The Effects of Weather Induced Variables on Large Building Vapor Intrusion Mitigation Systems

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ABSTRACT

This paper is a case study of a large building vapor intrusion mitigation system with multiple foundation types and blowers. Dynamic motor controls and remote monitoring systems have been designed and installed to achieve maximum operational efficiency, stabilize indoor air concentrations and demonstrate long term performance of the vapor intrusion mitigation system. Through analysis of continually recorded and telemetrically managed performance data, this paper will examine the effects of weather variables that influence mitigation system performance and the environmental impacts and costs associated with them. Variables recorded and analyzed at hourly intervals include; wind speed and direction, temperature, barometric pressure, and humidity. Through examination of this data, we will define the relationship between the aforementioned variables, sub slab pressure differentials, and the energy required to achieve a specified performance threshold. Additionally, this paper describes the integration of the appropriate vapor intrusion mitigation design tolerances in anticipation of the projected effects of seasonal variables.

INTRODUCTION

Vapor intrusion mitigation systems (VIMS) are primarily using technologies and design techniques pioneered over two decades ago. Although the principles originally applied still hold true to this day, technologies and techniques relating to efficient design and operation have changed drastically in the past few years. Pressure field extension mapping has revamped the way that systems are designed. This is a design technique that is now widely used, universally accepted, and for the most part, expected throughout the industry. For more information on this type of system design the authors suggest reading *High Vacuum, High Airflow Blower Testing and Design for Soil Vapor Intrusion Mitigation in Commercial Buildings*[1].

Since the development of dynamic controls and remote monitoring for Vapor Intrusion Mitigation Systems in 2010, the integration of these power saving technologies have been increasingly integrated as part of VIMS design and installation. Until now, the effects of weather driven variables on mitigation systems has not been fully explored. The integration of the aforementioned technologies allows us to better understand the effects of external variables on sub slab depressurization systems. The paper focuses on a building where dynamic controls was installed and has been monitored for ten months through the fall, winter, spring, and the start of summer. The paper also contrasts different sub slab fill types and draws comparisons between low permeable and highly permeable fill types. The best way to distinguish these two soil types is by graphing the pressure field extension testing data. Figure 1 displays how low permeable fill reacts to applied vacuum. Notice how the vacuum field drops off exponentially. This graph is a trend line based on actual data recorded during the initial diagnostic testing for the purpose of system design at the site to be later discussed in the case study.

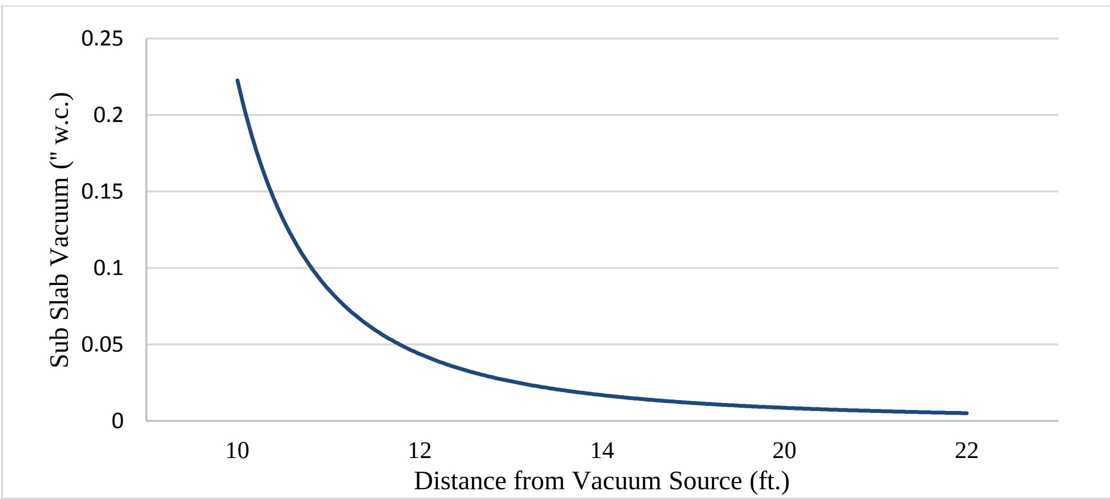

Figure 1

Figure 2 shows the results for an applied vacuum field in highly permeable standardized fill. This trend line graph was developed using data from a nearby building discussed later in the paper. The sub slab fill at this building was crushed stone. Notice how the vacuum field declines evenly over a long distance.

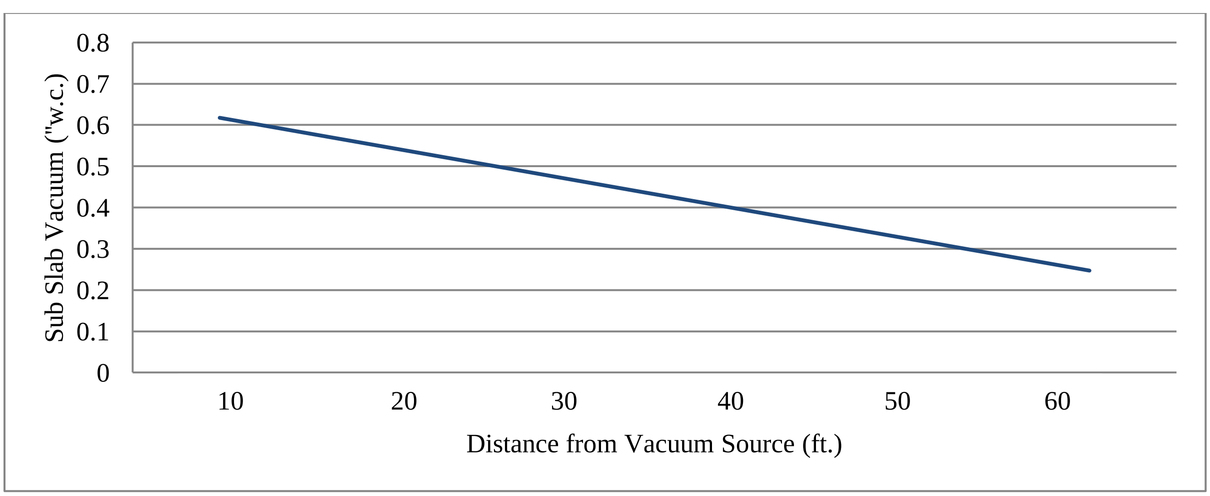

Figure 2

The case study will focus on a building constructed over low permeable fill in northern New Jersey, an area heavily affected by seasonal/weather driven building fluctuations.

CASE STUDY

Description of Site

The site area of concern is a former equipment and film manufacturing facility located in northern New Jersey (Figure 3). The building is approximately 66,300 square feet and the area where Contaminants of Concern (COC's) have been identified represents approximately 24,860 square feet. The original main section of the building is estimated to be over 110 years old and is constructed of brick, interior steel columns and a steel truss and wood plank roof. Each of the additions has a different roof elevation that contributes to varying vacuum induced pressure differentials as wind passes over and around the building. Sub slab soil gas surveying and indoor air sampling indicated elevated levels of TCE that were above NJDEP's screening levels for commercial structures.

Diagnostic activities and the design of a vapor intrusion mitigation system focused on the effected portion of the building only. The building's original use was for ice storage. Much of the original floor area was an elevated wood floor over a shallow crawlspace. Water from the melting ice could drain through separations in the wood floor to the space below where it evaporated or seeped into the soil. In subsequent years when the building was being used as a manufacturing site, random sections of the plank wood flooring were replaced with plywood, tongue grooved wood flooring and concrete. As the older planking was sporadically replaced as a result of folk lifts falling through, concrete was poured between the sections of sleeper floor prior to replacing the boards. This patchwork of concrete below the wood floor is what ultimately created enough cover to enable applying soil depressurization as a primary solution. Designing an effective vapor intrusion mitigation system required understanding how to manipulate the flow of soil gas relative to those floor substrates.

Figure 3

Once diagnostics were completed, the building was divided into multiple sections based on similar sub slab fill permeability, foundation sections, and floor coverings. The building was broken into 5 separate sections as shown in Figure 4.

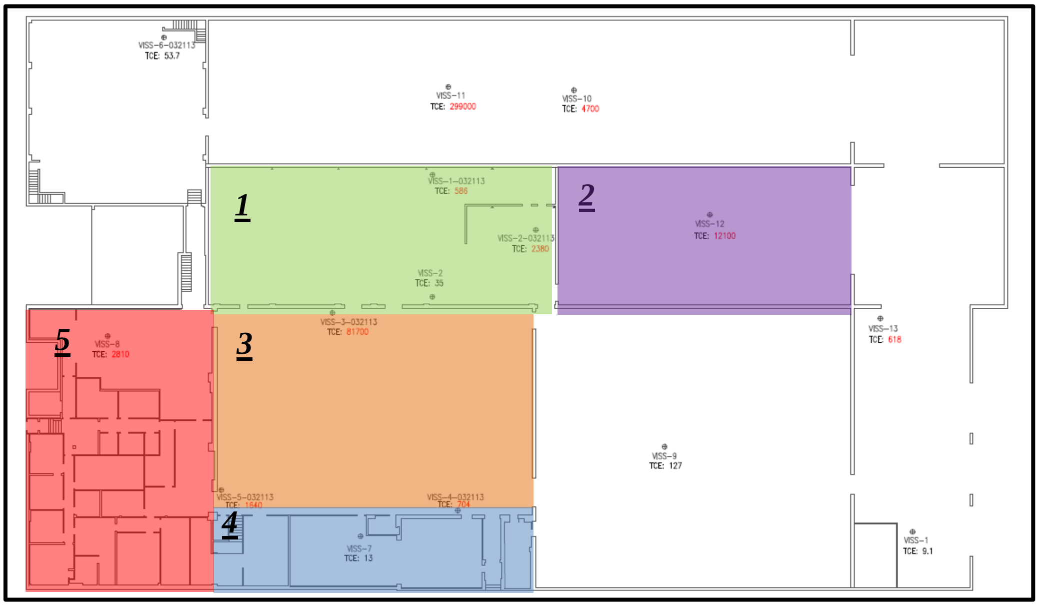

Figure 4

- ***Section 1*** measured approximately 6,250 ft^2. The floor in this area is poured concrete and the slab is approximately 4 to 6 inches thick. Sub slab fill consists of 1 to 2 inches of crushed stone over native soil.
- ***Section 2*** is a vacant warehouse measuring approximately 5,250 ft^2 formerly used as a garage. The slab is poured concrete measuring approximately 6 to 8 inches thick over a sub slab fill of silty sand.
- ***Section 3*** is approximately 8,250 ft^2 and features an irregular pattern of wood sleeper floors over concrete and partially poured concrete that is flush to the finish level of the sleeper floor. The slab thickness in this area ranges from 3 to 10 inches and the sub slab fill is low permeable fine silty sand.
- ***Section 4*** is approximately 2,500 ft^2 and features a wooden floor over a crawlspace with clearance varying between 2 and 3 feet. The crawlspace is ventilated through two 10" x 6" openings on the east side of the building.
- ***Section 5*** is finished office space with mixed tile and carpet over a poured concrete slab. The space measures approximately 6,500 ft^2, the slab thickness measures approximately 6 to 8 inches thick over a sub slab fill of silty sand.

After refined plume delineation through soil gas mapping, the client elected to mitigate spaces 1 through 3 at this time. The remainder of the report will focus on these sections and use the previously established numbering system when referring to building sections. The case study will focus specifically on Section 3.

Vapor Intrusion Mitigation System Design and Success Criteria

The selected mitigation technique was a sub slab depressurization system. The intent was to design a sub slab depressurization system that effectively depressurized the area of concern to the NJDEP Vapor Intrusion Technical Guidance Document's[2] recommended sub slab vacuum level of -0.004 inches of water column ("w.c.). Based on sub slab permeability mapping, a system was designed that featured 22 suction points with 3 inch risers and 4, individually controlled, roof mounted vapor mitigation blowers. Figure 5 indicates the locations of the blowers and suction points.

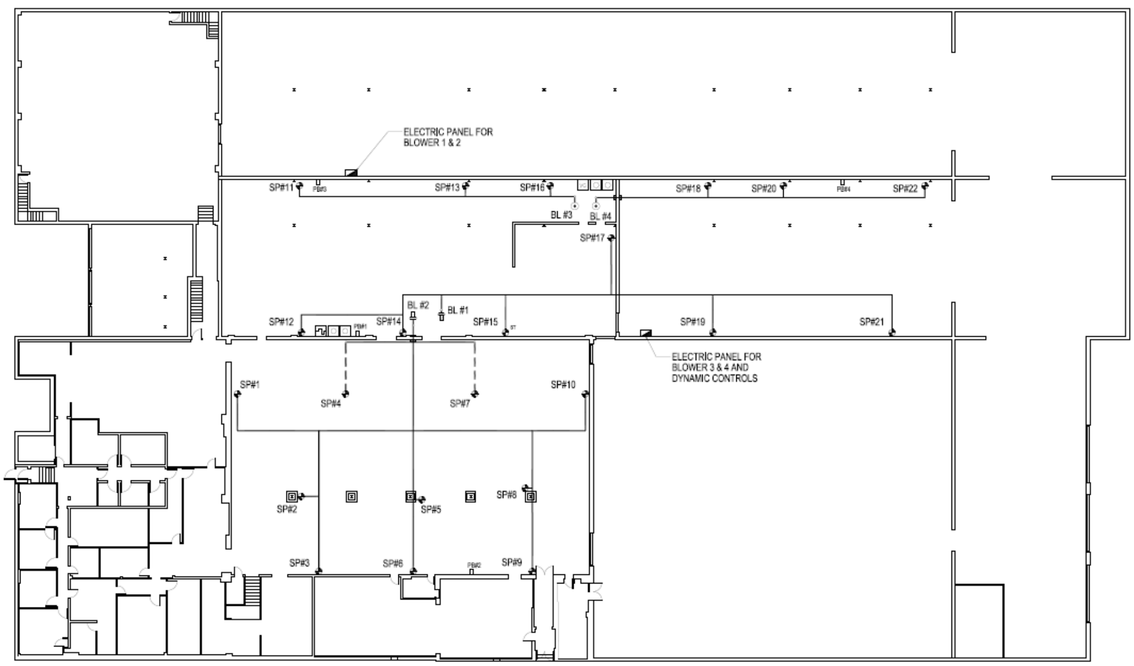

Figure 5

The Vapor Dynamics, LLC Vapor Guardian 5500™ was installed to remotely monitor and dynamically control the mitigation system (See Figure 6). Dynamic controls enable the vapor intrusion mitigation system to maintain a constant predetermined sub slab pressure differential that is set as part of the electronic management and monitoring system. The system monitors the sub slab vacuum levels and self corrects for pressure induced changes that may occur from HVAC operation, exhaust hoods, wind loading and weather induced indoor pressure differentials. The sub slab pressure differential pressure sensor is continually monitored by a programmable logic controller (PLC) which controls the variable frequency drive (VFD) to adjust the blower speed to maintain the predetermined sub slab vacuum set point. Time dampening to prevent harmonic responses that are induced by wind gusts were instituted as part of the startup procedures. Additionally, the PLC packets the data and outputs to a remote client login through a wireless cradle point. Two of the four blowers installed at this site feature the dynamic controls software; all four of the blowers are remotely monitored. The data is also stored for system analysis and regulatory reporting. Figure 7 shows the roof mounted blower systems.

Figure 6


Figure 7

At system start up, the blower was set to run in manual mode and the sub slab vacuum field mapped using a micromanometer to identify the least influenced area. The system was then balanced using riser gate valves. Sub slab vacuum set points were selected based on their correlation to the outer extent of the sub slab vacuum field which is the lowest sub slab pressure differential in the impacted area. One sub slab set point was selected per blower system. In order to determine the relationship between the set point value and the outer extent of the vacuum field, the system was run through multiple speeds and the sub slab vacuum was recorded at both the set point and the outer extent of the vacuum field (see Table 2 example). For the purpose this paper, we have selected one dynamically controlled system to examine the effects of weather driven variables. Table 1 shows the values selected for the system during commissioning along with the corresponding value at the outer extent of the vacuum field. The table also includes the Alert Level which is the vacuum level at which the consultant will receive a mobile alert informing them that the system has breached the acceptable sub slab vacuum threshold. Commissioning values were taken on October 8, 2013.

Blower Type:	Cincinnati PB15A
Blower Current (Amps):	1.69
System Vacuum (" w.c.):	3.28
Sub Slab Set Point (" w.c.):	-0.0400
Sub Slab Alert Level (" w.c.):	-0.0300
Outer Extent of Vacuum Field (" w.c.):	-0.0052

Table 1-Manual Start up Metrics

Anticipating that these low permeable soils would require greater applied vacuum to achieve a constant sub slab pressure differential during unfavorable weather conditions, a motor and radial wheel combination were selected in the design phase with an upper vacuum range to accommodate those conditions. In order to maintain the selected sub slab set point at start up the blower system's variable frequency drive was set up to run the motor at 50% of max speed. Max or base speed is achieved at 60 Hz or cycles per second of electricity.

Telemetric Monitoring and the Effects of Changing Temperatures

At the time of manual start up on October 8, 2013 the blower was set to run at 50% of base speed. The outdoor temperature was 74°F, applied vacuum 3.28 "w.c., the sub slab set point sensor read -0.0400 "w.c., and the outer extension of the negative pressure field measured -0.0052"w.c. On November 6, 2013, the day that the system was transitioned from manual to dynamic controls the average temperature was 55°F. The system was rebalanced and programed to hold the sub slab set point of -0.0400 "w.c. The resultant applied vacuum that day averaged 6"w.c. This transition is marked by the green arrow in Figure 8. As temperatures began to decrease the applied vacuum began increasing in order to maintain the sub slab set point. On December 7, 2013, with an ambient temperature of 28°F, the dynamic controls system raised the applied vacuum to 13 "w.c. or 90% of max blower speed in order to maintain the sub slab set point. On December 16, 2013, with an ambient temperature of 24°F, the system could no longer maintain the sub slab set point despite operating at 100% of the motor capacity. At this point 16 "w.c. was being applied and the system was drawing 3.7 Amps, over twice the commissioned value. The graph below displays the changes the system underwent as the winter progressed. On December 23, 2013, amid concerns of exceeding the motors service factor and premature failure, the system was manually returned to operate at 50% of base speed while corrective actions were considered. The noise impact on neighbors was also a factor in this decision. This event is marked by the red arrow in Figure 8.

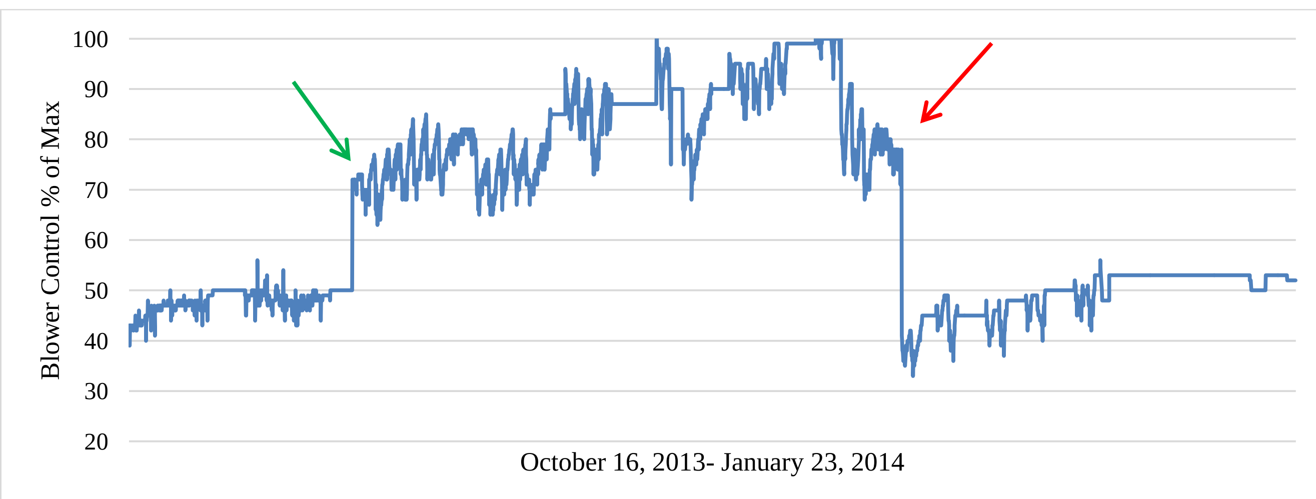

Figure 8

Figure 9 displays the corresponding applied vacuum and amperage required to maintain a predefined set point. When motor speed reached 100%, the system was returned to manual controls.

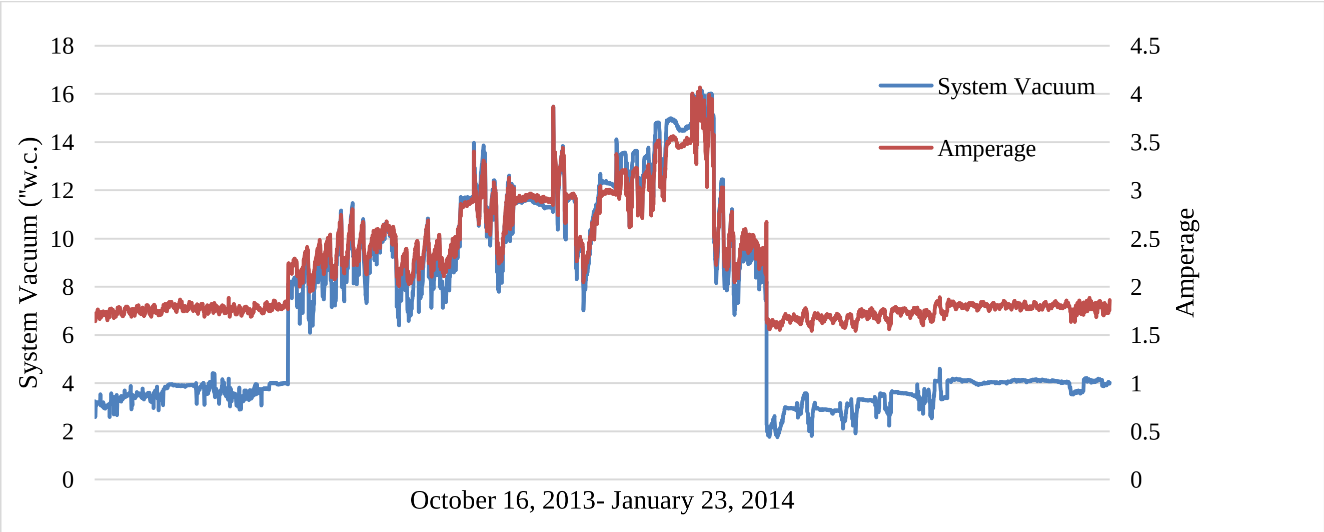

Figure 9

Because the system could no longer maintain the sub slab set point established during commissioning to meet NJDEP's minimum sub slab vacuum levels at the outer extent of the vacuum field, it became clear that mechanical corrective actions were required. A cost analysis was done to determine the feasibility of adding additional suction points versus upgrading the vapor blower. The decision to add additional suction points was made and on December 23, 2013, two additional suction points were added at the outer extent of the vacuum field. Figure 10 shows the new system layout with the additional two suction points.

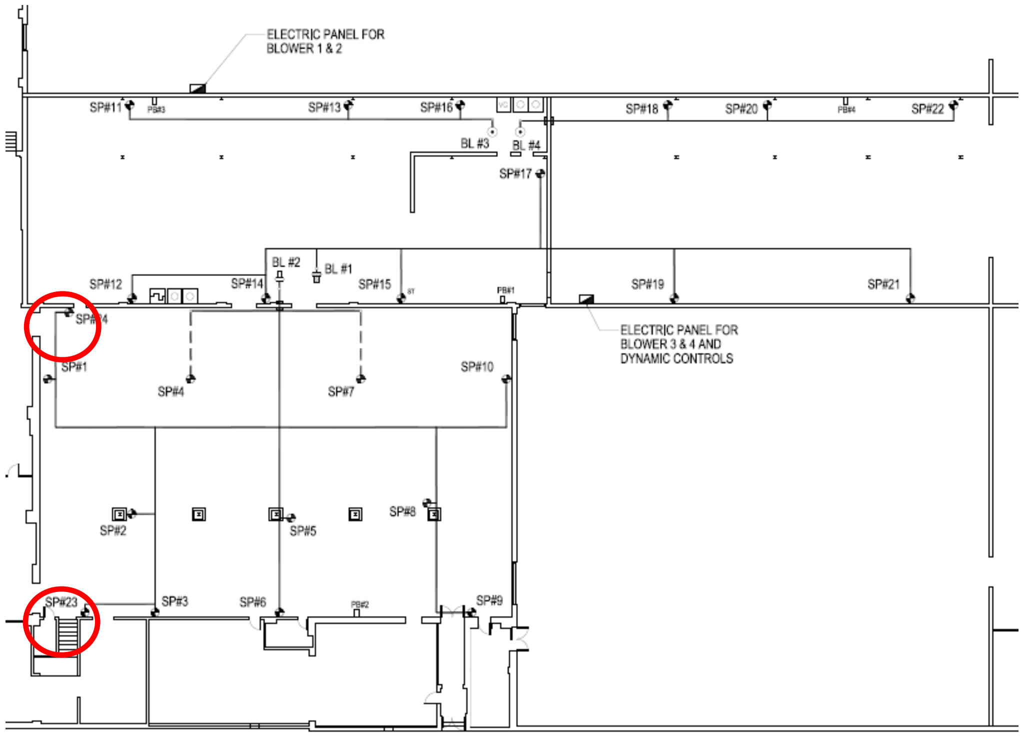

Figure 10

With the addition of the two suction points, the lowest sub slab pressure differential in the impacted area was raised to -0.0104 "w.c. which correlated to -0.0509 "w.c. at the sub slab sensor reference point with the blower running at 50% of base speed. After the addition of the two suction points, the system was temporarily set to run at 50% of motor speed as the firmware was being refined. During that time the area of concern was adequately depressurized. Table 2 shows the correlation between the sub slab monitoring port and the outer extent of the vacuum field with the two new suction points installed. The table was created by manually running the blower at multiple speeds and measuring the other listed dependent variables.

Blower Speed (% of max)	**Blower Speed (Hz)**	**Current (Amps)**	**Applied Vac ("w.c.)**	**Sub Slab Vac ("w.c.)**	**Outer Extent Vac ("w.c.)**
100	60	4.4	16	-0.1550	-0.0322
90	54	3.63	13	-0.3740	-0.0271
80	48	3.07	10.5	-0.1120	-0.0225
70	42	2.6	8	-0.0905	-0.0179
60	36	2.27	6	-0.0699	-0.0139
50	30	2.07	4.8	-0.0509	-0.0104
40	24	2.07	3	-0.0340	-0.0072
30	18	2.15	2	-0.0210	-0.0045

Table 2 – System Measurements at Multiple Fan Speeds

Although dynamic controls did not run from December 23, 2013 to July 10, 2014 as a result of required firmware upgrades, the system was remotely monitored and the data has been recorded to ensure that the vacuum at the sub slab monitoring port did not drop below -0.0210 "w.c. which correlates to -0.0045 "w.c. at the outer extent of the vacuum field. Graph 11 shows the sub slab vacuum since the addition of two suction points. The red line on the graph represents the reference point where the sensor is located which correlates to the outer extension minimum of -0.0045 "w.c. As shown in Figure 11, with the increased frequency of warmer days and decrease in indoor to outdoor temperature differentials the sub slab pressure consistently increased even though the vacuum applied remained constant.

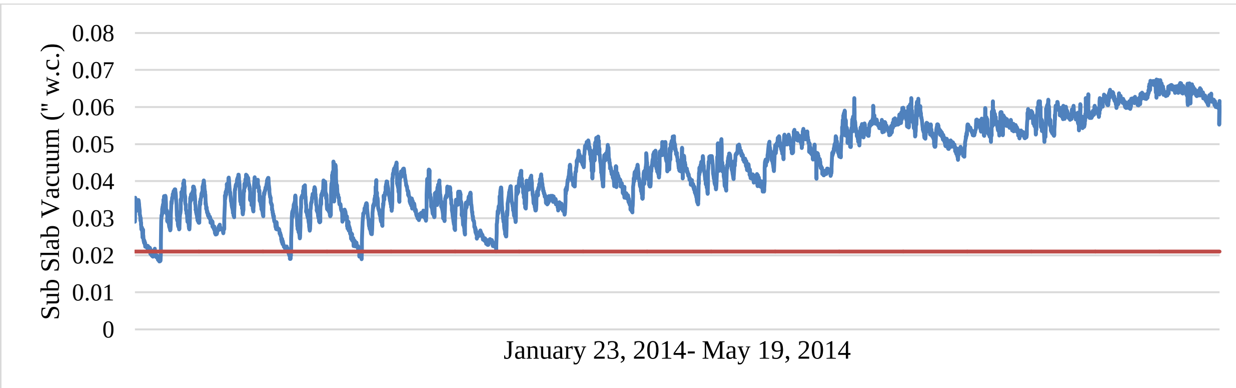

Figure 11

On July 10, 2014 the latest version of firmware was installed and dynamic controls once again began to operate as designed. The sub slab set point was programmed to operate at 0.05 "w.c. Figure 12 shows the applied vacuum required to hold the set point during the most recent period of dynamic controls operation.

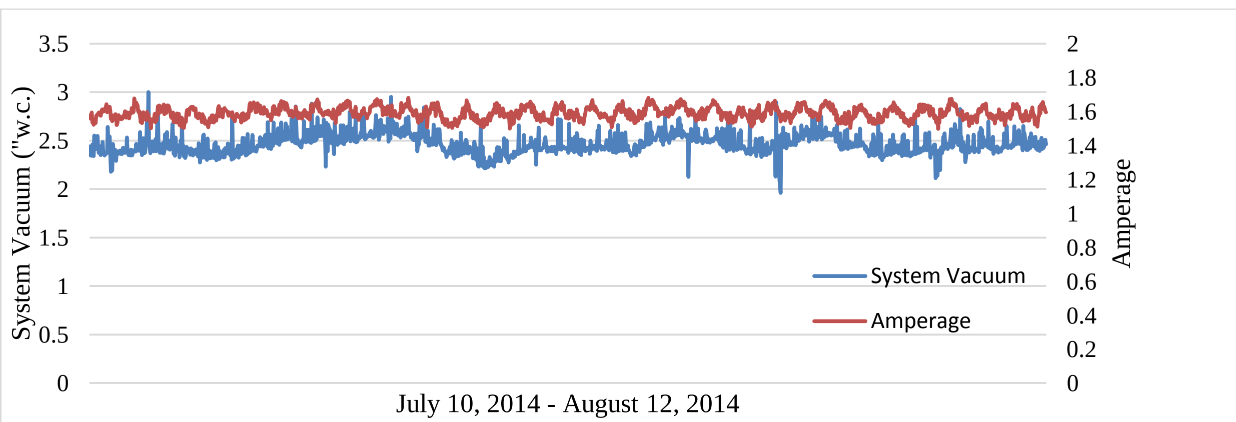

Figure 12

Figure 13 shows the sub slab vacuum measured at half hour intervals during the July 10, 2014 to August 12, 2014 dynamic controls run period. The maximum recorded value at the reference point was 0.0588 "w.c. and the minimum recorded value was 0.0451"w.c.

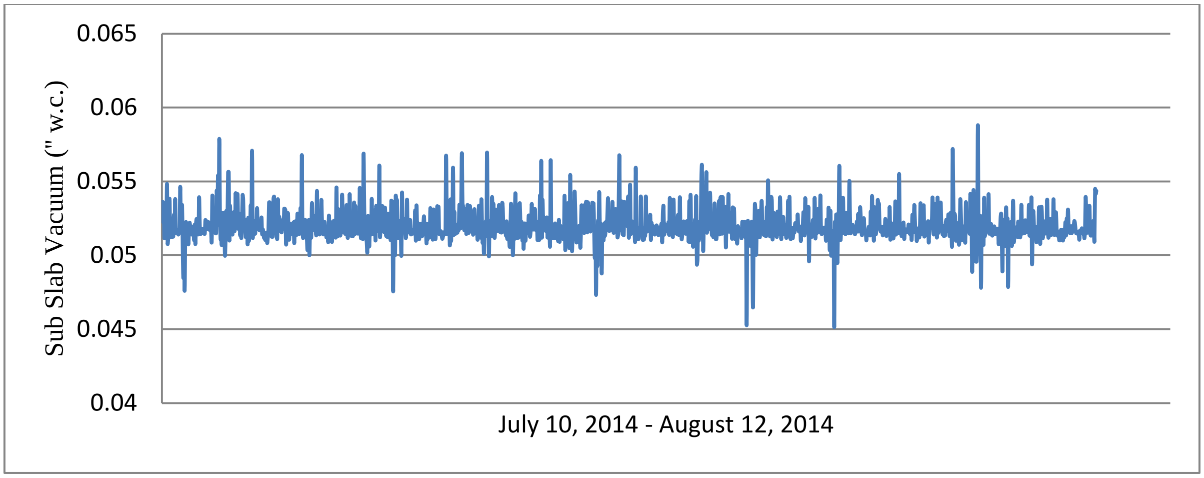

Figure 13

RESULTS AND DISCUSSION

Systems designed, installed, and commissioned using pressure field extension data recorded in warmer temperature months may be failing to meet sanctioned minimum performance metrics during colder months. As witnessed in the aforementioned case study and displayed in Figure 14, the required applied vacuum to maintain a constant sub slab pressure differential increases as the temperature decreases.

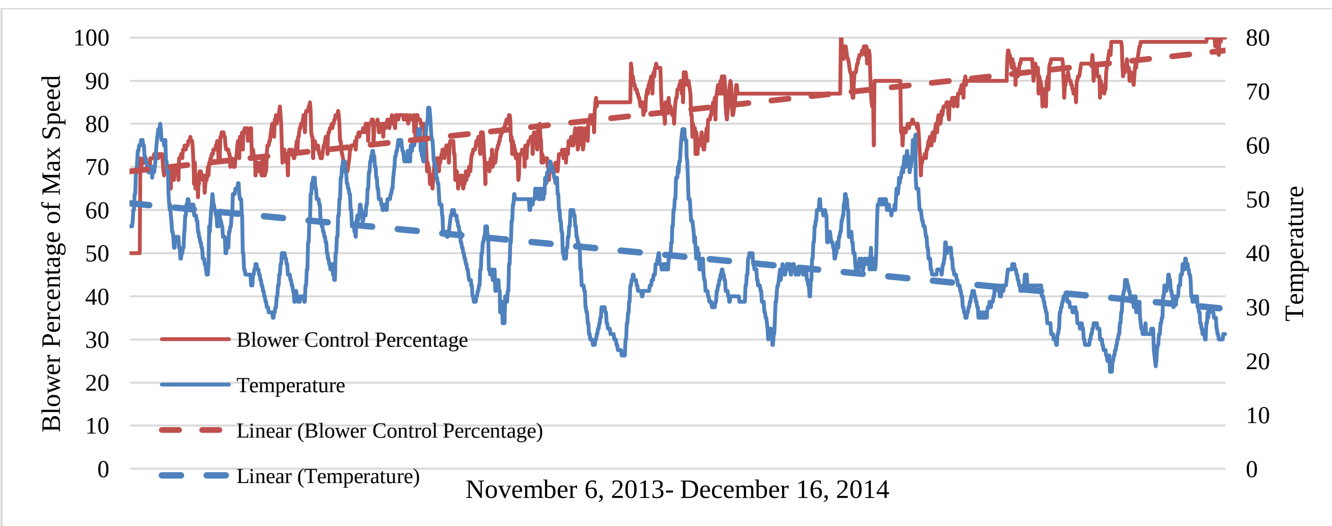

Figure 14

Graph 14 displays that an increase in blower speed is required as the temperature declines. The increase in blower speed is depicted as a percentage per degree of temperature reduction and increases exponentially as the temperature cools. It is important to note that at 74°F, the pressure differential objective of -0.0052 at the outer extension of the negative pressure field was achieved by applying 3.28 "w.c. at the suction point. At 24°F, the same sub slab pressure differential of -0.0052 could not be maintained even though 16"w.c was being applied at the suction point. The 50°F temperature decline required almost five times as much vacuum at the suction point to achieve the same sub slab pressure differential objective. Figure 15 displays the percent of motor change per degree of ambient temperature lost vs. ambient temperature.

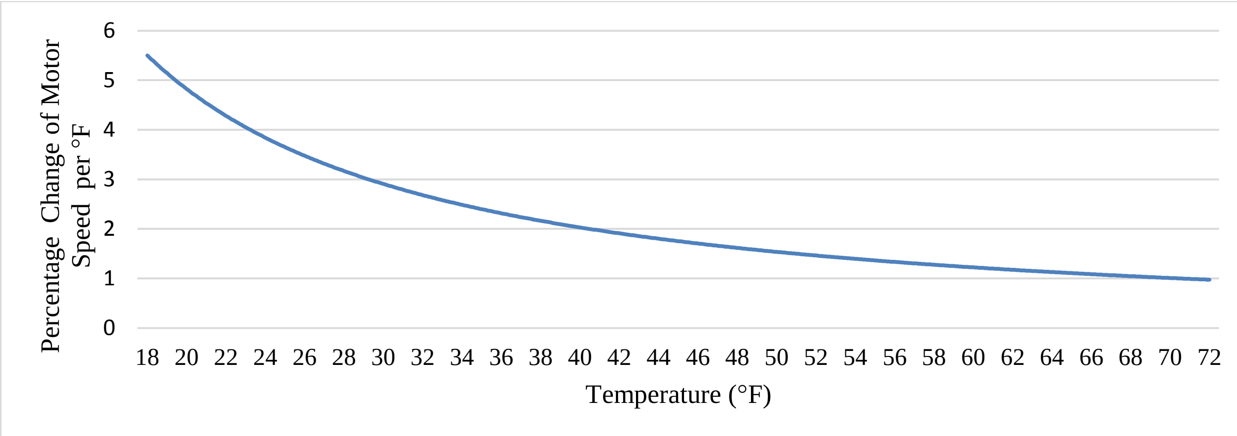

Figure 15

As shown in Figure 15, the relationship between percent of motor speed change per degree of ambient temperature lost is exponential. The graph illustrates that the power required to maintain a constant sub slab vacuum changes less than 0.3% per degree between 70 and 60°F but changes nearly 2.0% per degree when the temperature drops from 30 to 20°F.

In the climate zone where this case study was performed, there are, on average, 202 days or 55% of the year where temperatures drop below 32°F, further adding to the importance of a dynamically controlled system.

Another critical observation is the cost savings associated with running a dynamically controlled system as opposed to a traditional static system. Although the system was not run dynamically for the entire time, the cost savings were still apparent. In Figure 16, the blue area represents the Heating Season costs savings during the period where the system operated exclusively on dynamic controls. The $450 per month maximum cost represents the blower operating at 100% or max speed. The blue area represents the difference between the actual costs per month vs. the projected max cost per month. Figure 17 displays the costs savings associated with dynamic controls during the summer months. Like Figure 16, the orange area represents the difference between actual costs and calculated maximum operating costs.

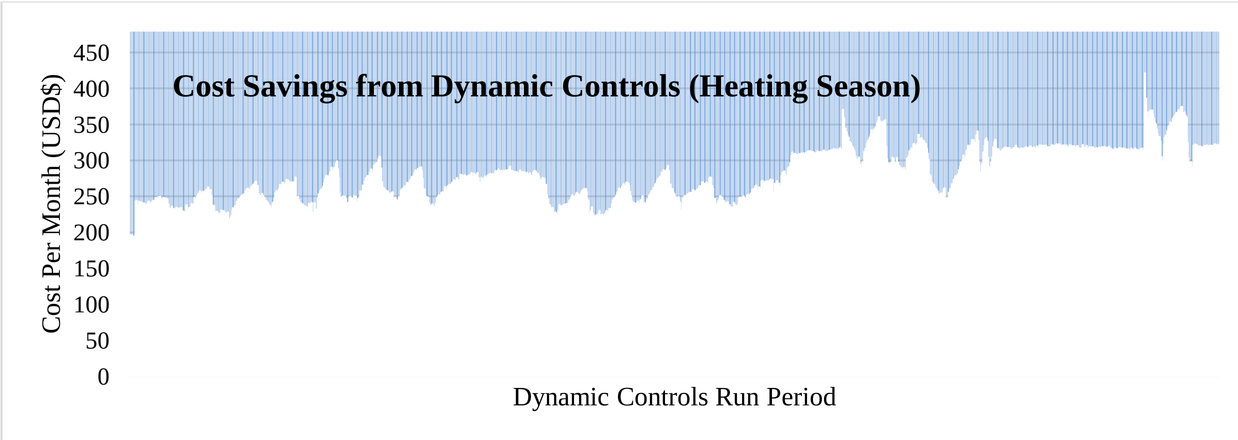

Figure 16

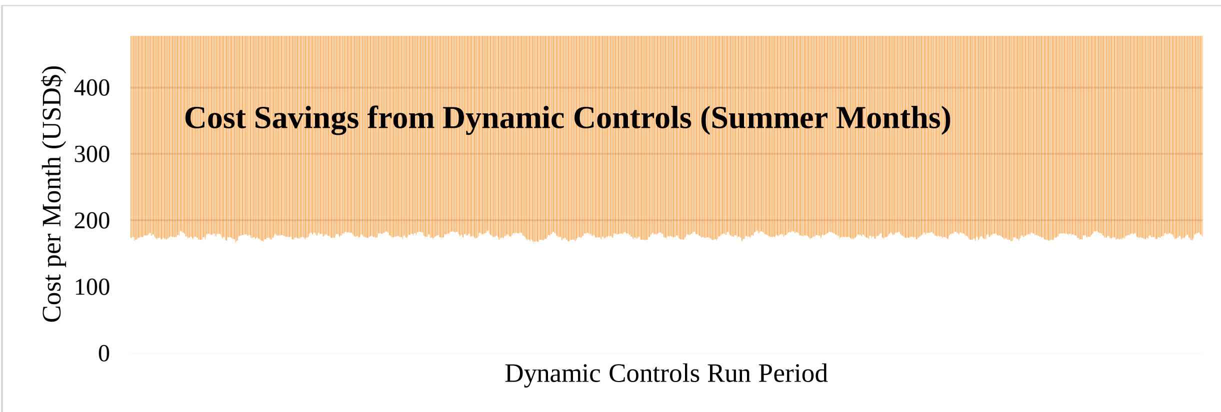

Figure 17

Comparing Sub Slab Fill Types

Monitoring data from a nearby site where a dynamically controlled sub slab depressurization system is running was accessed for the purpose of comparing low and high permeable fill types. The major difference between the two sites is that the second site has a 4 to 6 inch crushed stone layer below the slab as opposed to the native soils found at first site. The second site is a manufacturing plant where high airflow fume hoods cycle on and off during production resulting in the interior of the building being subject to greater pressure fluctuation. Excess motor capacity was built into the design at the nearby site to accommodate including another section of the building on the same motor. Figures 18 shows the native soil from the first case study site and Figure 19 shows the crushed stone from the nearby site.

Figure 18

Figure 19

Figure 20 shows the vacuum applied as a percentage of maximum motor speed to maintain a constant sub slab set point during a time period ranging from July 2013 to May 2014. When compared to Figure 21 it can be clearly seen that the effects of seasonal variables on sub slab depressurization systems is minimal when depressurizing a slab with crushed stone or a similar highly permeable fill material.

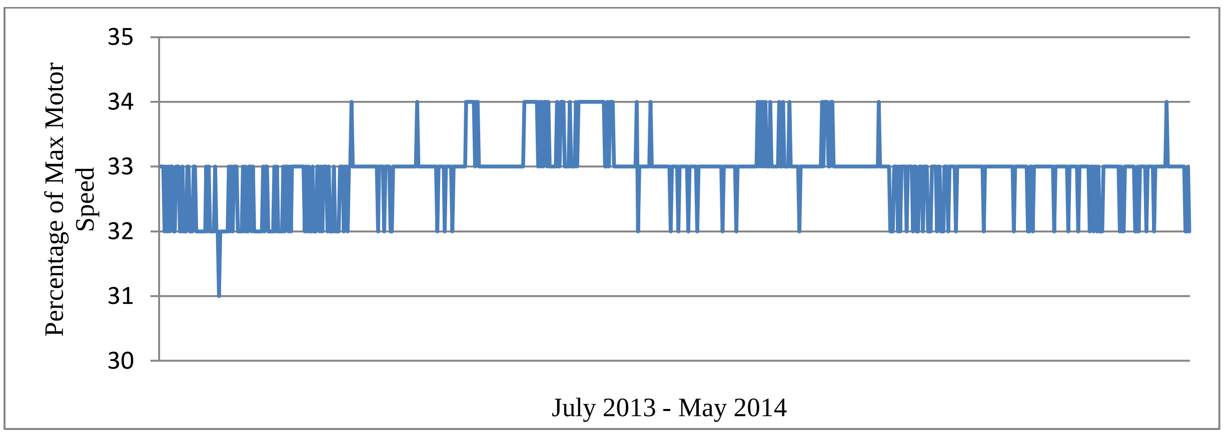

Figure 20

Figure 21 shows the sub slab vacuum recorded from July 2013 to May 2014. The sub slab vacuum control set point was set at 0.25 "w.c. and a delay was programmed into the motor to prevent the motor from over responding as fume hoods would cycle on and off during production cycles. As can be seen, the maximum deviation in sub slab vacuum is approximately 20%. If three anomalous events that are believed to be associated with a power grid shut down are removed from the graph, the maximum deviation drops to within 10% from the sub slab set point. Because of the presence of crushed stone at this site, 0.25 "w.c. can be maintained in the sub slab while only applying from 0.5 to 1"w.c. of vacuum from the roof mounted blower.

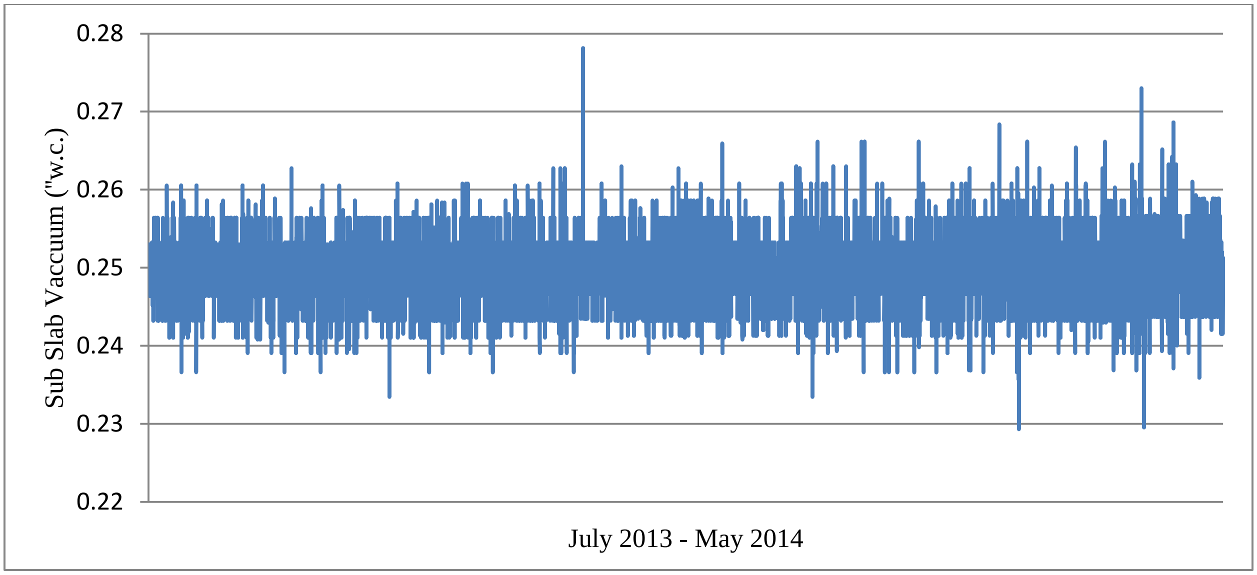

Figure 21

CONCLUSION

The effects of seasonal variables on sub slab depressurization vapor intrusion mitigation systems are evident. These effects become significantly amplified as the permeability of sub slab fill decreases. As ambient temperatures decrease, blower motor speeds in dynamically controlled systems are required to increase in order to maintain a constant sub slab pressure differential objective. Furthermore, the required percent increase in motor speed per degree doubles from 70°F to 40°F, a span of 30°F. However, between 40°F and 25°F, a span of only 15°F the motor speed doubles again. Continuing at an exponential rate, between 25°F and 15°F, a span of only 10°F the motor speed doubles again.

Systems design, installed, and commissioned during favorable weather conditions may require four to five times the amount of vacuum to be applied at the suction point to maintain the same sub slab vacuum field objective during the heating season. Not only may some systems be failing to maintain targeted sub slab vacuum levels during unfavorable weather conditions, but as pressure differentials at the outer extent of the pressure field shifts from negative to positive, there is a potential that unsuspecting building occupants may be exposed to sub slab vapors. By applying dynamic controls and remote monitoring technologies to mitigation systems, operators can develop a clearer understanding of how these systems are performing thus providing assurance that systems are maintaining depressurization goals during the full range of weather conditions. Integrating these controls substantially decreases power consumption and contributes to long term sustainability.

ACKNOWLEDGEMENTS

Kristin Hatton, Paul Kearney, Marcos Aguilera, Anders Nordstrom and the Clean Vapor Team.
Dave Everett, Tom Leonard, and the Vapor Dynamics Team.

REFERENCES

[1] Hatton, Brodhead, High Vacuum, High Airflow Blower Testing and Design for Soil Vapor Intrusion Mitigation in Commercial Buildings, 2010

[2] New Jersey Department of Environmental Protection – Vapor Intrusion Technical Guidance Document (March 2013, Version 3.1)

KEYWORDS

Vapor Intrusion Mitigation, Dynamic Controls, Building Diagnostics, Remote Monitoring, Sub Slab Depressurization, Efficient Mitigation Systems, Power Savings, Weather Driven Effects, Low Permeable Fill