

CARBON DIOXIDE ABSORPTION BY VARIOUS TYPES OF PAVEMENT BINDER
MATERIALS

By

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To my husband and my parents for your continued support and without whom this
would not be possible

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CO ₂	Carbon dioxide
EPA	Environmental Protection Agency
PC	Portland Cement
PSI	Pounds per Square Inch

Abstract of Thesis Presented to the Graduate School
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The subject of this thesis is the absorption of carbon dioxide by various types of construction binders. The purpose of this research is to provide a baseline for further experimentation into carbon dioxide absorption by mortar and applied to concrete types. Various types of binders that were investigated are Portland cement, Portland cement with fly ash, Portland cement with slag, Portland cement with fly ash and slag, Set 45 (Magnesium phosphate), and asphalt. Standard mortar cubes were made of each binder material and placed in a controlled environment.

The concentration of carbon dioxide was monitored over time as well as temperature and relative humidity. Baseline data was obtained for various environments. These environments were outside, inside a home, and inside an office building. Data collected from the mortar samples were compared to the baselines as well as the controls - no specimen, regular Portland cement and asphalt.

It was found that all types of mortars tested absorbed carbon dioxide. CO₂ was absorbed over the first 30 minutes rapidly, but did not continue to be absorbed over time beyond the initial 30-minute period. Portland cement mortar was just as effective at

absorbing CO₂ as other types tested. In fact, the absorption took place by Portland cement faster than was observed by any other type. Asphalt did not absorb CO₂ to any degree.

CHAPTER 1 INTRODUCTION

Background

A project's environmental impact has become an issue worth considering by designers and constructors alike. Growing popularity of Leadership in Energy and Environmental Design (LEED) has increased the knowledge base of the population while encouraging industry professionals to learn more about designing and constructing in a more environmentally friendly way.

Concrete is a material specified in nearly all construction projects in some way shape or form. Concrete is usually based on Portland cement, which is produced on the order of 1.7×10^9 tons per year – enough to produce over 6 km^3 of concrete (Gartner 2004). Cement production yields carbon dioxide. Due to the large volume of concrete produced each year, the amount of carbon dioxide produced as a byproduct is immense. According to Gartner, for each cubic meter of concrete that is produced, 0.2 tons of CO_2 are emitted as a byproduct (Gartner 2004). That comes to 1.36×10^8 tons of carbon dioxide annually.

Carbon dioxide is a naturally occurring compound, in the gaseous form at room temperature. It is essential to the health of plants and is removed from the air by them. While plants need carbon dioxide, if too much is prevalent in an atmosphere the plants and trees cannot absorb all. Excess carbon dioxide can cause smog as well as respiratory problems to humans and animals. According to a 2006 study of the U.S. Greenhouse Gas Emissions Inventory, concrete production is the fourth largest contributor of carbon dioxide emissions worldwide (EPA 2009). As one can imagine, a project's carbon footprint (or individual carbon dioxide contribution to the environment)

has become an issue to be considered when designing and constructing a building. Because concrete is prevalent in almost all buildings and since concrete is responsible for producing carbon dioxide, the construction industry has begun to take steps in the direction of reduction of carbon dioxide emissions.

Methods of carbon dioxide absorption do exist. One method is to use an additive in the concrete mixture that absorbs atmospheric carbon dioxide. This additive is also adaptable to paint products and can be applied to existing buildings to absorb atmospheric carbon dioxide. This would seem to be especially useful in densely populated areas where excess carbon dioxide in the atmosphere has already become a problem. Another method is to study different cement alternatives to the concrete mixture, such as fly ash, to evaluate carbon dioxide absorption over time. This thesis focuses on the evaluation of carbon dioxide absorption by various construction binder materials that are used in both road and building construction.

Research Hypothesis

Many types of concrete and many additives to the concrete mix design exist. Some concrete manufacturers claim that their product absorbs an unusually high amount carbon dioxide. It is expected that some types will absorb more carbon dioxide during the curing process than others. It is also expected that the compressive strength will be higher in those samples that have absorbed carbon dioxide and gone through the carbonation process on the outer surface than their counterparts that cured under water.

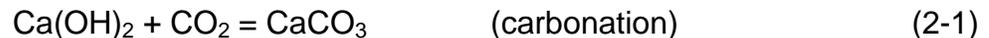
CHAPTER 2 LITERATURE REVIEW

Introduction

This literature review is divided into three parts. The first describes the effects of carbon dioxide on concrete and reinforcing steel. The second part describes the various types of mortars tested in this paper. Lastly, the standards and specifications used will be discussed.

Effects of CO₂ on Concrete

Carbon dioxide affects concrete both positively and negatively. Calcium hydroxide has a high pH, making it an alkaline compound. As CO₂ comes in contact with a concrete surface, the calcium hydroxide in the concrete reacts with carbon dioxide in the air to form calcium carbonate. This process is called carbonation. (See Equation 2-1)



The acidity in the CO₂ decreases the pH, thus decreasing the alkalinity of the concrete. The highly basic nature of concrete protects the reinforcing steel within. The rate of carbonation occurs on average at 0.04in. per year (ACI 2006). For example, if the concrete cover is about three inches, it would take about 75 years for the carbonated portion to reach reinforcing steel. Cracks in the concrete will decrease this number. Cracks in the surface allow CO₂ to penetrate into the concrete. The rate of carbonation “in a concrete crack 0.008 in. wide is about three orders of magnitude (1000 times) higher than in average-quality crack-free concrete” (ACI 2006). Once the carbonation has reached the reinforcing steel, the steel is no longer protected and will

begin corroding, ultimately weakening the structure. In addition, carbonation increases shrinkage of fully cured concrete, therefore causing additional cracking (ACI 2006).

Carbonation has a positive effect physically on the concrete itself. The process causes the structure to be denser, increases the strength, and reduces the permeability of concrete (ACI 2006). These enhance concrete but would be more beneficial in concrete that does not contain reinforcing steel.

Cement Mortar Types

The following paragraphs describe the types of mortars considered in this research. Some types are proprietary names and were not available for the study.

Portland Cement

Portland cement concrete is the most widely used type of concrete. Portland cement itself requires 94% of the total energy consumed in making concrete (BuildingGreen.com 2003). Carbon dioxide emissions come from two sources in the production of concrete and mortar. The first is from the burning of fossil fuels to operate the kiln used to make Portland cement. This source is the largest producer, at approximately $\frac{3}{4}$ tons of CO₂ per ton of cement (BuildingGreen.com 2003). The second is from the chemical process of calcining limestone into lime in the cement kiln, producing approximately $\frac{1}{2}$ ton of CO₂ for each ton of cement produced (BuildingGreen.com 2003). Worldwide cement production accounts for more than 1.6 billion tons of CO₂ annually (BuildingGreen.com 2003).

Portland Cement plus Fly Ash

The production of Portland cement takes a large amount of energy. To reduce the amount of Portland cement needed to make concrete or mortar would reduce the overall amount of energy needed. Fly ash, a waste byproduct of the coal industry, can

be substituted for 15-35% of the cement in concrete or mortar mixes (BuildingGreen.com 2003). Today, fly ash accounts for about 9% of the cement mix in concrete (BuildingGreen.com 2003). “Fly ash increases concrete strength, improves sulfate resistance, decreases permeability, reduces the water ratio required, and improves the pumpability and workability of the concrete” (BuildingGreen.com 2003). The EPA requires that all buildings constructed using federal funding include fly ash in the concrete mix (BuildingGreen.com 2003).

Portland Cement plus Slag

Slag granules are a waste component of the iron industry. The molten slag ends up at the bottom of the blast furnace when iron is made. The molten slag is removed from the furnace and rapidly quenched with water (SCA 2002a). Because it is cooled rapidly, crystals are unable to form and the product is glassy, non-metallic silicates and aluminosilicates of calcium (SCA 2002a). The granules are ground and can be used as an additive to Portland cement in concrete or mortar mixes. The addition of slag to Portland cement results in many benefits, including better workability, higher compressive and flexural strengths, and improved resistance to aggressive chemicals (SCA 2002a).

Portland Cement plus Fly Ash and Slag

Both fly ash and slag are products that can be recycled into concrete as a pre-consumer material. This provides an added environmental benefit. The properties of fly ash plus slag cement vary which in turn results in varied concrete properties. The variation seen is a result of the processes that make these products. For example, slag is a by-product of the iron industry, a tightly controlled process, which yields a similar result each time. Fly ash, on the other hand, is a by-product of electrical power

generation. This process is not as constant from source to source, yielding a product that varies from source to source (SCA 2002b). Because of this, slag cement yields a product with more uniform properties (SCA 2002b). Both cements lower permeability and increase resistance to sulfate attack (SCA 2002b). The differences between the two cements are based on the type of oxide contained in each. Table 2-1, summarizes the different oxides.

Table 2-1. Typical chemical oxides for various cementitious materials

	Portland cement	Slag cement	Fly ash C	Fly ash F
CaO	65	45	25	3
SiO ₂	20	33	37	58
Al ₂ O ₃	4	10	16	20
Fe ₂ O ₃	3	1	7	10
MgO	3	6	7	1

This table was taken from “Slag Cement and Fly Ash” from the Slag Cement Association (SCA 2002b).

SET® 45 (Magnesium phosphate)

SET® 45 is a prepackaged concrete patching and repair mortar manufactured by BASF Construction Chemicals, LLC. This product is ready to drive on after 45 minutes, hence the name. This product is convenient because it comes as a just-add-water mix. SET®45 contains magnesium phosphate and claims resistance to sulfate attack (BASF The Chemical Company 2008). While the company makes no claims of CO₂ absorption, it is worth testing because of the claim from other companies that the utilization of magnesium aids in the absorption of atmospheric CO₂.

Asphalt

According to the Asphalt Industry website, asphalt concrete can be defined as “a dark brown to black cementitious material in which the predominating constituents are bitumens, which occur in nature or are obtained in petroleum processing. Asphalt is a

constituent in varying proportions of most crude petroleum and used for paving, roofing, industrial and other special purposes” (Asphalt Institute 2003). Asphalt is widely used, especially in road paving, and the mix will not be manipulated in this test, which makes a good control for experimentation.

Novacem

Novacem is a company based in London making a product called Novacem. Novacem is made by converting magnesium silicate to magnesium oxide. After the addition of proprietary additives, the cement is complete (Evans 2008). This process replaces the traditional process of converting limestone to clinker and grinding to make Portland cement. Novacem claims that by utilizing magnesium silicate, CO₂ is not released as a byproduct (Evans 2008). Because of this and the absorption of CO₂ as Novacem cures, the claim is a negative effect of CO₂ (Novacem 2009).

Calera Cement

Calera Corporation, a California based company, has an emerging product called Calera cement. Calera cement utilizes seawater and flue gas to create a cement which can be a replacement for Portland cement and will absorb carbon dioxide (Hampton 2009). Copying a process used by coral to create reefs, Calera sends carbon dioxide emissions through seawater to create a carbonate byproduct (Block 2009). Calera claims that for every ton of cement produced 2/5 of a ton of carbon dioxide are stored within the cement (Block 2009).

Eco-Cement

Eco-Cement is the trade name for a cement made by TecEco Pty. Ltd. This cement has a large amount of reactive magnesia, or magnesium oxide, allowing this cement to sequester large amounts of CO₂ from the atmosphere in the production

process (TecEco 2009a). (See Figure 2-1). TecEco also claims that Eco-Cement provides a greater resistance to sulphate and chloride and reduced corrosion of steel and other reinforcing (TecEco 2009a). In addition to the sequestration of carbon dioxide during the production of the cement, Eco-Cement absorbs CO_2 from the atmosphere as it sets and hardens (TecEco 2009b). Eco-Cement is made by combining reactive magnesia with Portland cement (TecEco 2009b). Eco-Cement is able to include a greater amount of waste (saw dust, slag, bottom ask, plastic, paper) than other cements, such as Portland cement, because it is much less alkaline, which reduces the incidence of delayed reactions that reduce the overall strength of the concrete (TecEco 2009b).

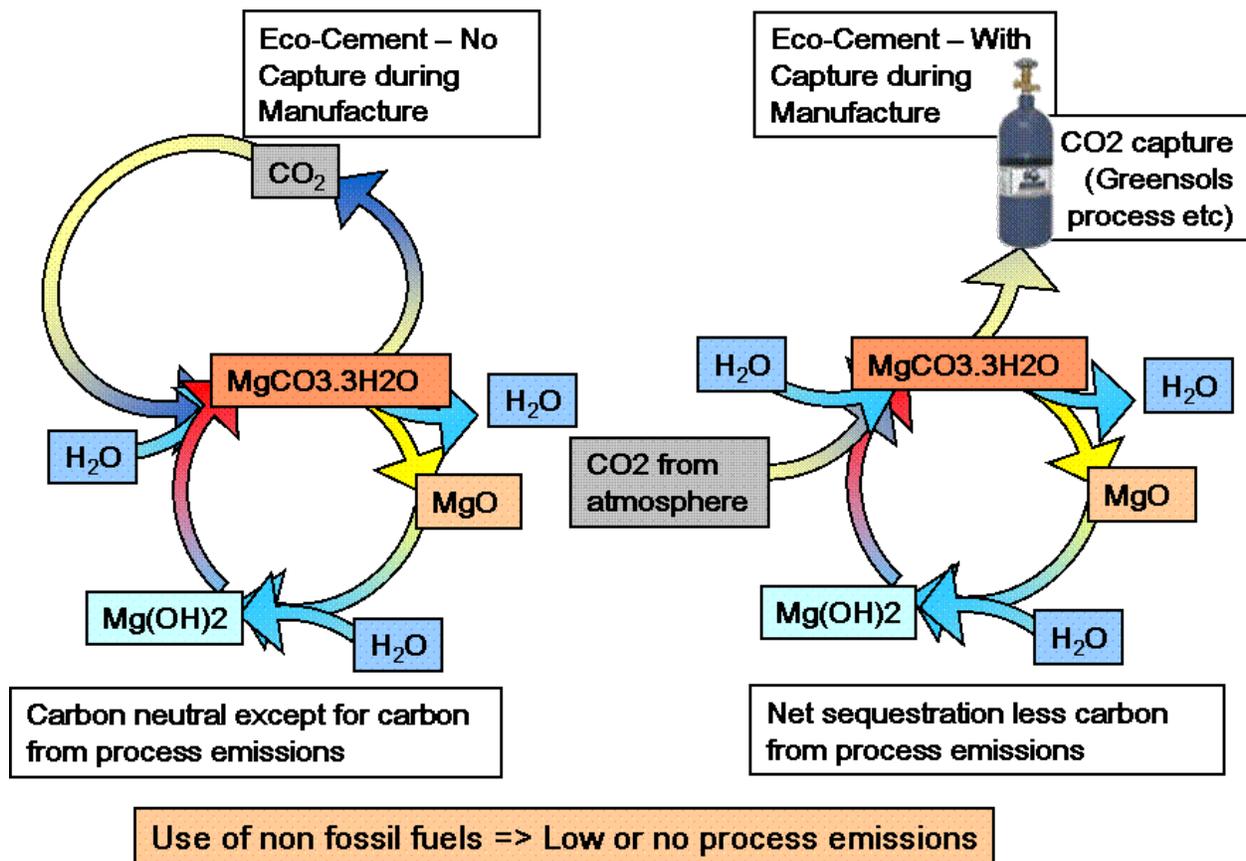


Figure 2-1. Process of making Eco-cement (TecEco 2009b).

Standard

ASTM C109, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-inch Cube Specimens) was used in this thesis for the procedure to make standard cement mortar cubes and also for finding the compressive strength of the standard cement mortar cubes. This standard was used in order to establish a universally accepted means of making and testing the specimens used in this thesis.

CHAPTER 3 RESEARCH METHODOLOGY

Introduction

The following procedure was performed on all test samples. A CO₂ monitor was used to detect and record CO₂ concentration in the air, temperature, and relative humidity. All samples were tested under similar conditions. The same CO₂ monitor was used for all readings.

Procedure

The procedure used in this paper was adapted from ASTM C109.

Baselines

To gather a baseline for comparison, CO₂ readings were gathered for a 24 hour period in three places: outside, inside a home, and inside an office building. See Appendix A for the data.

Standard Mortar Cubes

Standard mortar samples were made using ASTM C109. Ingredients were weighed out according to the formulas listed in Table 4-1.

The water was added first into the mixing bowl. Next, the cement was added and mixed for 30 seconds at slow speed. Standard sand was slowly added over a 30 second interval while the mixer was continuously mixing. The mortar was mixed at medium speed for another 30 seconds and then allowed to rest for 90 seconds. The mortar was mixed at medium speed another 60 seconds.

Filling the Molds

A thin coating of mold release was applied to the interior of each specimen mold. A 1-inch layer of mortar was added to each of the molds. Each cube was tamped 32

times in four rounds, set at right angles to each other. Another layer of mortar was added to each cube and tamped, as was done in the first layer. The excess mortar was removed from the top of each cube by using a knife in a sawing motion across the top. When complete, each cube was 2 inches deep. Six 2-inch cubes were made for each type of concrete tested.

Curing

The cubes were allowed to cure under water for at least 24 hours. The molds were removed after 24 hours.

Data Collection and Testing

Three of the cubes were placed in an air tight desiccator along with the CO₂ monitor. Measurements for CO₂ concentration, temperature, and relative humidity were taken for 24 hours. The three remaining cubes were left to cure underwater. After the 24 hour period, all six cubes were tested for compressive strength using ASTM C109.

Group 1

Group 1 for each type of mortar consisted of the three sample cubes that were tested for compressive strength after curing in water. Each cube was placed below the center of the upper bearing block of the testing machine. The test was initiated and the load at failure was recorded. Compressive strength for the three samples were computed in psi and averaged.

Group 2

Group 2 for each type of mortar consisted of the three sample cubes allowed to absorb CO₂. The desiccator, with silica gel in the bottom, and CO₂ monitor consisted of the testing apparatus. Data was collected for 30 minutes before the samples were added in order to establish the atmosphere inside the desiccator. The three samples

were added to the apparatus and the apparatus was sealed. Silica gel was placed in the bottom of the desiccator in order to lower the humidity since the cubes had been curing under water. After 24 hours, the apparatus was opened and the samples removed. The data, CO₂ concentration, temperature, and relative humidity, were removed from the CO₂ monitor. Each sample was tested for compressive strength. The load at failure was recorded. Compressive strength for the three samples were computed in psi and averaged. The findings for Groups 1 and 2 were compared.

CHAPTER 4 DATA ANALYSIS AND RESULTS

Baseline Information

Baseline figures were obtained for CO₂ concentration that would typically be found. The three baselines obtained were outside, in a home, and in a small office building. Each baseline was run over a 24-hour period.

The peak CO₂ obtained outside was 824ppm, the low was 460ppm and the average was 530.7ppm. (See Appendix A, Figure A-1a.) The peak value was also the initial value taken. The CO₂ concentration is initially high, but stabilizes after 14 minutes. (See Appendix A, Figure A-1b) Taking this into consideration, the average remains almost the same at 530.0ppm with a peak at 584ppm and a low at 460ppm. Overall, the CO₂ concentration outside remained fairly steady with no real trend increases or decreases.

The baseline in the office building showed trends that are explainable by the occupation of space by people over time. (See Appendix A, Figure A-2) The data starts midday and CO₂ concentrations increase as the time gets closer to 5:00pm. The peak high reached was 1000ppm. A decline was seen throughout the evening and night resulting in a low of 516ppm. At 8:00am the CO₂ concentration began to rise again. The typical workday in this office building is 8:00am to 5:00pm, consistent with the data seen. The low concentration of 516ppm is consistent with the average outdoor concentration as seen in Figure A-1a.

The baseline representing inside a home shows data that varies greatly. The CO₂ concentration decreases over a period of about 10 hours, increases for the next 10 hours, and begins to decrease again. (See Appendix A, Figure A-3) The occupants of

this house include two adults and three cats. The increase and decreases in the data represent when levels of activity were higher or lower. The average CO₂ concentration observed was 1055ppm with a peak of 1290ppm and a low of 620ppm. One would not expect the concentration to reach that of the outdoor average since the house was continuously occupied.

Mix Designs

ASTM C109 was utilized to obtain typical proportions of the ingredients. For example, one part cement to 2.75 parts sand and a water-cement ratio of 0.485 were applied. Table 4-1 shows the quantities used for each type of concrete tested.

Table 4-1. Mix designs for concrete samples (for 6 cubes)

Type	Cement (g)	Sand (g)	Water (g)	Fly Ash (g)	Slag (g)
PC	500	1375	242	--	--
PC + FA	400	1375	242	100	--
PC + Slag	250	1375	242	--	250
PC + FA + Slag	200	1375	242	100	200
SET® 45	2000*		160		

* SET® 45 is a prepackaged blended cement with a proprietary amount of cement, fine aggregate and fillers.

Data

Carbon dioxide Absorption and Compressive Strength

After curing for 24 hours, the mortar cubes were removed from the molds. For each type of specimen tested, the samples from Group 1 were left to cure under water while the samples from Group 2 were placed in the desiccator to be tested for carbon dioxide absorption for 24 hours. The data obtained during testing is summarized in Tables 4-2 through 4-7. After this period of time, all six samples were tested for compressive strength. Figures 4-1 through 4-7 show the CO₂ concentration in parts per million, temperature in degrees Celsius, and the relative humidity in percent of the air

inside the desiccators during the testing. Portland cement was used as a control.

Additional controls, with no specimen (see Figure 4-1) or with asphalt (see Figure 4-8) were utilized.

Table 4-2. Portland cement specimen data

Sample number	W=Wet cured D=Desiccated	Load (lb)	Strength (psi)	Days cured	Average strength (psi)
1	W	7410	1852	5	1902
2	W	6900	1725	5	
3	W	8510	2130	5	
4	D	6170	1542	5	1997
5	D	9600	2400	5	
6	D	8200	2050	5	

Table 4-3. Portland cement plus fly ash specimen data

Sample number	W=Wet cured D=Desiccated	Load (lb)	Strength (psi)	Days cured	Average strength (psi)
1	W	9410	2350	7	2147
2	W	8210	2050	7	
3	W	8170	2040	7	
4	D	7390	1847	7	1961
5	D	7220	1805	7	
6	D	9840	2230	7	

Table 4-4. Magnesium phosphate specimen data

Sample number	W=Wet cured D=Desiccated	Load (lb)	Strength (psi)	Days cured	Average strength (psi)
1	W	11040	2760	6	2907
2	W	12860	3210	6	
3	W	11010	2750	6	
4	D	11520	2880	6	2700
5	D	9030	2260	6	
6	D	11850	2960	6	

Table 4-5. Portland cement plus slag data

Sample number	W=Wet cured D=Desiccated	Load (lb)	Strength (psi)	Days cured	Average strength (psi)
1	W	10230	2560	12	2429
2	W	7300	1826	12	
3	W	11610	2900	12	
4	D	11220	2810	12	2640
5	D	8910	2230	12	
6	D	11530	2880	12	

Table 4-6. Portland cement plus fly ash and slag data

Sample number	W=Wet cured D=Desiccated	Load (lb)	Strength (psi)	Days cured	Average strength (psi)
1	W	8660	2160	14	
2	W	9570	2390	14	
3	W	7180	1795	14	2115
4	D	5750	1437	14	
5	D	3250	813	14	
6	D	8070	2020	14	1423

The strength for the Group 1 and Group 2 samples for each specimen type were averaged and this average is displayed in the last column of Tables 4-2 through 4-6. A significant difference is not seen between Groups 1 and 2. It is to be noted that all of the samples for all of the specimen types were made on the same day, each type was tested one at a time and after each testing session those cubes tested were broken. Therefore, each specimen type was a different age when broken. Sample cubes were compared with other cubes of the same type, but compressive strength was not compared to other specimen types except to view a trend.

The first 30 minutes of data in Figures 4-2 through 4-7 depict the starting atmosphere for this specimen test. It is apparent when the cubes were added by the drop in CO₂ concentration. Data for each specimen group was analyzed to determine the rate of absorption and length of time to reach equilibrium.

It is noted that the CO₂ concentration in the test with no specimen present does fall over the 24 hour period. The CO₂ concentration reduces from approximately 1050ppm to approximately 1015ppm (See Figure 4-1). This reduction may be associated with a small amount of absorption from the silica gel. The reduction, however, is negligible when compared to the change in CO₂ concentration seen in all specimens tested.

Figure 4-2 shows the absorption form Portland cement mortar. Due to a complication with the CO₂ monitor, data was collected for only four hours forty minutes. The data clearly depicts carbon dioxide absorption and that equilibrium was reached, however.

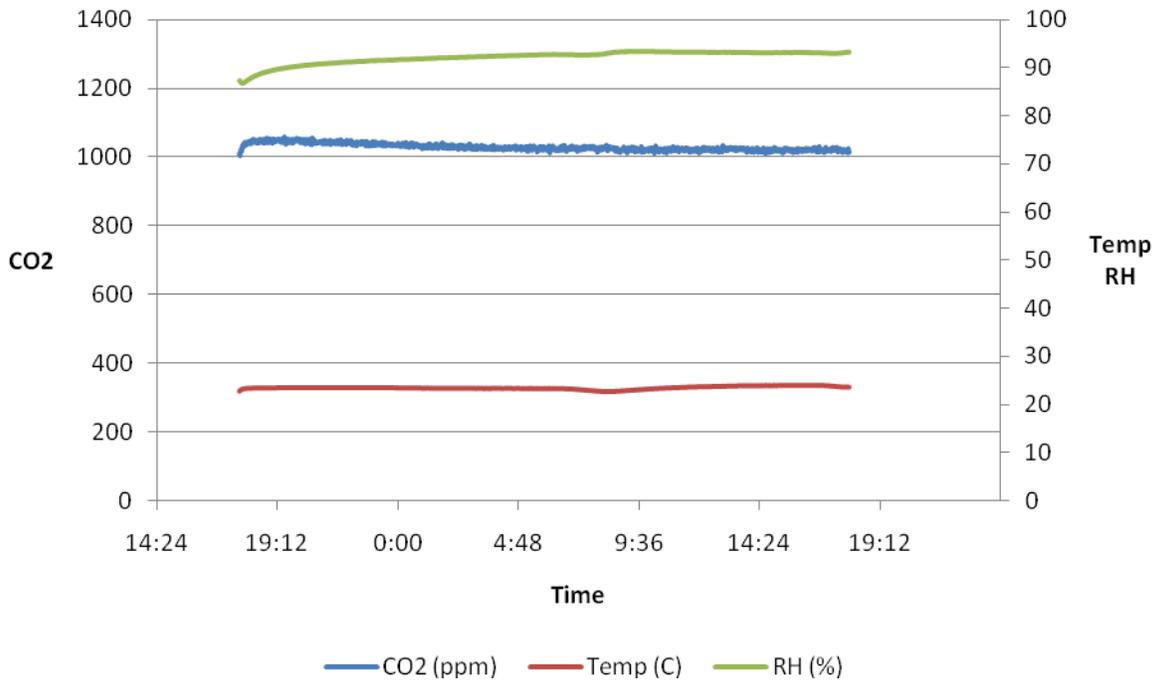


Figure 4-1. No specimen – empty desiccators

Portland cement mortar reduced the CO₂ concentration to below 200ppm (Figure 4-2). When fly ash was added to Portland cement, the absorption was not as good, resulting in a final concentration right around 200ppm (Figure 4-3). Figure 4-4 shows the CO₂ absorption by magnesium phosphate, which is comparable to Portland cement with fly ash. When slag was added to Portland cement, for both specimen types of Portland cement plus slag and Portland cement plus fly ash and slag (Figures 4-5 and 4-6), the absorption resulted in a CO₂ just above 200ppm.

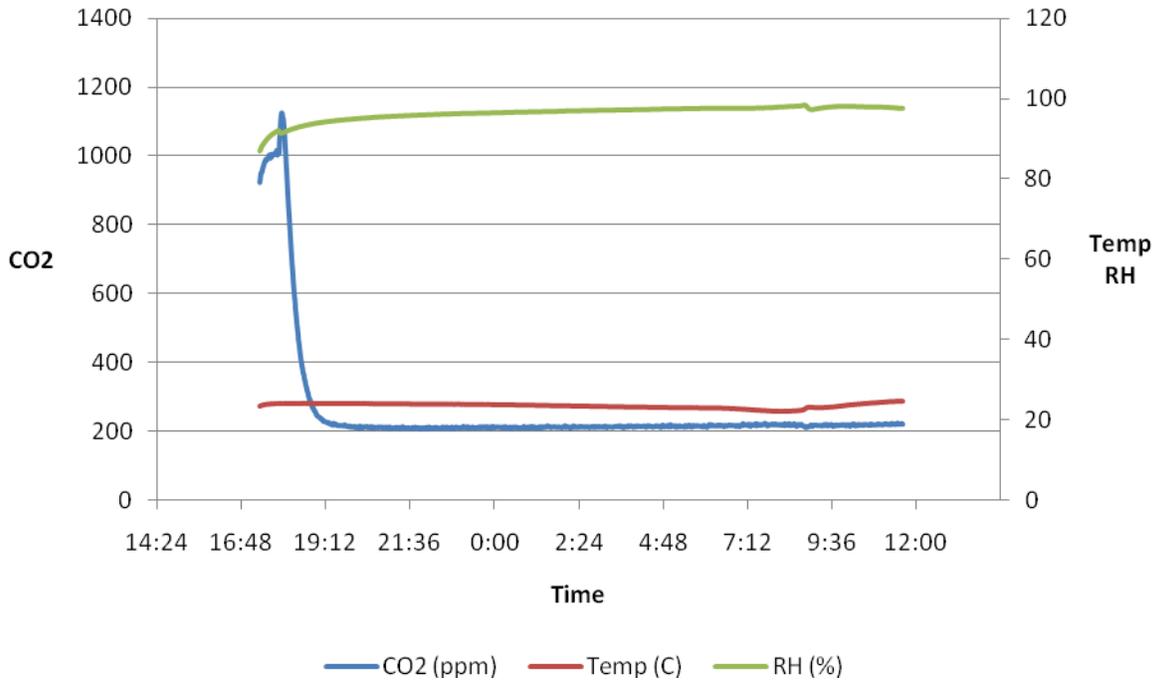


Figure 4-2. Portland cement mortar

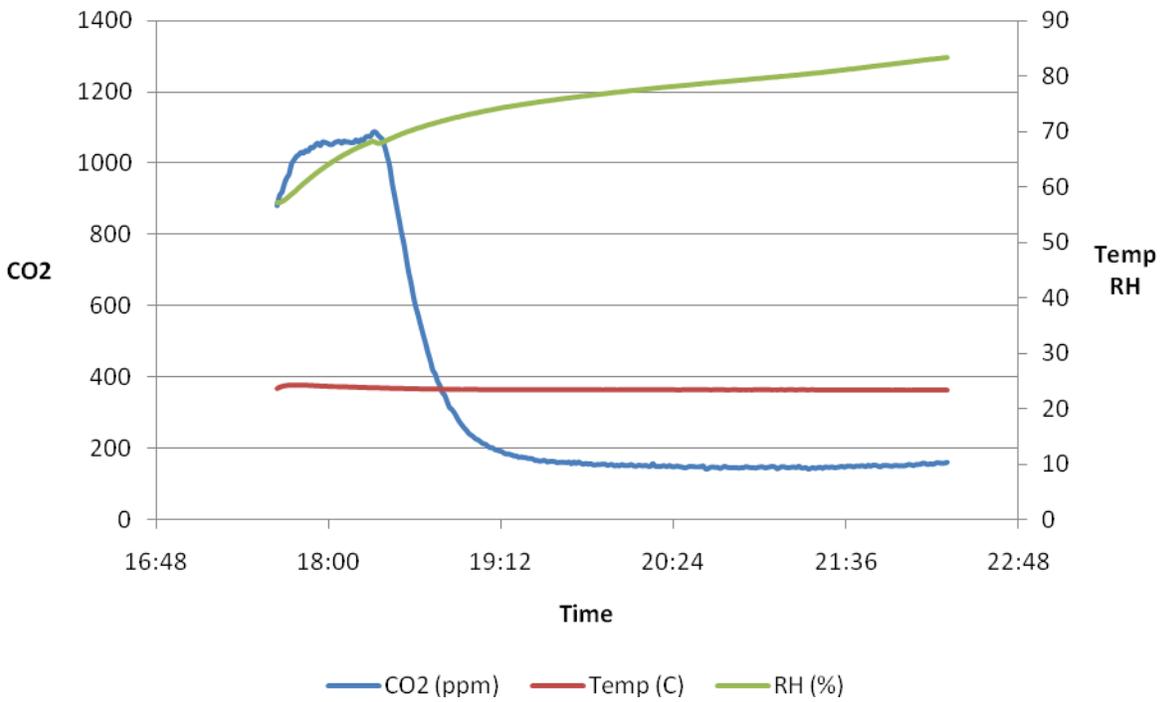


Figure 4-3. PC plus fly ash mortar

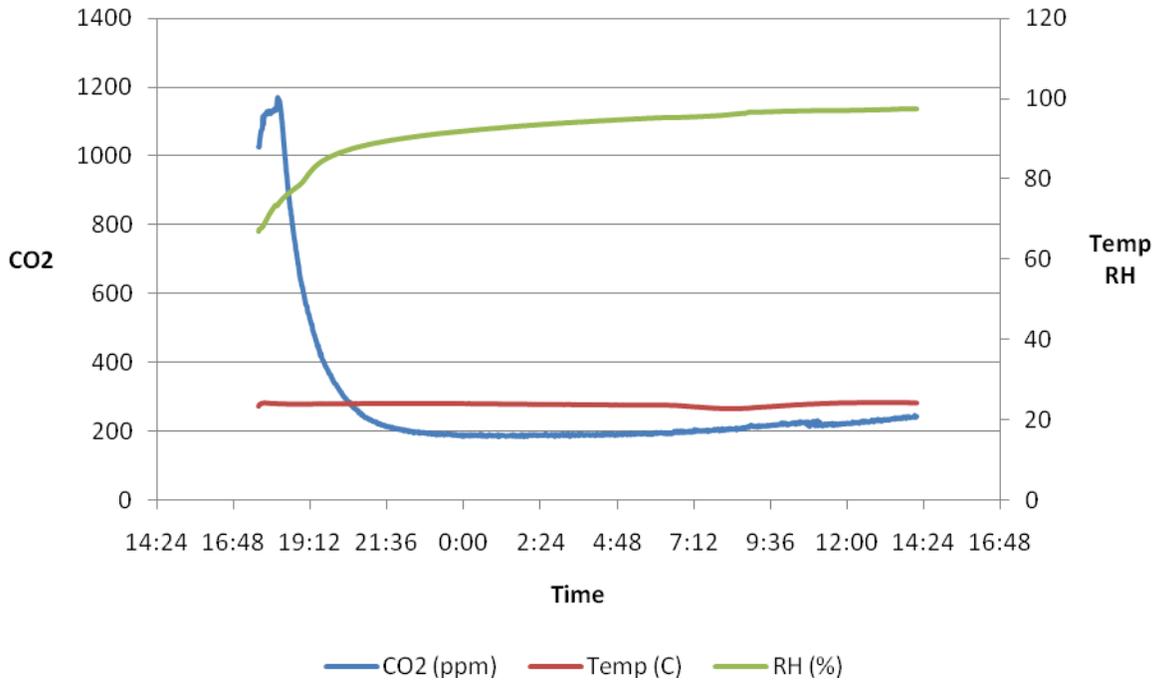


Figure 4-4. Magnesium phosphate SET@45

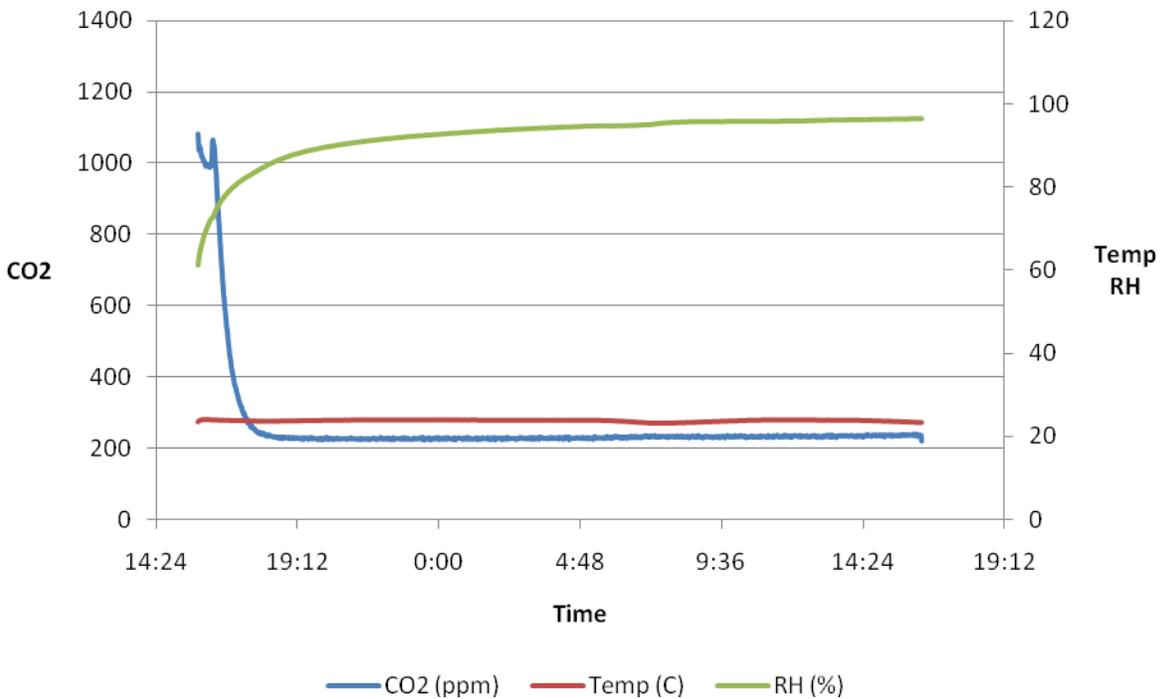


Figure 4-5. Portland cement plus slag mortar

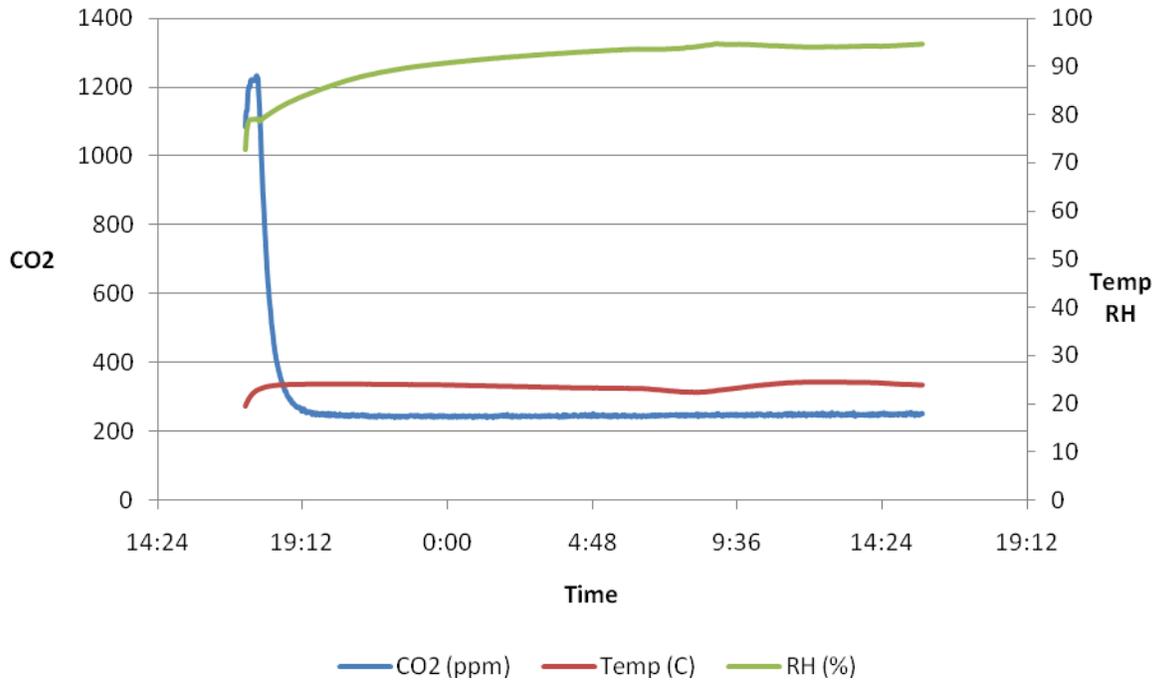


Figure 4-6. Portland cement plus fly ash and slag mortar

All of the mortar samples in Figures 4-1 through 4-6 were cured under water. The asphalt samples, however, were not cured under water. Figure 4-7 shows that no CO₂ absorption occurred while in the desiccators. Asphalt was not expected to absorb CO₂, but it must be noted that the curing process was not consistent with that of the other samples.

Constant Humidity

To determine whether the humidity level in the desiccator influenced CO₂ absorption, testing using Drierite to maintain constant humidity was performed. Tests were run on plain Portland cement mortars and on magnesium phosphate mortars. See Figures 4-8 and 4-9 for the data.

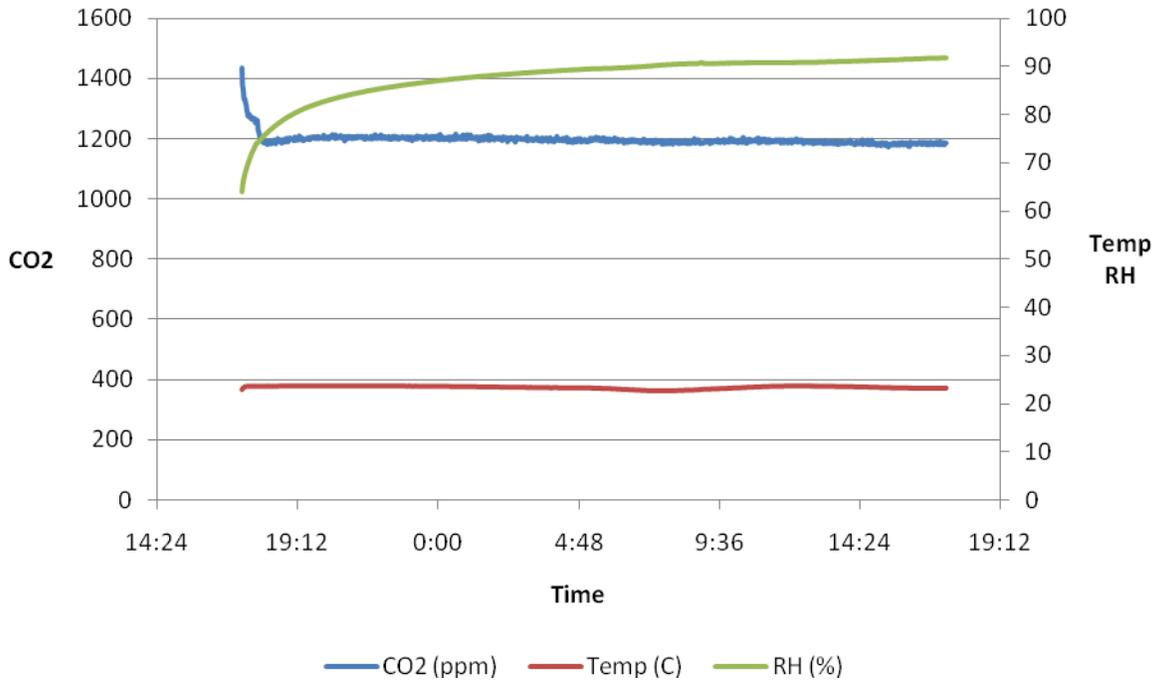


Figure 4-7. Asphalt concrete

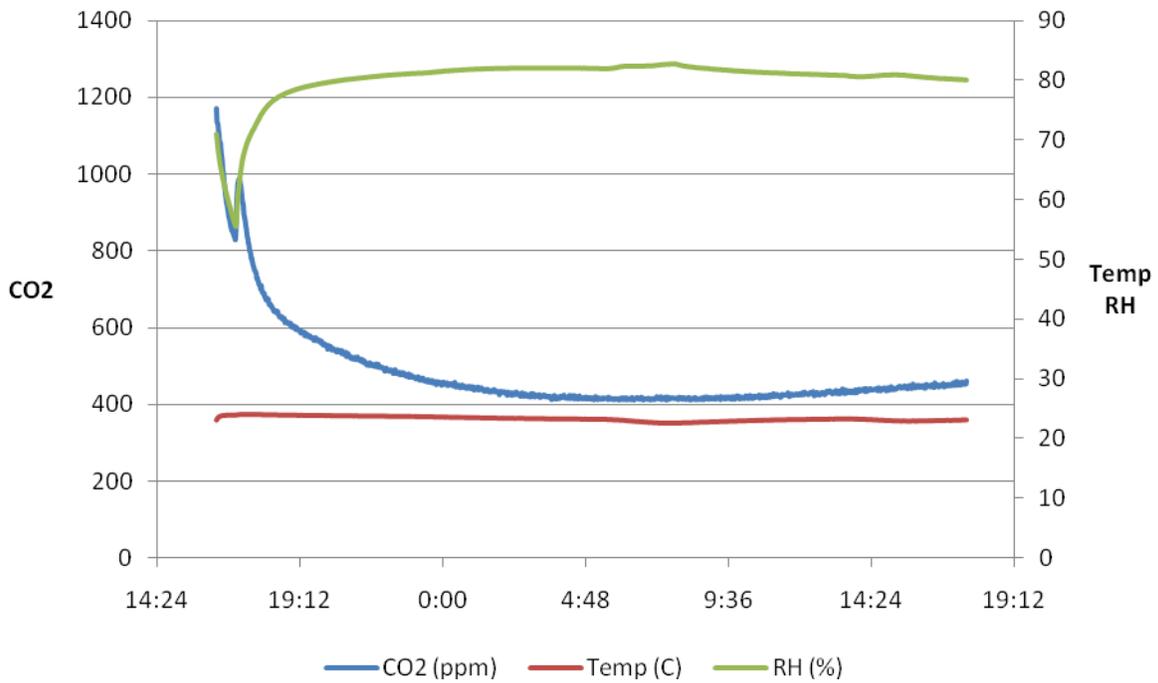


Figure 4-8. Constant humidity Portland cement mortar

Constant humidity specimen testing consisted of placing three 2" x 2" x 2" mortar cubes in the desiccators and replacing the silica gel with Drieirite. The Drieirite held the relative humidity near 80% whereas the specimens tested without Drieirite saw the humidity rise over time, nearing 100% by the end of the 24-hour period. Constant humidity tests were performed for Portland cement mortars and for magnesium phosphate, SET®45 specimens only.

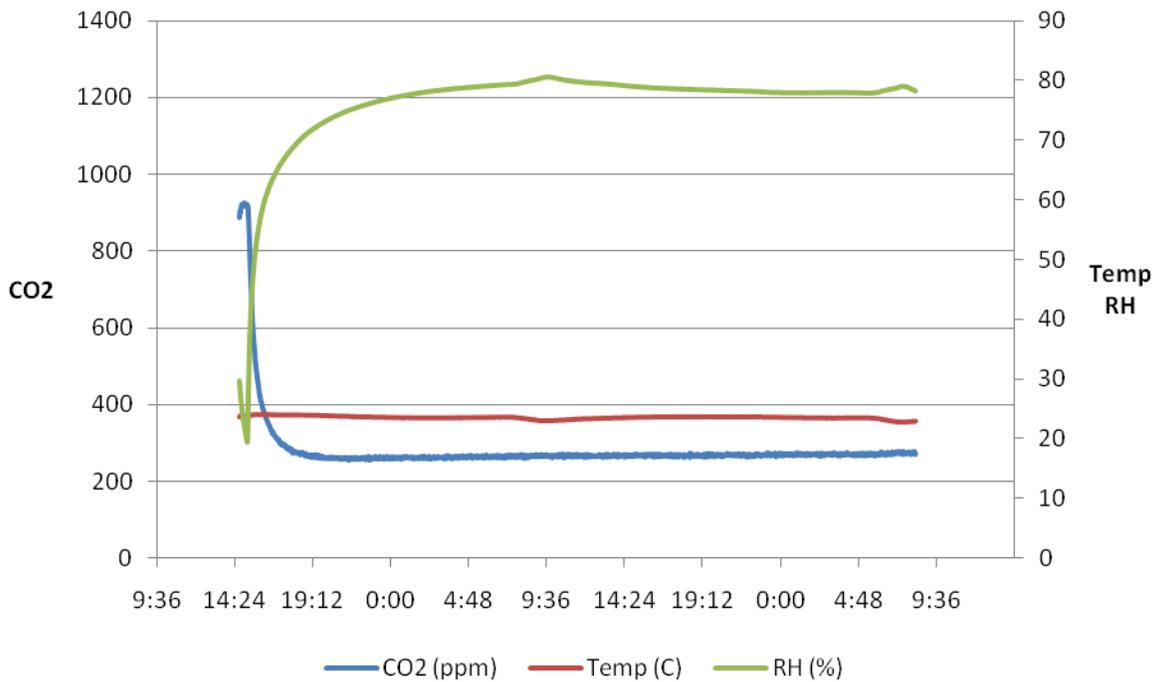


Figure 4-9. Constant humidity magnesium phosphate, SET®45 mortar

CHAPTER 5 CONCLUSION

Carbon dioxide Absorption

Carbon dioxide was absorbed by all samples. This absorption occurred over the first 30 minutes of exposure and was rapid. Approximately 800 ppm were absorbed over the 30-minute interval. After this initial interval, no CO₂ was observed to be absorbed. The level of CO₂ within the apparatus remained constant with no significant difference over the next 23 hours.

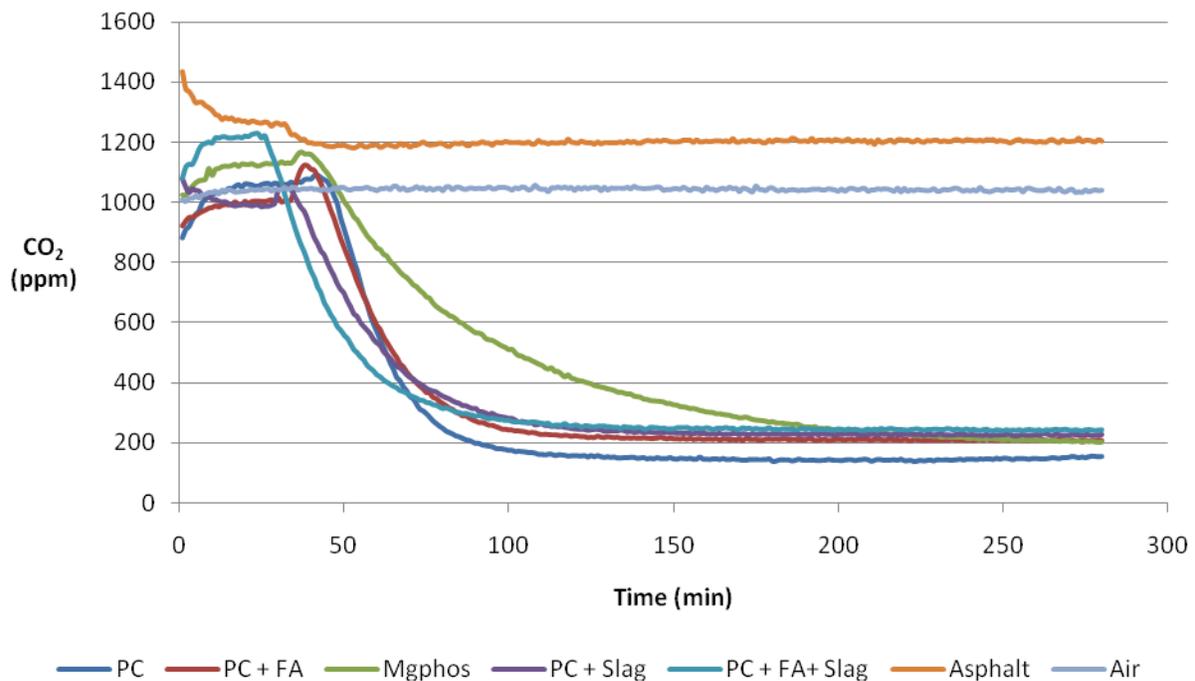


Figure 5-1. Carbon dioxide absorption by specimen type

Figure 5-1 shows that the absorption by magnesium phosphate, SET®45 mortar occurred slower than by all other types of mortars tested. Also, Portland cement mortar was seen to have absorbed more CO₂ than the other specimen types. It can be inferred

that it may not be necessary to specify another type of mortar for the purpose of absorbing CO₂ solely.

All of the mortar samples were 2" x 2" x 2" cubes, yielding a total surface area of 24 in² per cube. Three cubes were placed in the desiccator during each test giving a total surface area of 72 in² or 0.5 ft². The asphalt samples were cylindrical with a diameter of 5-15/16" and a height of 1-5/8" yielding a surface area of 85.69 in² or 0.60 ft². The volume of the desiccator was found to be 6500 cc and can contain 0.23 ft³ of air. Table 5-1 compares the change in CO₂ concentration during each test to the absorption area and to the volume of the container.

Table 5-1. Absorption per specimen area and per volume of air

Sample type	CO ₂ absorption, (ppm)	Total specimen surface area, (ft ²)	CO ₂ absorption per ft, ² (ppm)	Volume of air, (ft ³)	CO ₂ absorption per ft ³ of air, (ppm)
Control - air	0	-	-	0.23	-
PC	949	0.50	1898	0.23	4126.09
PC + FA	919	0.50	1838	0.23	3995.65
PC + slag	862	0.50	1724	0.23	3747.83
PC + FA + slag	991	0.50	1982	0.23	4308.70
Mag. phos.	985	0.50	1970	0.23	4282.61
Asphalt	263	0.60	438.33	0.23	1143.48

Absorption was calculated as the difference between peak CO₂ concentration and the lowest CO₂ concentration. The Portland cement, Portland cement plus fly ash, Portland cement plus slag, Portland cement plus fly ash and slag, and magnesium phosphate mortar specimens absorbed about the same amount of CO₂ with Portland cement plus fly ash and slag mortars absorbing the highest amount both per area and per volume (See Table 5-1). Asphaltic concrete absorbed only a small amount of CO₂

as compared to all other samples. The test with just air did yield a very small amount of CO₂ absorption can be attributed to absorption by the silica gel.

Compressive Strength

Compressive strength was obtained for all samples. The results are listed in Tables 4-2 through 4-6. It does not appear that a significant difference exists between samples that were wet cured as opposed to samples that underwent exposure to CO₂.

Constant Humidity

Data from the constant humidity testing is tabulated in Table 5-2. Results for both Portland cement and magnesium phosphate mortars showed lower absorption quantities than when humidity was not controlled. However, in both cases Portland cement mortars performed slightly better.

Table 5-2. Constant humidity data

Sample type	CO ₂ absorption, (ppm)	Total specimen surface area, (ft ²)	CO ₂ absorption per ft ² , (ppm)	Volume of air, (ft ³)	CO ₂ absorption per ft ³ of air, (ppm)
PC	758	0.50	1516	0.23	3295.65
Mag. phos.	671	0.50	1342	0.23	2917.39

From the data collected in this research, no one type of mortar performed significantly better than any other, with the exception of the asphalt concrete which did not absorb much CO₂. The conclusion of this research is that no one type of cement mortar was significantly better at absorbing CO₂ from the atmosphere than any other type tested. But the research does indicate that pavements constructed using Portland cement binders with or without mineral admixtures, and magnesium based binders may indeed reduce the carbon footprint of a particular area, eg. a subdivision, relative to pavements in a subdivision constructed using asphalt as a binder.

CHAPTER 6 RECOMMENDATIONS

This paper focused on establishing baseline data regarding the absorption of carbon dioxide by various types of mortars. It does not compare all types of mortar or concrete that may absorb CO₂. Further evaluation is recommended to expand upon the findings noted herein.

Continuation of Research

To further support the conclusions reached in this paper and extrapolate further, research to continue this thesis may be performed. The desiccator used in this research held 0.23 ft³ of air. Studies may be done using different sizes of container or even in controlled rooms to see the effect that the initial amount of CO₂ available in the environment has on the absorption. This may be further investigated by controlling and manipulating the concentration of the initial CO₂ in the environment.

Other Types of Binders

There are companies that explicitly claim that their product or type of concrete is superior because of its ability to absorb atmospheric CO₂. Three of these types, Novacem, Calera cement, and Eco-cement, were unable to be tested for the purpose of this thesis, but would be beneficial for further study.

Effect on Reinforcing Steel

Concrete and mortar, because of the calcium hydroxide in it, has a pH around 10. The alkalinity of the substrate protects reinforcing steel contained within it from sulfate attack which weakens steel. When carbon dioxide is absorbed by concrete or mortar, a chemical reaction occurs which converts calcium hydroxide (or lime) into calcium carbonate and in turn lowers the pH. This more neutral pH does not protect

reinforcing steel which would result in a weaker concrete or mortar unit if sulfate attack occurs. Further study would be prudent to determine the depth of CO₂ absorption with regard to the depth of reinforcing steel.

APPENDIX A
BASELINE FIGURES

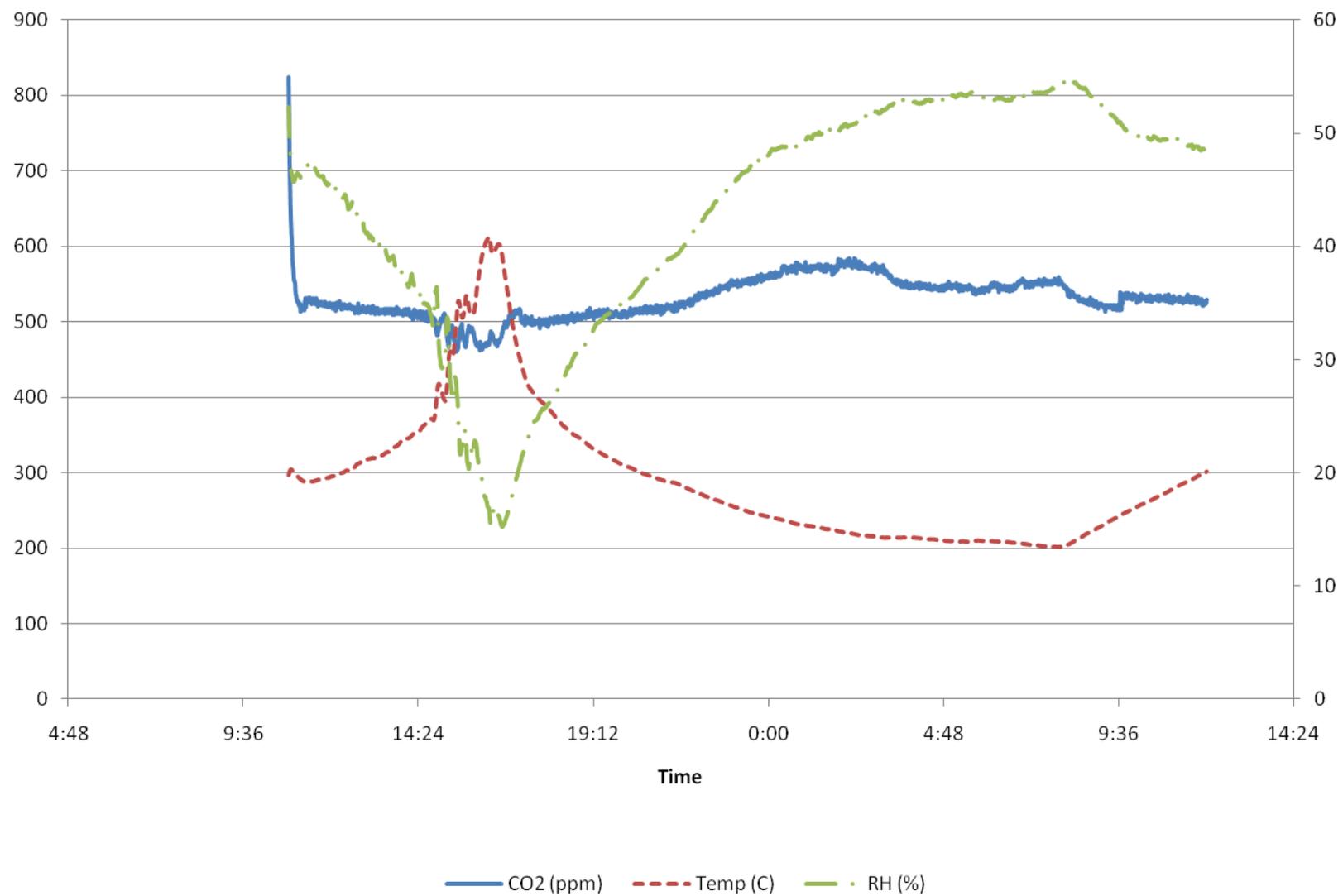


Figure A-1a. Baseline figures taken from outside.

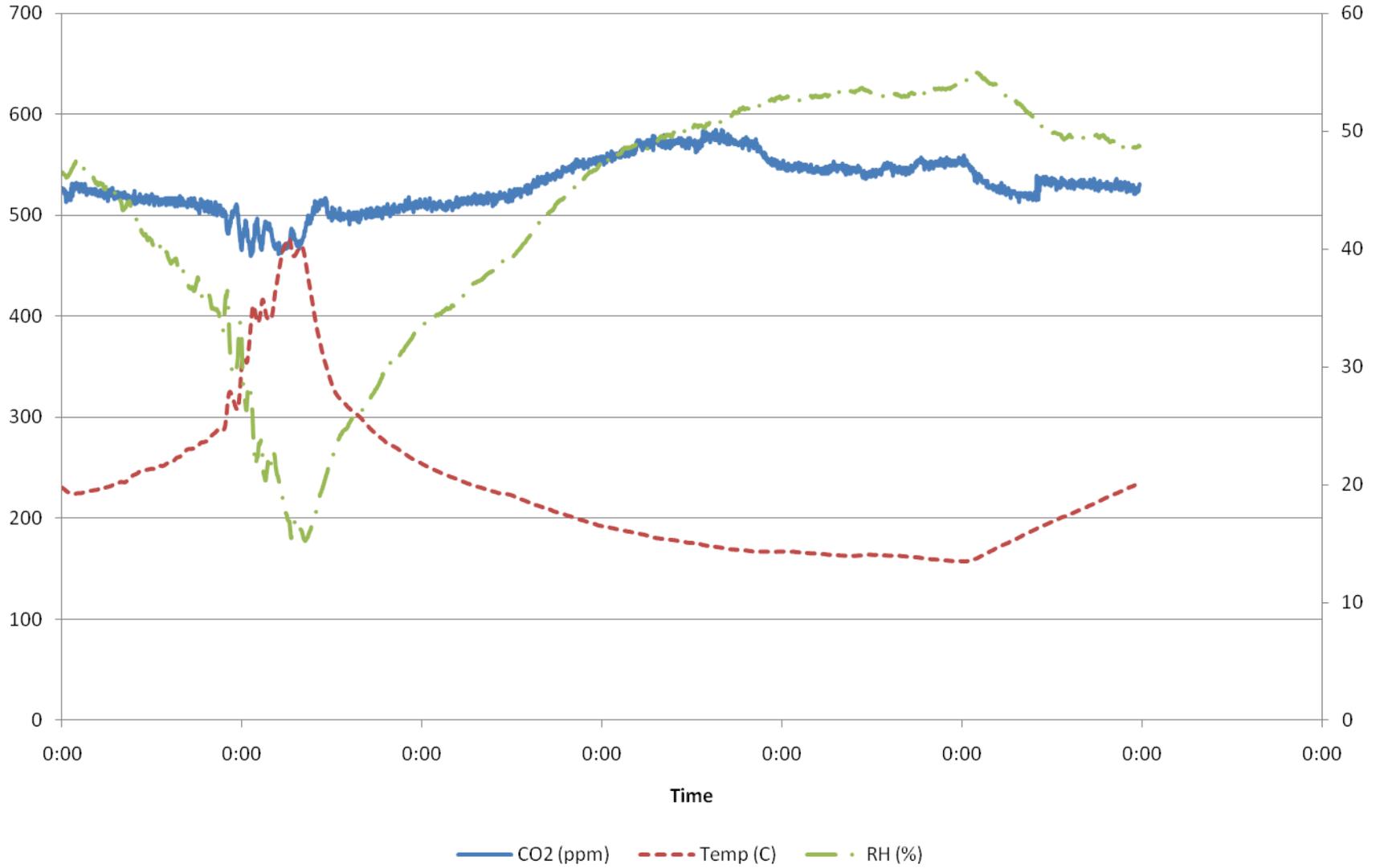


Figure A-1b. Baseline figures from outside excluding stabilization.

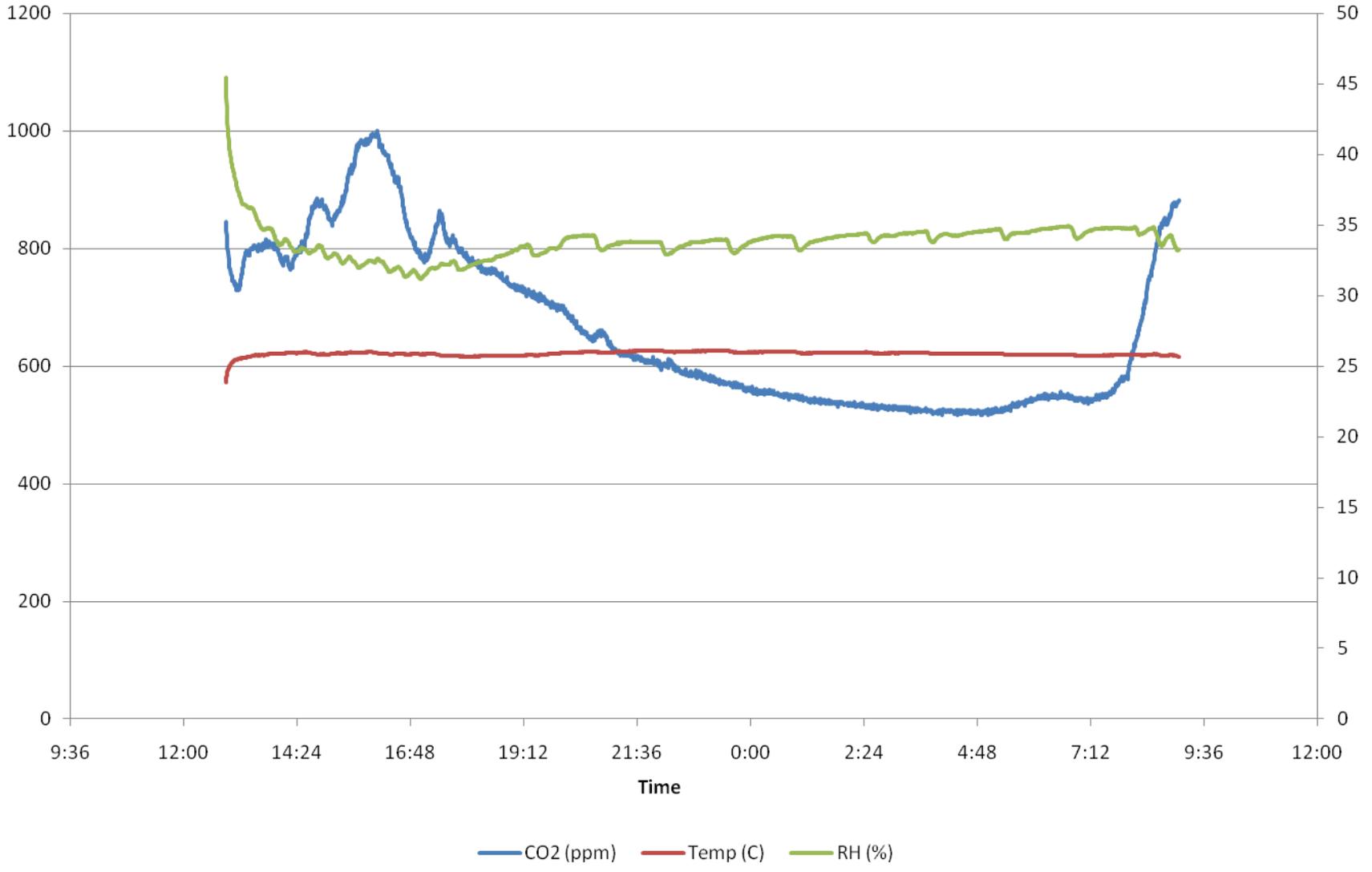


Figure A-2. Baseline figures taken from office

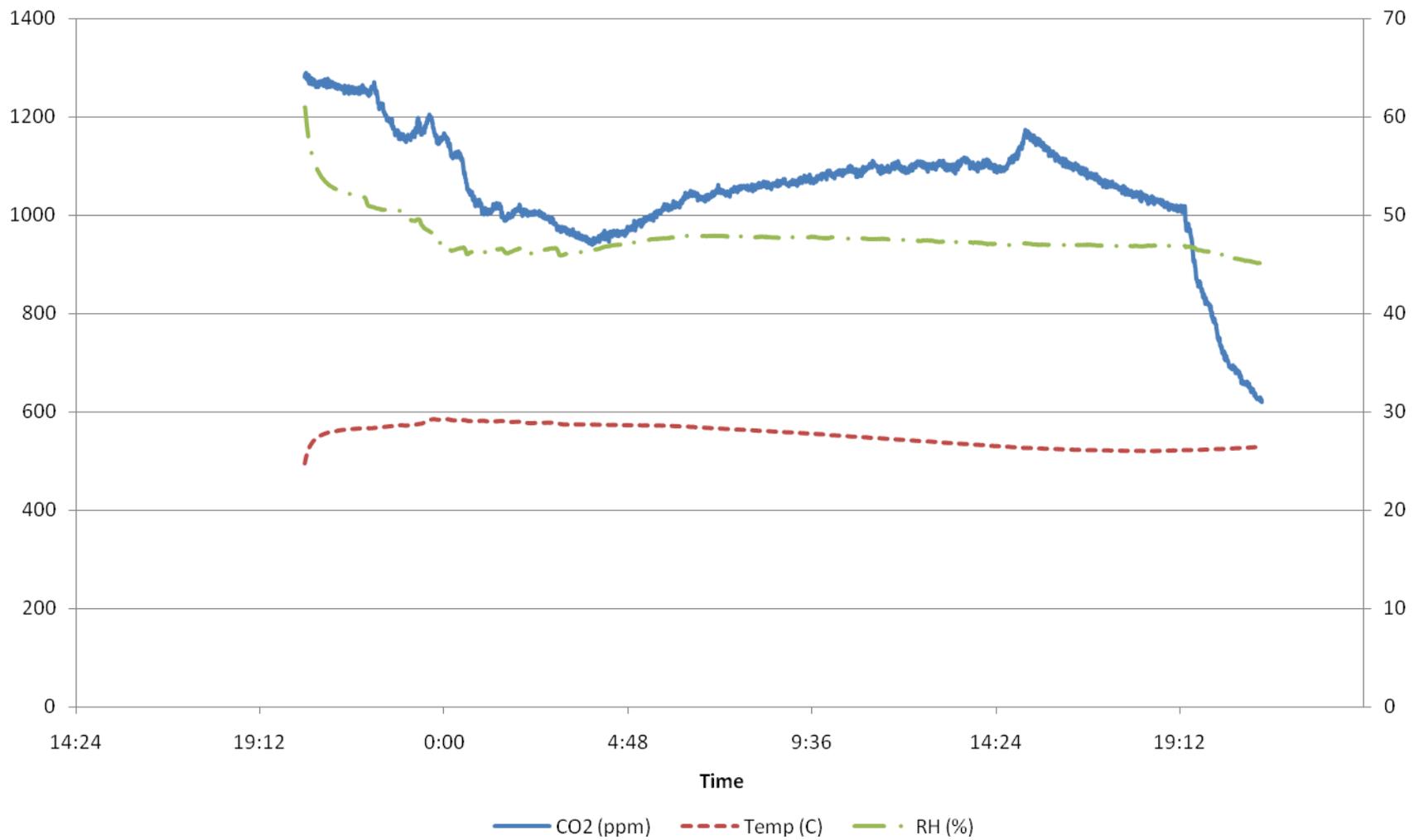


Figure A-3. Baseline figures taken from house.

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BIOGRAPHICAL SKETCH

Ashley Layne Lopez was born in January 1982 to Edward and Patricia Yankowich in Roanoke, Virginia. In the summer of 1983, the Yankowich family moved to Longwood, Florida (a suburb of Orlando) where she spent the next 17 years. Ashley graduated from Lake Brantley High School in Altamonte Springs in May 2000. In May 2005, she earned a Bachelor of Science in biology from the University of Central Florida. A year later, in 2006, she married J.A. Lopez, a tax accountant. Currently, she is completing a Master in Building Construction at the M.E. Rinker, Sr. School of Building Construction at the University of Florida.