:00
10:36:00
11:36:00
12:36:00
Hour
Lab
Top
Left
Bottom
Right
Center



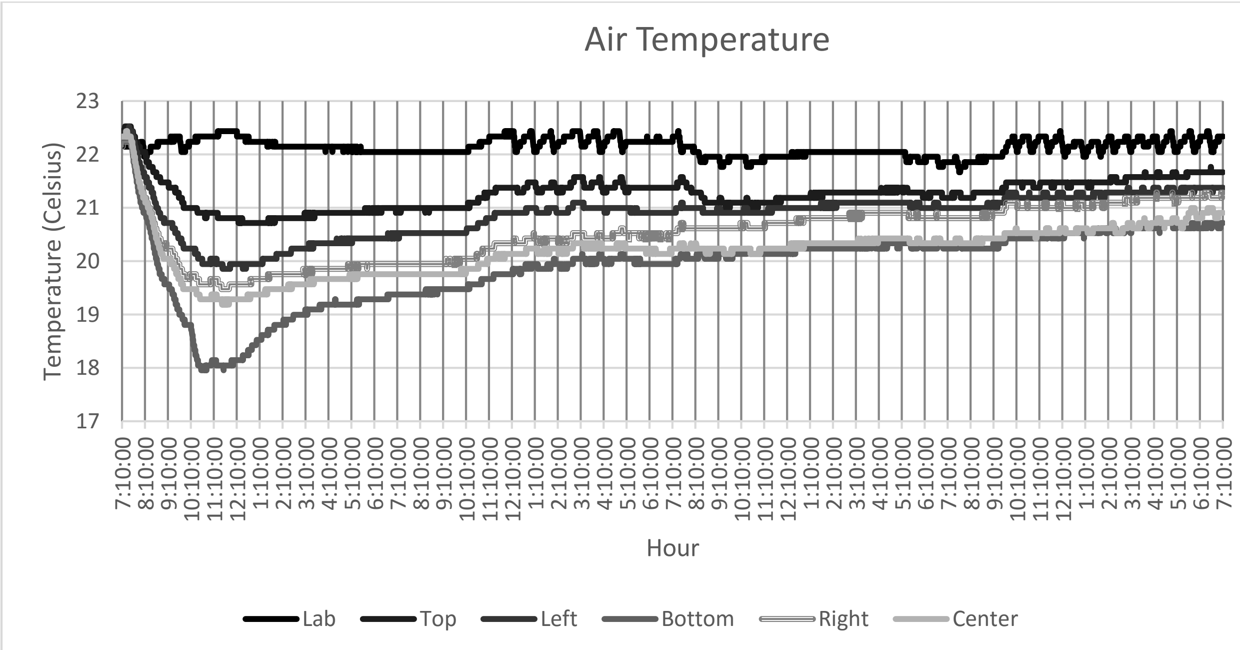
Relative Humidity
95
85
75
65
55
45
35
25
15
Relative Humidity
1:20:00
2:20:00
3:20:00
4:20:00
5:20:00
6:20:00
7:20:00
8:20:00
9:20:00
10:20:00
11:20:00
12:20:00
1:20:00
2:20:00
3:20:00
4:20:00
5:20:00
6:20:00
7:20:00
8:20:00
9:20:00
10:20:00
11:20:00
12:20:00
1:20:00
2:20:00
3:20:00
4:20:00
5:20:00
6:20:00
7:20:00
8:20:00
9:20:00
10:20:00
11:20:00
12:20:00
1:20:00
2:36:00
3:36:00
4:36:00
5:36:00
6:36:00
7:36:00
8:36:00
9:36:00
10:36:00
11:36:00
12:36:00
Hour
Lab
Top
Left
Bottom
Right
Center

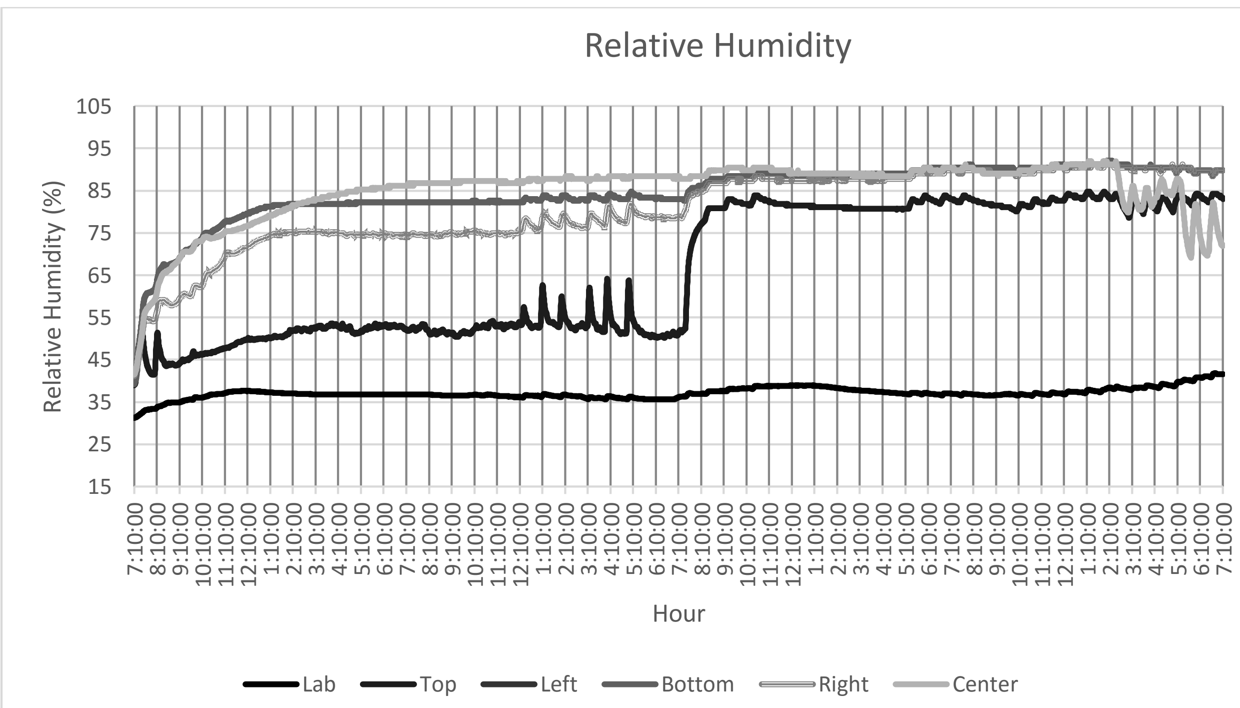
D3_NoVent_V1


Air Temperature
24
23
22
21
20
19
18
Temperature (Celsius)
12:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
Hour
Lab
Top
Left
Bottom
Right
Center

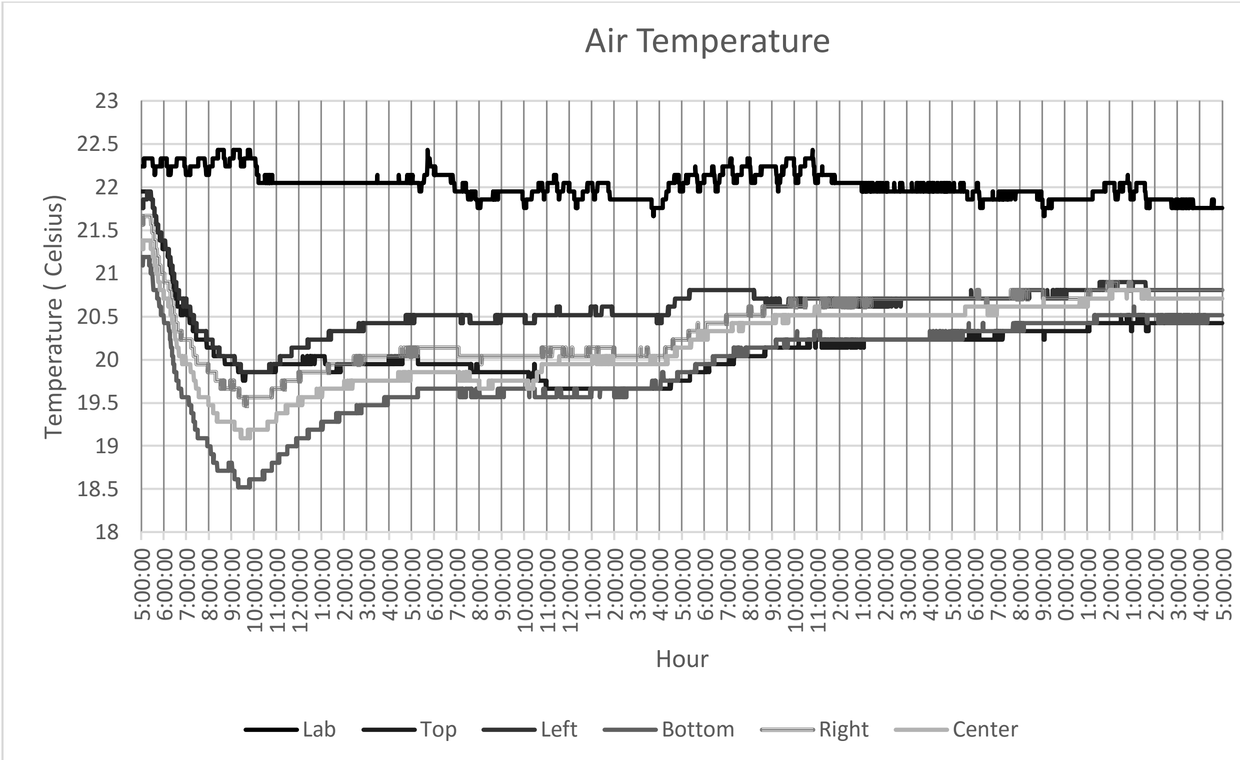

Relative Humidity
105
95
85
75
65
55
45
35
25
15
Relative Humidity (%)
12:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
Hour
Lab
Top
Left
Bottom
Right
Center

D3_NoVent_V2


Air Temperature
Temperature (Celsius)
23
22
21
20
19
18
17
7:10:00 8:10:00 9:10:00 10:10:00 11:10:00 12:10:00 1:10:00 2:10:00 3:10:00 4:10:00 5:10:00 6:10:00 7:10:00 8:10:00 9:10:00 10:10:00 11:10:00 12:10:00 1:10:00 2:10:00 3:10:00 4:10:00 5:10:00 6:10:00 7:10:00 8:10:00 9:10:00 10:10:00 11:10:00 12:10:00 1:10:00 2:10:00 3:10:00 4:10:00 5:10:00 6:10:00 7:10:00 8:10:00 9:10:00 10:10:00 11:10:00 12:10:00 1:10:00 2:10:00 3:10:00 4:10:00 5:10:00 6:10:00 7:10:00
Hour
Lab
Top
Left
Bottom
Right
Center


Relative Humidity
Relative Humidity (%)
105
95
85
75
65
55
45
35
25
15
7:10:00 8:10:00 9:10:00 10:10:00 11:10:00 12:10:00 1:10:00 2:10:00 3:10:00 4:10:00 5:10:00 6:10:00 7:10:00 8:10:00 9:10:00 10:10:00 11:10:00 12:10:00 1:10:00 2:10:00 3:10:00 4:10:00 5:10:00 6:10:00 7:10:00 8:10:00 9:10:00 10:10:00 11:10:00 12:10:00 1:10:00 2:10:00 3:10:00 4:10:00 5:10:00 6:10:00 7:10:00 8:10:00 9:10:00 10:10:00 11:10:00 12:10:00 1:10:00 2:10:00 3:10:00 4:10:00 5:10:00 6:10:00 7:10:00
Hour
Lab
Top
Left
Bottom
Right
Center

D3_NoVent_V3


Air Temperature
Temperature (Celsius)
23
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
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11:00:00
12:00:00
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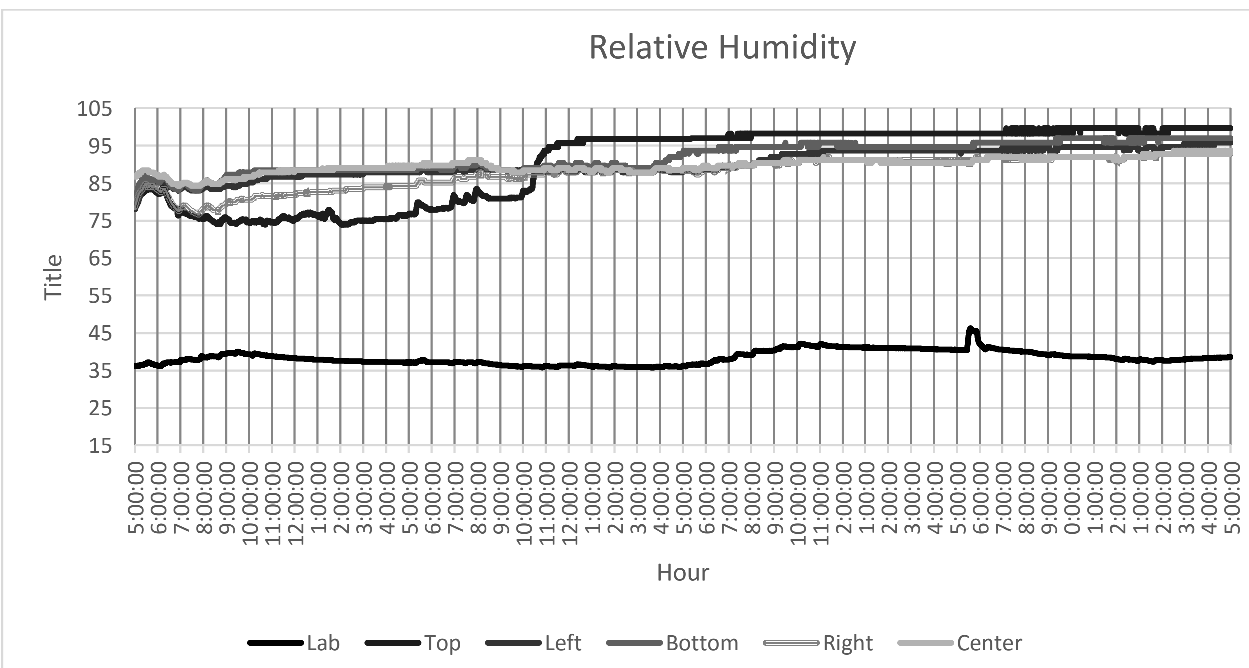
2:00:00
3:00:00
4:00:00
5:00:00
Hour
Lab
Top
Left
Bottom
Right
Center


Relative Humidity
Title
105
95
85
75
65
55
45
35
25
15
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
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12:00:00
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9:00:00
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11:00:00
12:00:00
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4:00:00
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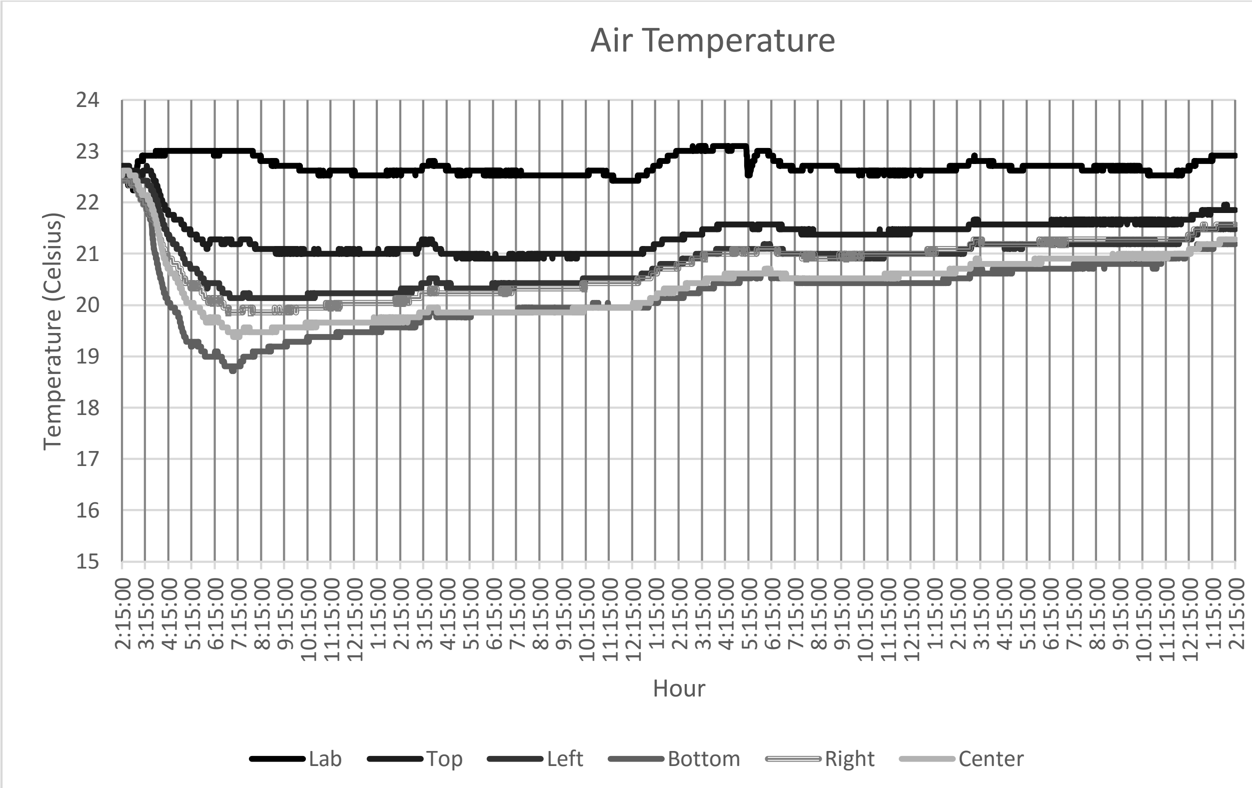
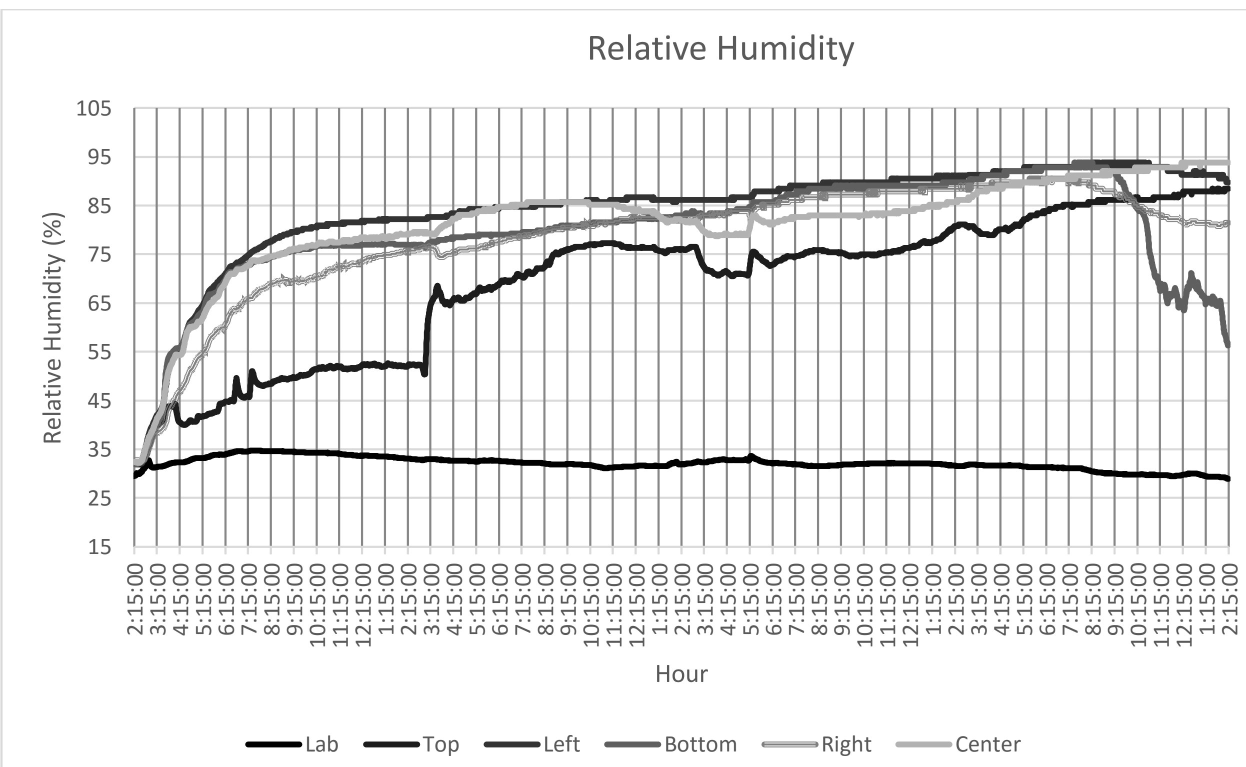
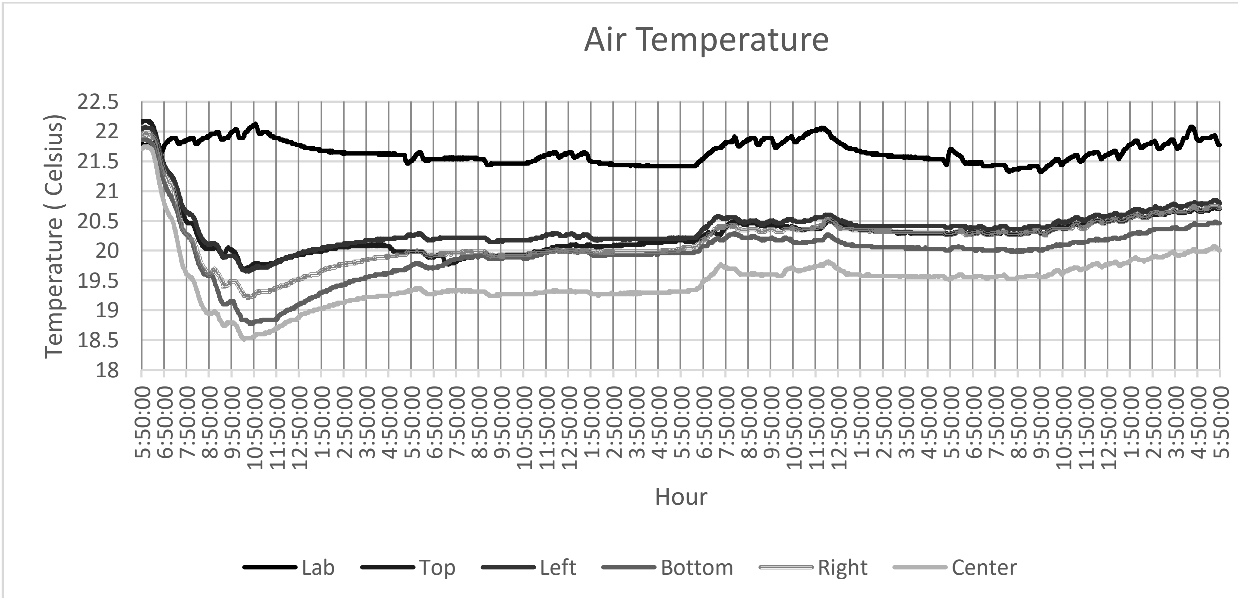
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
Hour
Lab
Top
Left
Bottom
Right
Center

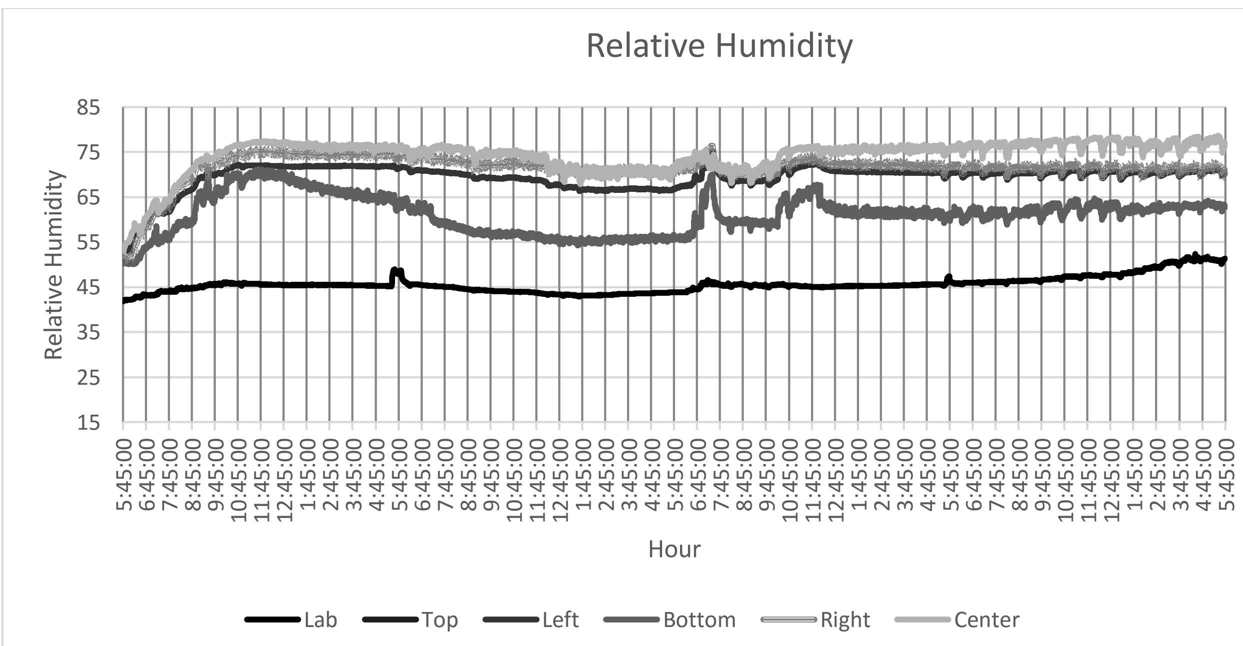
D1_5ACH_V1


Air Temperature
Temperature (Celsius)
24
23
22
21
20
19
18
17
16
15
2:15:00
3:15:00
4:15:00
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
3:15:00
4:15:00
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
3:15:00
4:15:00
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
3:15:00
4:15:00
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
Hour
Lab
Top
Left
Bottom
Right
Center

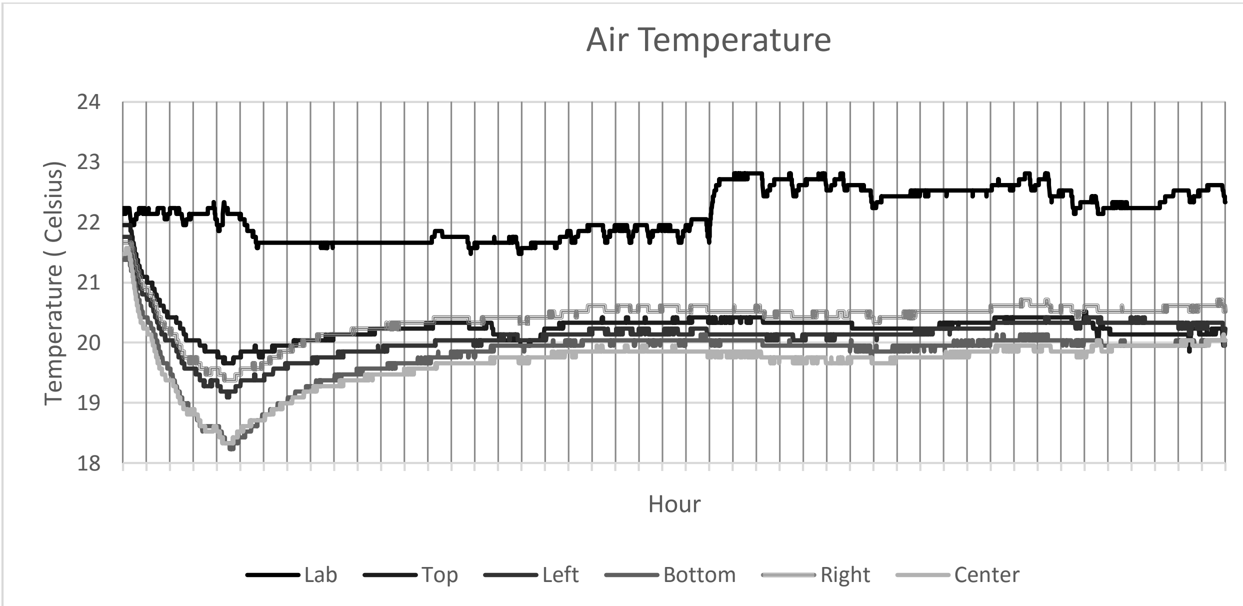

Relative Humidity
Relative Humidity (%)
105
95
85
75
65
55
45
35
25
15
2:15:00
3:15:00
4:15:00
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
3:15:00
4:15:00
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
3:15:00
4:15:00
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
3:15:00
4:15:00
5:15:00
6:15:00
7:15:00
8:15:00
9:15:00
10:15:00
11:15:00
12:15:00
1:15:00
2:15:00
Hour
Lab
Top
Left
Bottom
Right
Center

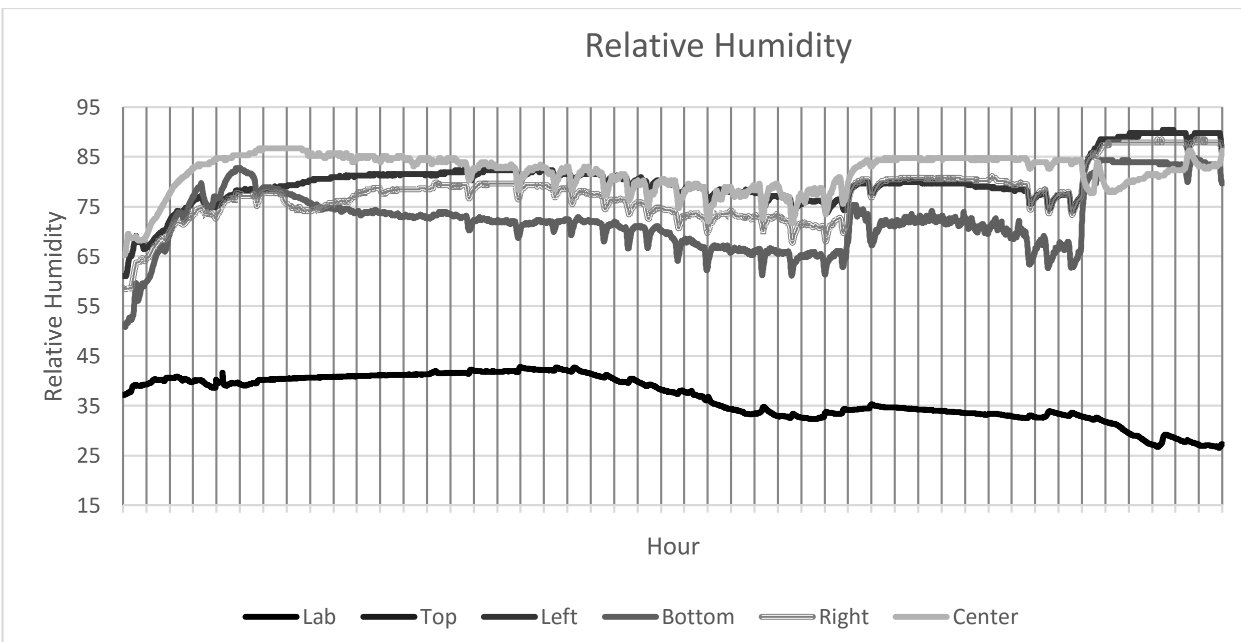
D1_5ACH_V2


Air Temperature
Temperature (Celsius)
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
Hour
Lab
Top
Left
Bottom
Right
Center

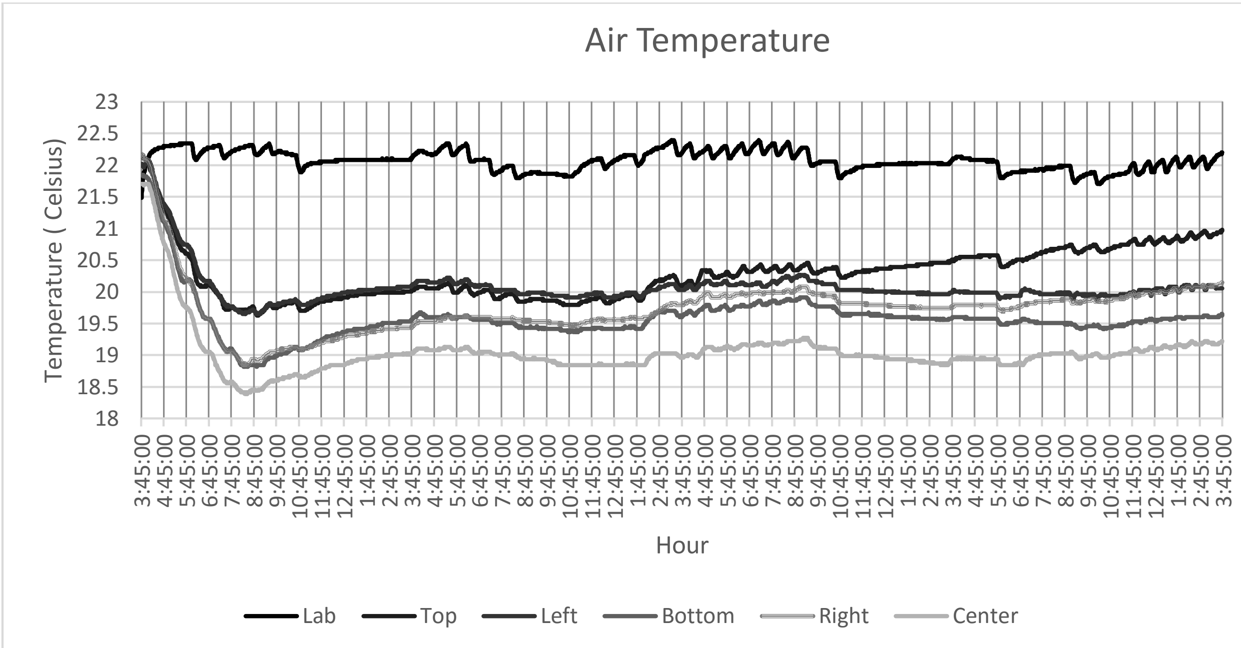

Relative Humidity
Relative Humidity
85
75
65
55
45
35
25
15
Hour
Lab
Top
Left
Bottom
Right
Center

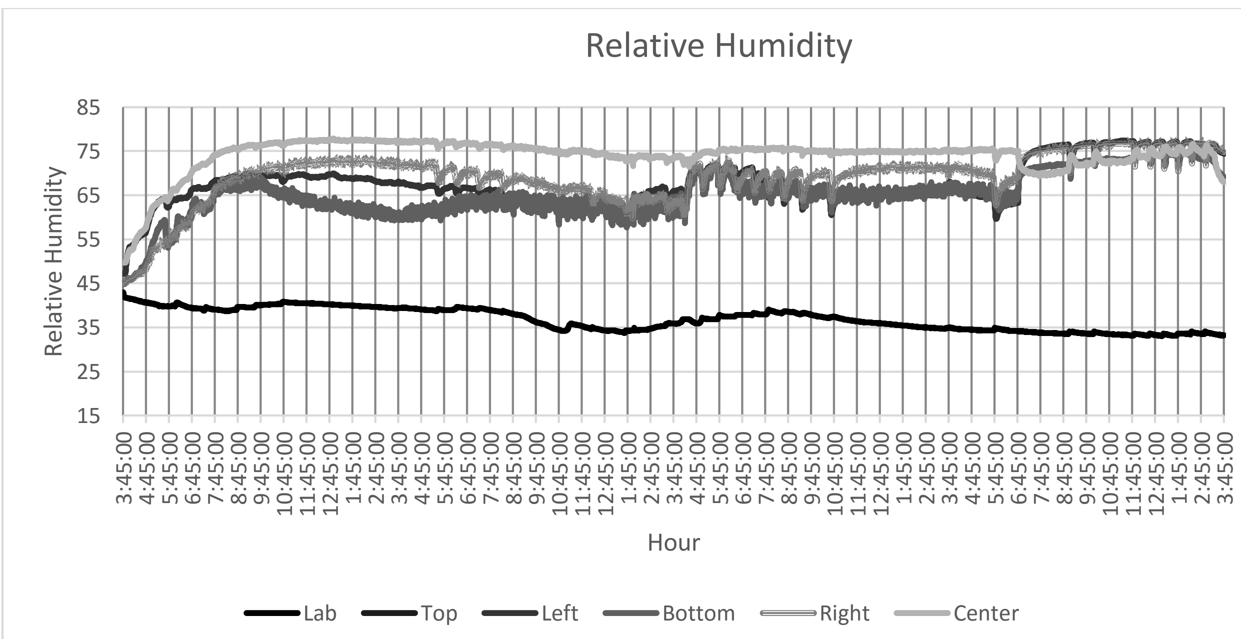
D1_5ACH_V3


Air Temperature
24
23
22
21
20
19
18
Temperature (Celsius)
Hour
Lab
Top
Left
Bottom
Right
Center

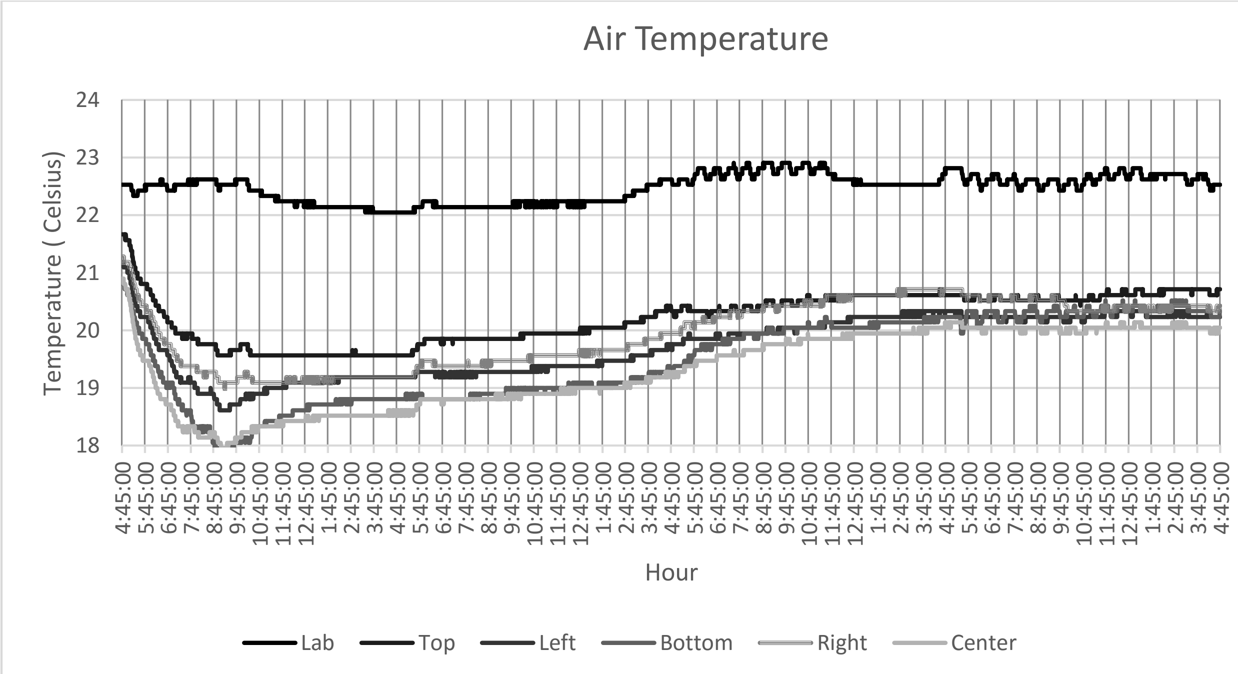

Relative Humidity
95
85
75
65
55
45
35
25
15
Relative Humidity
Hour
Lab
Top
Left
Bottom
Right
Center

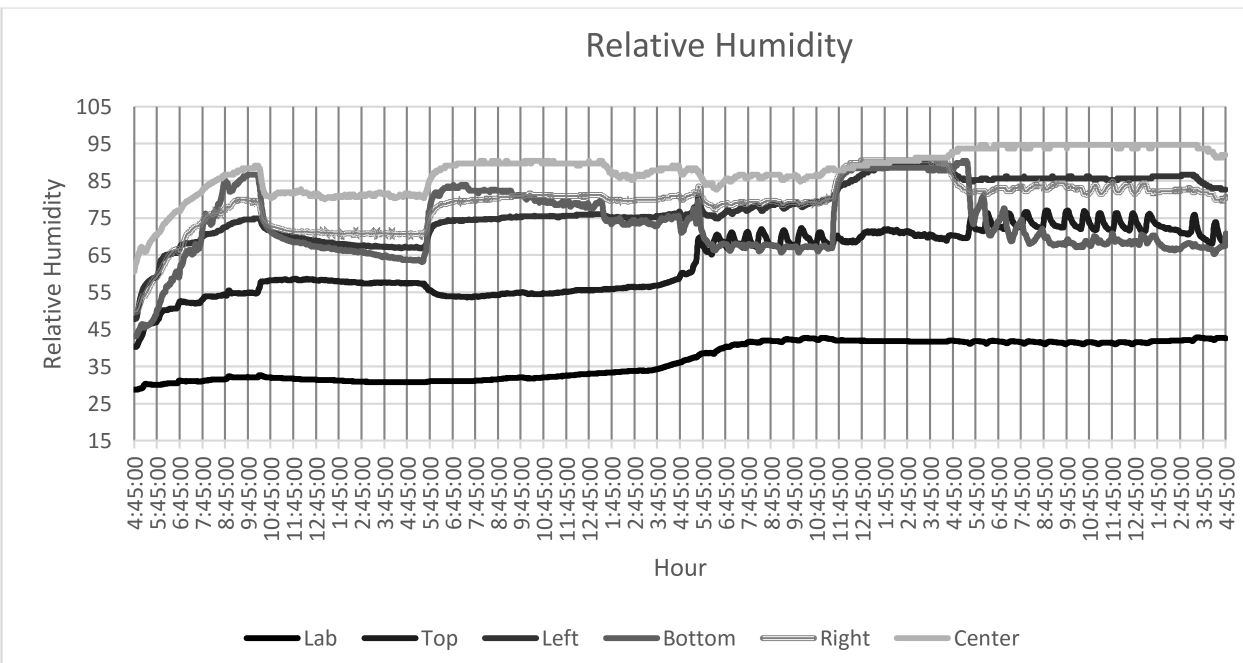
D2_10ACH_V1


Air Temperature
Temperature (Celsius)
23
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
Hour
Lab
Top
Left
Bottom
Right
Center

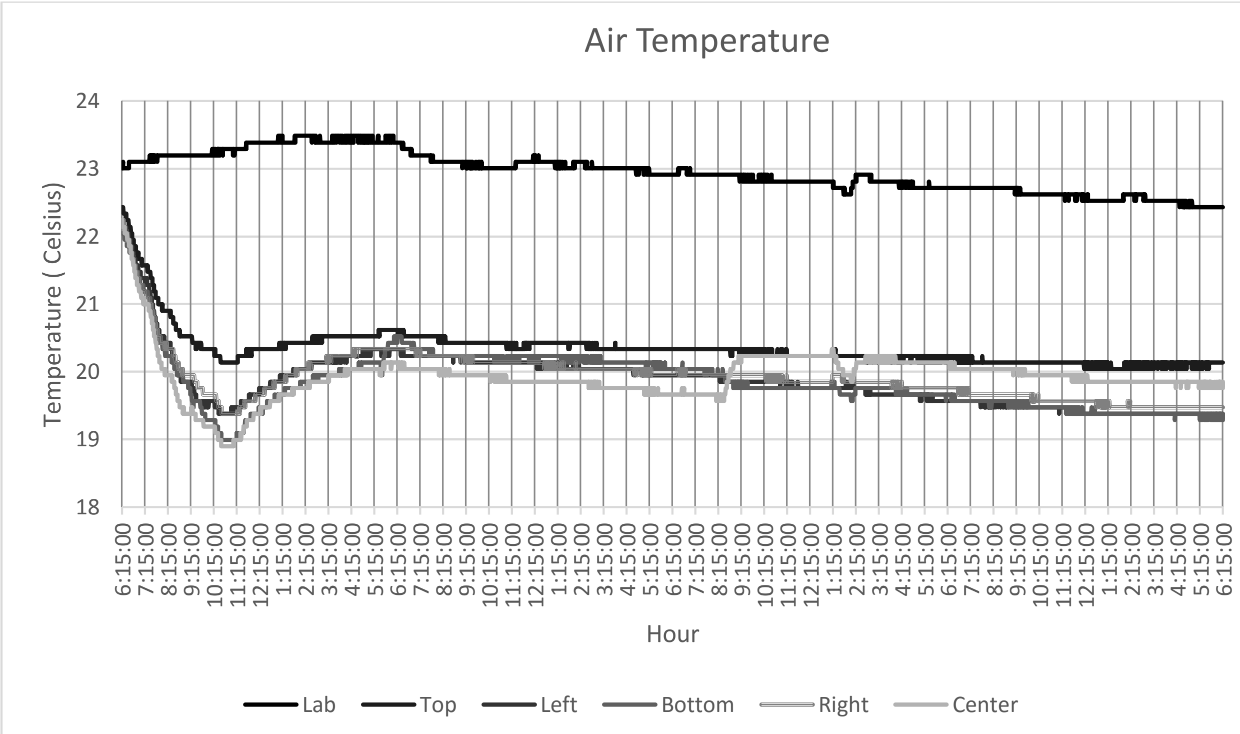

Relative Humidity
Relative Humidity
85
75
65
55
45
35
25
15
Hour
Lab
Top
Left
Bottom
Right
Center

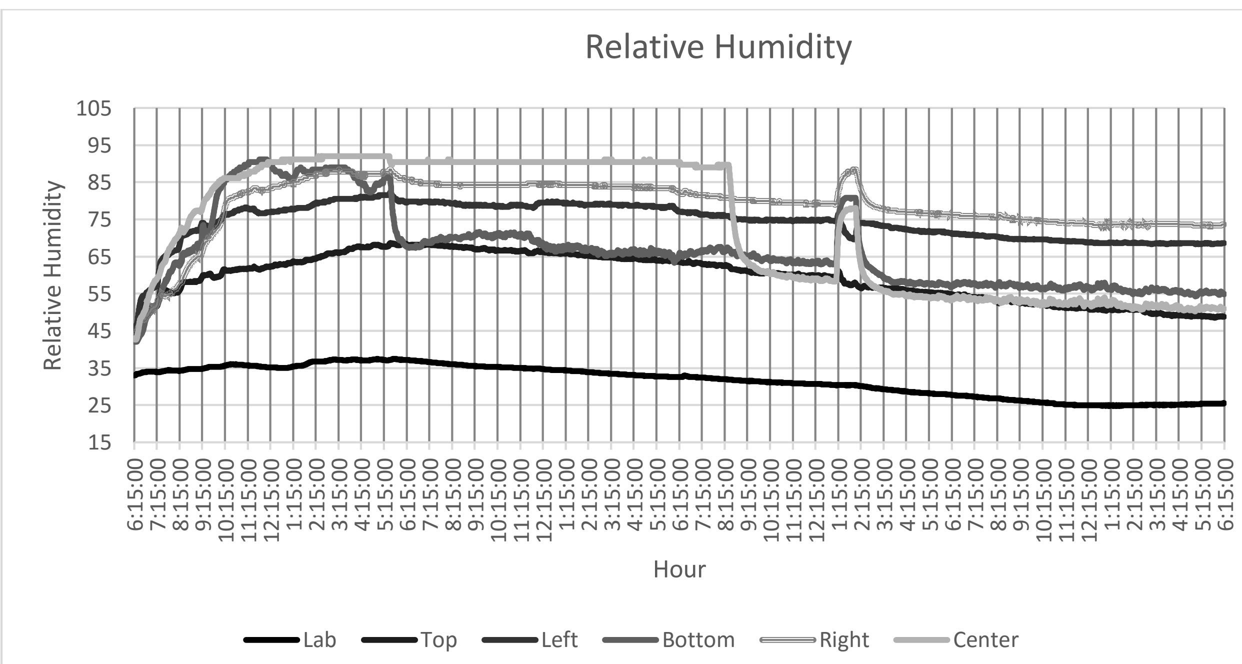
D2_10ACH_V2


Air Temperature
Temperature (Celsius)
24
23
22
21
20
19
18
4:45:00
5:45:00
6:45:00
7:45:00
8:45:00
9:45:00
10:45:00
11:45:00
12:45:00
1:45:00
2:45:00
3:45:00
Hour
Lab
Top
Left
Bottom
Right
Center


Relative Humidity
Relative Humidity
105
95
85
75
65
55
45
35
25
15
4:45:00
5:45:00
6:45:00
7:45:00
8:45:00
9:45:00
10:45:00
11:45:00
12:45:00
1:45:00
2:45:00
3:45:00
Hour
Lab
Top
Left
Bottom
Right
Center

D2_10ACH_V3


Air Temperature
Temperature (Celsius)
24
23
22
21
20
19
18
6:15:00 7:15:00 8:15:00 9:15:00 10:15:00 11:15:00 12:15:00 1:15:00 2:15:00 3:15:00 4:15:00 5:15:00 6:15:00 7:15:00 8:15:00 9:15:00 10:15:00 11:15:00 12:15:00 1:15:00 2:15:00 3:15:00 4:15:00 5:15:00 6:15:00 7:15:00 8:15:00 9:15:00 10:15:00 11:15:00 12:15:00 1:15:00 2:15:00 3:15:00 4:15:00 5:15:00 6:15:00 7:15:00 8:15:00 9:15:00 10:15:00 11:15:00 12:15:00 1:15:00 2:15:00 3:15:00 4:15:00 5:15:00 6:15:00
Hour
Lab
Top
Left
Bottom
Right
Center


Relative Humidity
Relative Humidity
105
95
85
75
65
55
45
35
25
15
6:15:00 7:15:00 8:15:00 9:15:00 10:15:00 11:15:00 12:15:00 1:15:00 2:15:00 3:15:00 4:15:00 5:15:00 6:15:00 7:15:00 8:15:00 9:15:00 10:15:00 11:15:00 12:15:00 1:15:00 2:15:00 3:15:00 4:15:00 5:15:00 6:15:00 7:15:00 8:15:00 9:15:00 10:15:00 11:15:00 12:15:00 1:15:00 2:15:00 3:15:00 4:15:00 5:15:00 6:15:00 7:15:00 8:15:00 9:15:00 10:15:00 11:15:00 12:15:00 1:15:00 2:15:00 3:15:00 4:15:00 5:15:00 6:15:00
Hour
Lab
Top
Left
Bottom
Right
Center

Appendix D – Mock Test

Mock Test 1

Mock Test on Wall Specimen A3

A mock up test was performed on wall specimen A3 to evaluate the validity of the experimental procedure. It became clear that the 5 minute and 10 minute drying intervals did not leave enough time for all the necessary measurements to be taken. The amount of time needed was a full 20 minutes.

Wetting of the backside cavity was first observed during the 1st interval of wetting. For the most part, water did not accumulate in large enough amounts to drain to the bottom cloths to be weighed and measured. The liquid water was either collecting on the mortar droppings or dripping too far off the wall, thus landing on the bottom piece of insulation instead of draining past it. This meant the leakage water could not be measured accurately without removing the chamber.

Moisture content readings worked out for the most part, however there were some probes which were not properly sealed and readings were much higher than one would expect. Water was likely trapped in the hole thus influencing readings.

Penetration

The table below shows the before and after weights of the moisture absorbent cloths. The cloths were measured prior to each wetting cycle, and roughly one minute after each wetting cycle. The delay in measurement after each wetting cycle was performed to allow penetrated water to completely drain to the bottom.

Nov 11th		**Weight of Cloths (g)**		**Leakage (g)**
Interval	**Time**	**Before Wetting**	**After Wetting**	
1	12:02	52	52	0
2	12:46	52	52	0
3	13:03	52	54	2
4	13:37	52	52	0
5	14:32	52	54	2
6	16:07	52	54	2

Table 10 - Table of values showing before and after weights of moisture absorbent cloth. The amount of water penetrated through the wall is given by the difference in weight. 1 g = 1 ml of pure H^2O

The results from this measurement are inconclusive. It was clear from visual observation that penetrated water was not being measured accurately. Please read the section below on proposed method changes.

Absorption/ Blockage

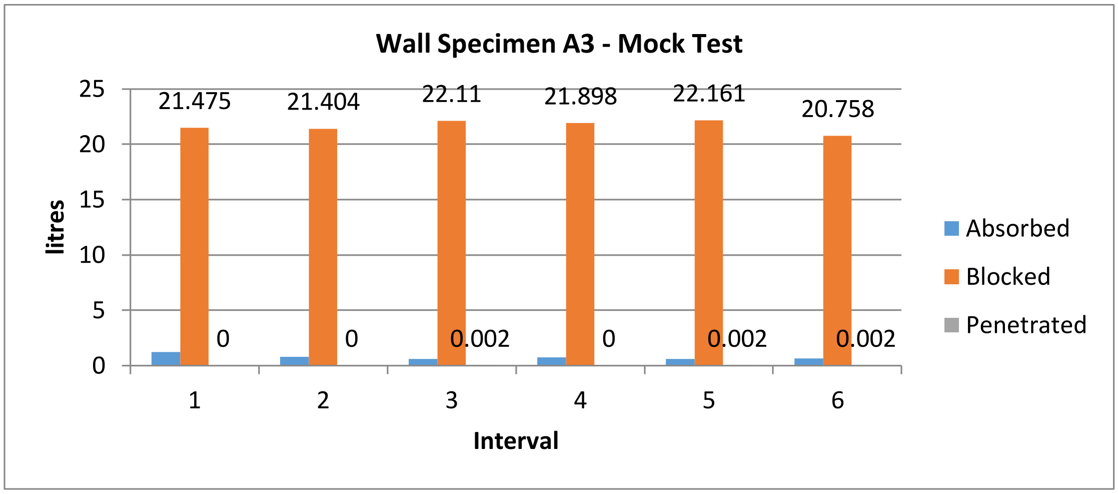


Figure 61 - Results from mock test

The pump truck scale was used to measure the wall specimen before and after wetting cycles. The graph above shows the results. The total amount of water which was delivered to the wall specimen ranged from 25.458 – 26.99 L. The amount of water absorbed by the wall was 1.22 L during the first interval, and subsequent intervals showed significantly less absorption. They were 0.77L, 0.59L, 0.72L, 0.59L, 0.63L respectively. The initial wetting cycle showed significantly more absorption, this was expected because the bricks were dry to begin with. The amount of water absorbed fluctuated between the 2nd and 6th wetting cycle. There is no clear trend or correlation between the amount of water absorbed and the length of drying cycle. Perhaps the change in length of drying cycle is adding a complexity to the experiment which cannot be measured effectively.

It might worth revising the current intervals to have the same length of drying period. This would simplify the experiment. The drying cycle can be reduced to 20 minutes, with 15 minute rain intervals.

Moisture Content

The moisture content measurement locations are as follows; locations 1,2,3,4,5 are top, center left, bottom, center right and dead center respectively. They were measured on the external side of the wall specimen at approximately the center of the wall. The results are as follows:

Hanson Brick Cortes Max 3:1								
Date	**Nov 11th**		**Location MC %**					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
17:30		Before	2.9	2.7	3.1	2.7	2.8	2.84
12:02	1	After	3	2.7	3.4	1.8	2.8	2.74
		Before						
12:46	2	After	3.3	2.7	8.4	2.1	3.3	3.96
		Before						
13:03	3	After	3.4	2.8	7	2.7	2.8	3.74
		Before						
13:36	4	After	3.7	2.8	19.8	2.7	2.9	6.38
		Before						
14:32	5	After	4.6	2.9	19.8	3	3	6.66
		Before						
16:07	6	After	13.2	3	19.8	3.1	3.1	8.44
18:47	Final		13.4	3.4	15.4	3	3.3	

Table 11

Type N Mortar								
Date	**Nov. 11th**		**Location MC %**					
Time	**Interval**	**Wetting**	**1**	**2**	**3**	**4**	**5**	**Avg**
17:30		Before	0.6	0.5	0.9	1	0.8	0.76
1202	1	After	0.2	0.2	1.4	0.8	1.5	0.82
		Before						
12:46	2	After	0.4	0.4	1.6	1.5	0.4	0.86
		Before						
1:03	3	After	0.5	0.3	1.6	2.2	1.4	1.2
		Before						
1:36	4	After	0.4	0.3	1.4	2.2	1.8	0.975
		Before						
2:32	5	After	0.5	0.5	1.9	2.3	1.6	1.36
		Before						
4:07	6	After	0.5	1.4	2.1	2.3	2	1.66
18:47	Final		0.5	1.7	2.1	2.2	1.9	1.68

The highlighted numbers are suspected to be compromised pins. It is likely that the silicone seal failed and water leaked into the hole, causing decreased accuracy. Overall, the trend of increased moisture content from start to finish can be observed. In some circumstances the MC decreased for a short time during the test. This could be caused by a number of reasons. Evaporation during the drying cycle could account for some water loss however, evaporation losses would be minimal in the lab setting. Moisture redistribution through the brick and mortar during the test may give the impression of drying. The moisture may have been transported to another point in the wall.

Cavity Chamber Conditions

Temperature and RH was monitored at 5 locations in the cavity chamber. Data loggers took measurements at 10 second intervals. The interval can be lengthened for future tests as the data does not display properly. The data logger displays data with three decimal places; the graphing software shows each minor change in temp/RH and the resulting graph looks far too jumbled. It is difficult to see the change on a graph.

Locations 1,2,3,4,5,6 are top, right center, bottom, left center, dead center, and external conditions, respectively.

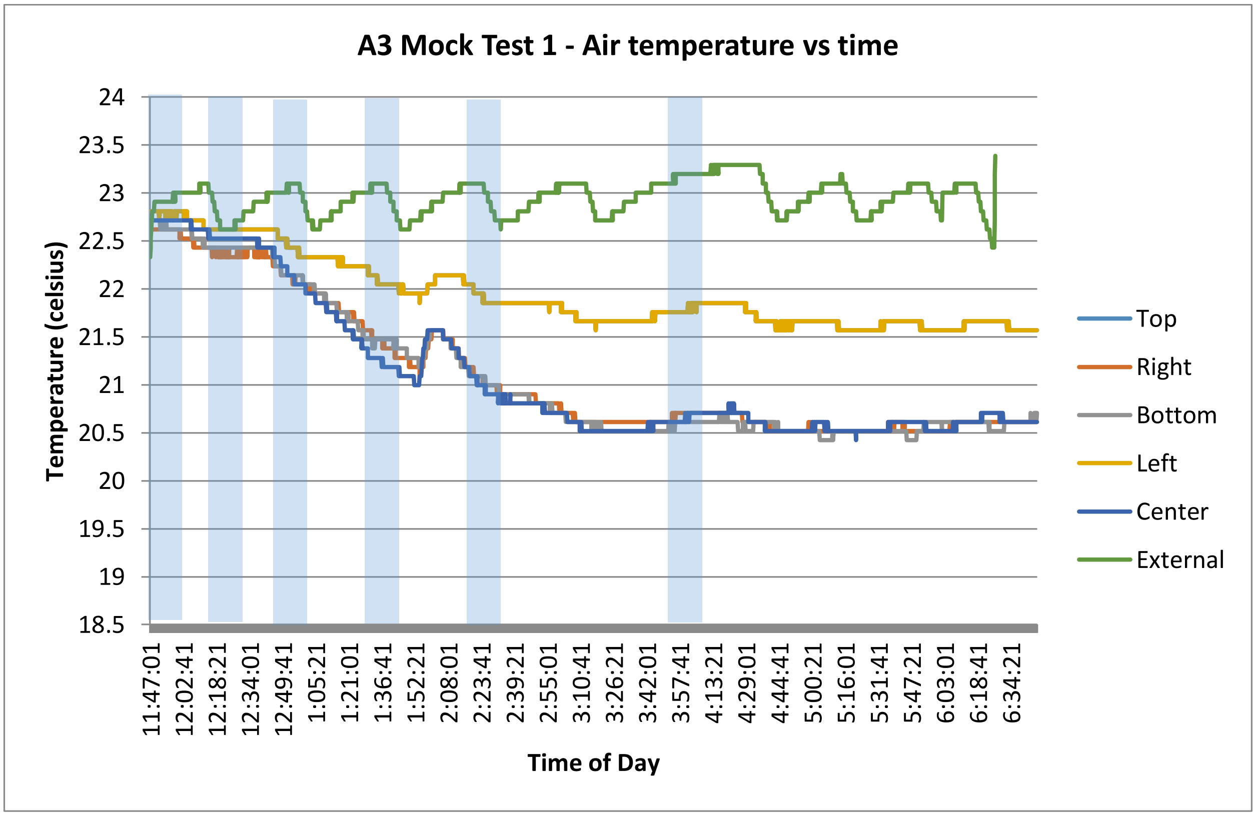


Figure 62 - A3 Mock up test 1air temperature over the test period. The shaded areas represent a wetting cycle, while the space between shaded bars are the drying cycles

The hump which is experienced at the 1:55 mark was a result of the cavity chamber being removed so debris could be extracted from the cavity wall. Mortar dust from drilling had accumulated on the mortar droppings and was absorbing penetrated water. Overall, temperatures were slightly lower in the cavity than the external lab conditions. It is difficult to see any trends on the graphs above, longer intervals for the data loggers may help this.

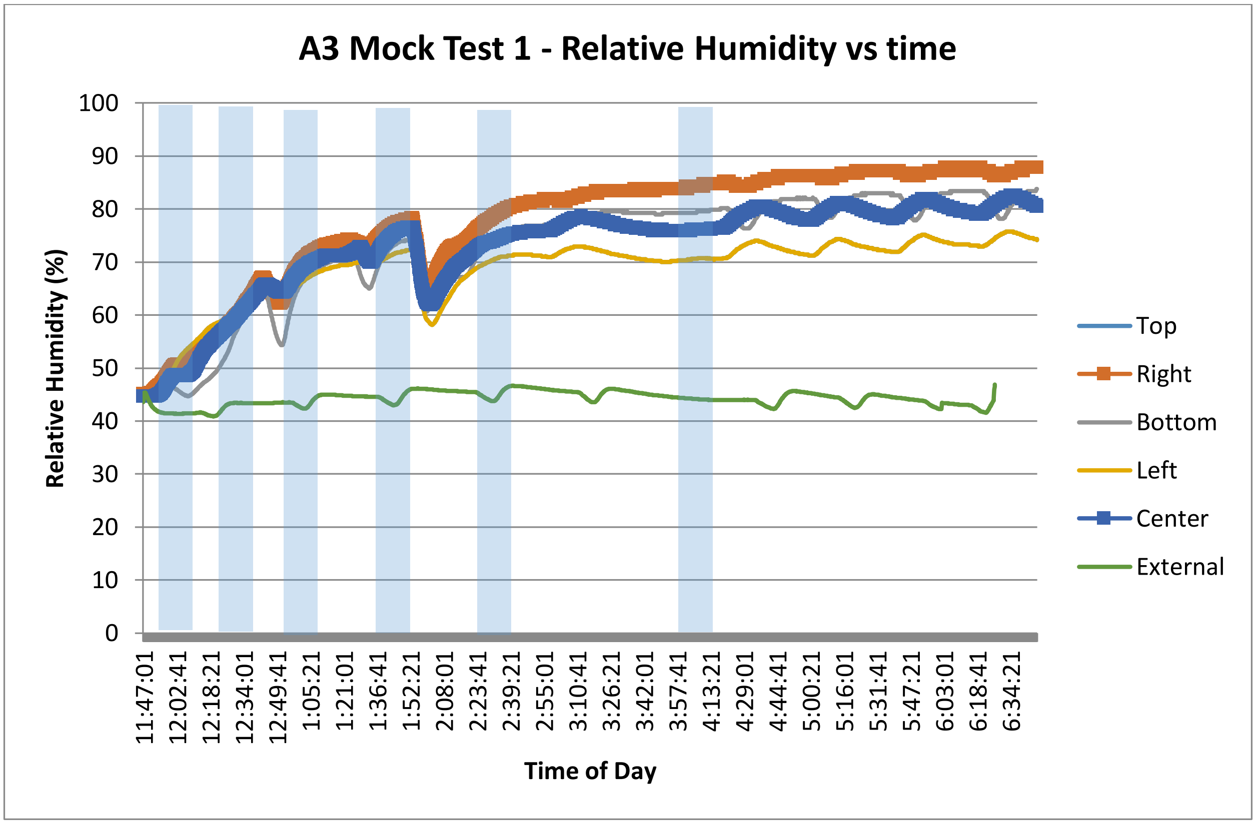


Figure 63 - Relative humidity inside the cavity chamber over the testing period

Proposed changes to experimental procedure

Drying Intervals

The short drying intervals of 5 and 10 minutes did not provide enough time to take measurements, thus the drying intervals should be extended. The minimum time interval shall be 20 minutes. A review of the "doubling factor" of drying interval length should be done. This could be scrapped for a consistent drying interval which will simplify the experiment. A constant interval of 20 min is proposed.

Penetrating water

The penetrated water was not collected efficiently during the first test. Removing the bottom piece of insulation would allow water to drain down the wall *and* water which drips off mortar to be collected. With the bottom piece of insulation removed, this would also provide an area for simulated ventilation air to be applied at the bottom of the wall.

In addition, the idea of "penetrated water" should be revised in the thesis. After observing the experiment it became clear that much of the penetrated water was not draining to the bottom to be collected. Water accumulated on the mortar droppings. It really isn't possible to measure the moisture which accumulates on the wall surface without taking the cavity off the wall, which defeats the purpose of this experiment. Water penetration should be redefined as the amount of liquid water which successfully drains to the bottom of the cavity. Any water which accumulates on the wall but does not make it to the bottom cannot be measured and can't be included in penetration results.

Moisture Content

It became apparent after the mock-up test that the moisture pins required additional sealant to ensure a watertight seal. For future tests the sealant shall be placed in two coats. The second coat to be applied a minimum of three hours after the 1st coat has been laid. This will provide more accurate readings as no standing liquid water will interfere with the readings

Blockage/Deflection

No changes needed for this measurement.

Ventilation

The ventilation strategy (not performed on this mock test) will be performed manually with a hot air gun. The gun will be set to fan mode as not to introduce excessive evaporation. The fan has a mass flow rate of 23 CFM (0.01085 m^3/s) and air velocity at the outlet is 3000 FPM (15.24 m/s), according to the manufacturer's specifications. There is no option for a variable flow rate. The cavity chamber has a volume of 0.05618 m3. The length of time for which the gun must be turned on during a drying interval reflects the mass flow of the gun, cavity volume, and number of desired ACH (air changes per hour). The table below outlines the length of time the gun is required to be set to the "on" position.

	ACH				
Drying Interval Length (min)	**1**	**5**	**10**	**15**	
5	0.4314	2.1565	4.313	6.4695	**Length of time (s)**
10	0.8626	4.313	8.626	12.939	
20	1.7252	8.626	17.252	25.878	
40	3.4505	17.252	34.504	51.756	
160	13.802	69.008	138.02	207.02	

Table 12 Outline of ventilation requirements for different drying intervals and ACH

Full versions of ACH 1-20 are available. This ventilation times will be broken into even intervals to provide an even distribution of ventilation air throughout the drying interval. The chart below outlines the length of time between each 1 second burst.

	ACH				
Drying Interval Length (min)	**1**	**5**	**10**	**15**	
5	150	100	60	42.857	**Time between bursts (s)**
10	300	120	66.667	46.154	
20	600	133.333	66.667	46.154	
40	600	133.333	68.514	46.154	
160	685.71	137.14	69.065	46.154	

Table 13 Time between bursts assuming the drying interval starts with the air gun set in the "off" position

The third chart in this series represents the adjusted length of each 1 second burst. The total ventilation requirements do not align evenly with 1 second intervals, so each burst will vary slightly in length depending on the length of drying cycle and ACH.

	ACH				
Drying Interval Length (min)	**1**	**5**	**10**	**15**	
5	0.4343	1.0782	1.0782	1.0782	**Adjusted Burst Length (s)**
10	0.8626	1.0782	1.0782	0.9953	
20	0.8626	1.0782	1.0782	0.9953	
40	1.1501	1.0148	1.0148	1.0148	
160	1.0617	1.0001	1.0148	1.0001	

Table 14 Adjusted burst lengths for ventilation requirements.

The calculations in Table 4 show a small adjustment in the burst length. In reality, this adjustment cannot be performed manually by hand. An assumption of all burst lengths are equal to 1 second will be will simplify the ventilation delivery procedure.

Delivering the ventilation air at one second intervals may prove to be too arduous a task. The burst can be doubled to 2 seconds and thus the time between bursts would be doubled. This would decrease the number of bursts applied during the drying cycle, thus the work would be less strenuous. The only downfall to this would be a decrease in the consistency of air flow through the cavity chamber.

The changes to the ventilation strategy are related to the changes in water penetration measurement. As previously stated, the bottom piece of insulation will need to be removed to allow for more efficient water collection. The air gun will be placed at the bottom of the cavity chamber, as air will be blown up the wall. A small pocket will be removed from the top piece of insulation to simulate a the venting effect. The size of this pocket, including the revised drainage gap at the bottom of the cavity will be based on a typical ratio of vent area to wall surface area (0.4% - 2%).

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