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PSU Green Building Summer Internship Final Report, 2017: Interior Environmental and Indoor Air Quality Assessments of Workspaces for Future Maintenance of Parkmill's Constant Air Volume (CAV) HVAC System

Bassam Alduhaim
Portland State University

Sofia Chavez Cruz
Portland State University

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Interior Environmental and Indoor Air Quality Assessments of Workspaces for Future Maintenance of Parkmill's Constant Air Volume (CAV) HVAC system.

Bassam Alduhaim and Sofia Chavez Cruz
Green Building Internship Program
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Portland State University

Introduction

Parkmill's Design, Construction, and Mechanical Systems

The Parkmill building is located on the lower south section of Portland State University's (PSU) urban campus between SW Park Avenue and SW Mill Street.The lot space, originally selected for the design proposal in 1956, was located between two buildings including the acquired Parkway Manor (currently designated as PSU housing) and former frame house-type buildings. The proposed building would supplement the evening and summer curriculum courses offered by the General Education Division (GED) in partnership with Portland State College and would become a vital resource for students in the Portland metropolitan area.

The original design involved a reinforced concrete construction with a brick veneer exterior that would be divided into three levels; a basement, first, and second floor, delineated on the 50 foot x 100 foot lot. Programming on the first floor involved the allocation of support staff that reported to the GED dean. The prospective office concepts included a primary office space for the dean with neighboring 13.5'x15' and 10'x13.5' offices that housed the assistant dean, the assistant director, and assistant to the dean. A considerable section of the first floor accommodated file storage, secretary work spaces, and a general service area.

In an effort to allocate space for the expanding services of the GED, the lot adjacent to the General Extension Building (GEB) was proposed as a possible space for a building addition. The second section of the GEB would encompass 15,000 square feet of office and supporting seminar/conference spaces with identical architectural and structural features to existing building.

Indoor Environmental Standards and the Work Space

The physical work space is delineated by a history that specifically emphasizes the shortcomings of building design from the 1950s to late 1960s. The occupant, in this vast portrait of the American office landscape, was and in some instances continues to be marginalized by space demands, cost-efficient design objectives, and architectural oversight (Saval, 2016; Berg and Kreiner, 1990; Romijn et al, 1996). Not until recently that there has been a provocative inquiry into indoor environmental quality, including indoor air quality, and occupant comfort. During the early 1900s, researchers in the U.S and throughout Europe began to identify issues within indoor environments due to significant health ailments associated with increased exposure to poor indoor air quality and a general lack of ventilation (Sundell, 2004). However, it was not until 1980, when the term "sick building syndrome" was publicized, that there was a widespread acknowledgment both in architectural and medical discourse that marked buildings as a central source of occupant health concerns (OED, 1983-1999).

At the height of a changing socio-political climate in the U.S, there emerged an increased awareness for environmental conservation and employee work conditions, with the establishment of the Environmental Protection Agency (EPA) in 1970 and the Occupational Safety and Health Administration (OSHA) in 1971. In a span of 30 years, legislation provided for significant changes in environmental policy that expanded into the home and place of work. In 1973, ASHRAE publicated its first standard on indoor air quality with a considerable revision to the original standard 62 in 1999. During this period, the United States Green Building Council (USGS) was formed in order to provide direction and incentive for environmentally-conscious construction. USGS was the first organization to develop a point-based certification system for building design and construction that categorized factors contributing to satisfactory indoor environmental quality and building sustainability. Presently, the management of appropriate indoor environmental conditions such as indoor air quality and thermal comfort are covered by ASHRAE standard 62, IAQA/ASHRAE, LEED prerequisites for obtaining certification, and IESO.

As buildings underwent alterations in accordance to enacted policies, construction and mechanical standards as well as medical, scientific, and sociological research, the office employee also saw an unceasing transformation in their workplace environment. When a higher percentage of the U.S population shifted to indoor occupations, the office typology changed from the cartesian employee grid and open space plan, to the perimeter and cubicle work spaces, to a hybrid of the traditional open plan that partitions, divides, and groups employees to articulate “cross-pollination”. Nonetheless, the development of the modern “open plan” office concept has also been the center of concern by researchers as well as the typical office worker (Oldham and Brass, 1979; Brennan et al, 2002; Witterseh et al, 2004; Saval, 2014).

Background

<u>Indoor Environmental Quality and Work Space Design</u>

Indoor Environmental Quality (IEQ) provides an overall reference of a building's’ systems that not only serve to provide thermal comfort but constitute factors affecting indoor air quality. Studies on indoor environmental quality have presented the critical components of the physical work space that increase occupant health, productivity, and overall perceived satisfaction with the office landscape. As such, the indoor environment is dependent on multiple mechanisms,encompassing a building’s mechanical cooling, heating, and air distribution measures that provide “particle filtration, air recirculation, and outdoor air ventilation” (Wyon and Wargocki, 2013).

Pejtersen et al, conducted a study of Danish office occupants to analyze whether a specific office plan produced an increase in sick-related absences (Pejtersen et al, 2011). Utilizing a workplace survey as the principal assessment type, the researchers correlated a higher number of reported sick days with employees working in an open office plan. In contrast, employees that reported occupying an individual office space or a “cellular” office showed the least percentage of sick-related absences.

Taking into account the factors outlined in the research study by Petjersen et al, Frontczak et al published an article evaluating the components of U.S office buildings that relate to occupant comfort and satisfaction with indoor environmental quality (Frontczak et al, 2011). Similar to Pejtersen et al, the study relied on occupant survey data provided by Center for Built Environment (CBE) to inform which aspects of the office environment are major contributors to the occupant’s perceived satisfaction with their work space. From their analysis, they concluded that the “most predictive value” for occupant satisfaction was related to the amount of individual work space they were provided.

A consequence Pejtersen et al measured was that increasing the number of occupants in a communal work space layout may have the effect of escalating "sickness absences" among those employees. From these two studies, it can be inferred that a simultaneous benefit for distributing office spaces effectively while prioritizing individual work space designs could result in greater health benefits and maximize overall occupant satisfaction. In Pejtersen et al's research, however, there are notable limitations in the questionnaire assessment in regards to informing a precise analysis of whether a sick absence is related to the work environment, a preexisting or unique health condition. Their references to other studies note that sick absences among occupants in open office spaces may be associated with inadequate acoustics or "noise exposure", "ventilation type", "exposure to viruses [due to] air movement [and/or] air ventilation", "psychosocial work environment", and "lack of autonomy". Frontczak et al also discuss the limitations of an exclusively qualitative research approach in which the major source of data was derived from occupant survey responses. In their report, they mention that a complementary study involving an "objective" investigation of office and/or building characteristics could provide additional support for the resulting "subjective" data.

Taking into account the advantages of the occupant comfort surveys and location testing, Choi et al, examined various office buildings in the U.S, in order to assess comfort levels within indoor environmental factors (Choi et al, 2012). Their study examined occupant work spaces for a 15-minute time block and provided on-site questionnaires to analyze thermal and air quality, illuminance, air velocity, and acoustical characteristics. In contrast to Frontczak et al's results, Choi et al found that thermal quality was a deciding factor in "occupant satisfaction" with regards to situation of the workstation. An interesting pattern emerges in which the quality of occupant satisfaction/comfort is related to either the type of workspace (whether "cellular" or open plan" or the location of the workspace (a "perimeter zone" or "interior zone".

Illumination Strategies

An aspect of indoor environmental quality that promotes productivity and occupant comfort is the implementation of strategic illumination within the workspace or office design (Katzev, 1992; Veitch and Newsham, 2000; Boubekri et al, 2014). Reinhart and Weissman, provided a methodology, as developed through architecture course projects, to develop DIVA for Rhino plug-in simulations that analyzed daylighting of interior spaces (Reihart and Weissman, 2012). Zomorodian et al, investigated the effects of lighting and thermal properties of spaces at Texas A & M University campus through simulations, questionnaires, and on-site testing (Zomorodian et al, 2017).

Reinhart et al's approach focused primarily on the development of simulations and on-site daylighting values to produce data visualizations illustrating light intensity through student and digitally generated data. The research undertaken by Zomorodian et al contained three methods of analyzing "visual [and] thermal comfort"through objective and subjective evaluations. In order to produce data sets on light intensity for select spaces on campus, Zomorodian et al relied on the DIVA plug-in to produce lighting simulations and data specific to LEED daylight credit requirements. In their respective studies, Zomorodian et al and Choi et al emphasize the significance of occupant surveys in order to identify the issues directly affecting occupant comfort and/or satisfaction in the classroom or workstation. As an ancillary measure, quantitative testing, such as sensor or point-in-time evaluations could result in an informed study that may introduce procedures for improving indoor environmental factors.

Methodology

Zones

We decided to divide the floorplan for the first floor of PKM into two zones to better assess and organize data for indoor air and environmental quality. Zone A is the School of Gender, Race, and Nations offices. Zone B is the Office of Graduate Studies offices. Figure 1 illustrates the zones on the first floor of Parkmill. We divided the first floor into two zones in order to have an understanding of how solar path affects their respective facades (figure 2).

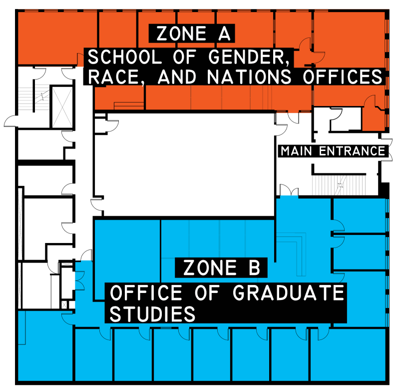

Figure1 illustrates the zones in PKM first floor

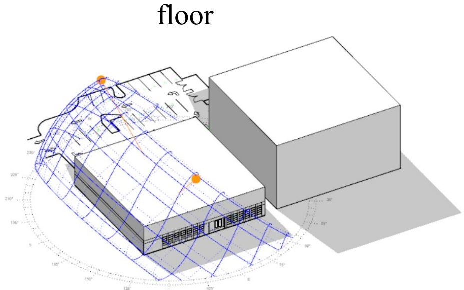

Figure2: shows the solar path on PKM during the study.

Temperature and relative humidity

Kestrel DROP D2 data logger (See Fig. 3) can monitor and record the temperature and relative humidity in indoor and outdoor environments. 20 Kestrel DROP D2 sensors were used and placed in different spaces in PKM first floor. The sensors were checked weekly and the data was viewed and retrieved using Kestrel LiNK app from the beginning of the study.

Figure 3. shows Kestrel DROP D2 model.

Carbon Dioxide (CO2)

Onset HOBO MX1102 CO2 loggers (See Fig. 4) were put in 4 different spaces in PKM. The logger can measure and record the CO2 in indoor environments. It can measure the CO2 concentration from 0 - 5,000 ppm. The HOBOmobile app allows users to access the data using mobile phones or tablets within 100 foot range. It has also a USB port to access the data via computers. In addition, the sensor can measure temperature and relative humidity.

Fig. 4 : Onset's HOBO MX1102 CO2 logger.

Particulate Matters (PM)

The Fluke 983 Particle Counter (Figure 5) was used to investigate the PM levels in the PKM building. Space 119 was selected as a location for the investigation. The Fluke 983 measures six different bins of particle sizes from 10 μm down to 0.3 μm as well as temperature and humidity. The Fluke 983 has an internal pump that forces air into its test chamber at 0.1 cfm through an isokinetic probe. The Fluke 983 was deployed in space 119 for 48 hours before and after the duct cleaning.

Figure5: Fluke 983 Particle Counter. Image courtesy of Fluke.

Air velocity

The TSI VelociCalc 8350 meter (See Fig. 6) has the ability to measure the Air velocity as well as the air temperature. It was used to gauge the air velocity in two locations in PKM 1st floor; one in zone A and another in Zone B. The VelociCalc 8350 has a mounted telescoping probe that contains the velocity and the temperature sensors. The AVERAGE reading was computed by using the STORE and AVERAGE keys. The reading were taken before and after the duct cleaning.

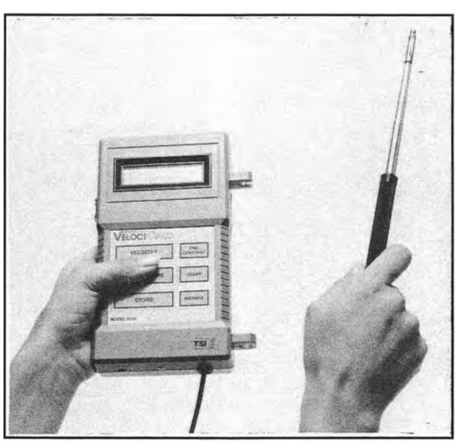

Fig. 6 shows the VelociCalac 8350 with the probe held in hand.

<u>Materials and Procedure</u>

Sun Path Simulation

Through the DIVA plug-in, developed for Rhinoceros and the Grasshopper plug-in, we were able to produce studies on sun positioning with respect to the facades of the Parkmill building (PKM). Our intention was to analyze the time interval at which solar exposure may have correlated with an increase in internal air temperature of office spaces and/or zones. This required us to extract the location file detailing weather information for Portland, OR utilizing the ".epw" file associated with the PDX International Airport weather station. We utilized Grasshopper to visualize sun and shading patterns across PKM's facade through a "slider" input so that we could effectively visualize different times during the day in which the sun was directly facing a northern, eastern, or southern facade. Before conducting this simulation, we created a 3d model of Parkmill, including single-surface glazing details for the first floor (testing location), the trees on the east side (on Park Avenue) of the building, and the adjacent PSU Parkway housing building located to the north.

Integrated Daylighting Simulations, and Artificial Lighting Visualizations

Light intensity simulations through the Rhinoceros DIVA plug-in was implemented utilized to daylighting intensity data (Lux) from offices with daylighting sources over a period of a typical week. In a detailed analysis, the simulation was programmed to produce values during the morning (10:00) , noon (12:00), and afternoon (16:00) to determine the overall variability of daylight in offices with glazing. Illumination simulations and visualizations were conducted as follows:

1. The DIVA plug-in was utilized within the Rhinoceros 3d modelling software and weather data for Portland, OR was uploaded into the DIVA “location” folder.
2. The adjacent PSU Parkway housing building and the trees located on the eastern (on Park Avenue) were included as factors that would influence daylighting values of offices with glazing.
3. For daylighting simulations, we selected the Illuminance option through Metrics.
4. Similar to the daylighting simulations, artificial lighting visualizations were produced through Metrics. We modelled the actual furniture arrangement for the select rooms located throughout the testing location.

We referred to Standard 90.1 for ASHRAE Energy guidelines and previous research on lighting levels and control applications for different office types (Levin et al, 2013). Testing on artificial lighting assessed and compared the minimum and maximum values specific to workspace illumination while presenting possible lighting strategies for work spaces without daylight exposure.

Occupant Survey

A secondary part of our research incorporated a qualitative and analytical approach exploring the implementation of post occupancy surveys as means of identifying the occupant’s experience in their workspace (Table 1). The survey was modelled after questionnaires and survey studies concerning Post Occupancy Evaluations (POE) in conjunction with procedures for distributing and analyzing occupant response data (Hedge and Erickson, 1997; Zagreus et al, 2004; Pejtersen et al, 2011; Frontczak et al, 2011; Hiromoto, 2015) . The resulting survey was divided into four categories with the purpose of supporting quantitative data obtained from on-site sensors and point-in-time readings of the first floor of Parkmill. The questions were organized according to the following categories:

1. Thermal comfort: as based on ASHRAE standards (i.e air temperature, use of cooling/heating devices)
2. Illumination (i.e color of light,quality of light,preference for daylight or artificial light, ability to control illumination, experiences due to type of illumination)
3. Air quality (i.e experiences relating to Sick Building Syndrome, collection of dust particles on their workspace surfaces, odors, type of air)
4. General qualities (i.e preference for a window, possibility of re-situating, use of plants and quantity, satisfaction with current furniture)

Table 1. List of primary occupant Survey questions in relation to IEQ factors.

IEQ Factor	Survey Section	Survey Question
Thermal Comfort	Air temperature	During the summer, I find that the air temperature in my work space is:
		Please rate your satisfaction with the air temperature in your work space during the past month.
	Individual devices/controls	During the past month, have you used a personal space heater or personal cooling device (e.g fan)?
Interior Air Quality	Air Quality	How would you rate the indoor air quality in your work space?
	Environmental Conditions	Have you experienced any of the following environmental conditions in your work space?
	Particulate Matter	Have you experienced the presence of accumulated dust or finer particles (not related to work activities) in your work space?
Lighting	Illumination	Rate your satisfaction with the overall illumination (e.g glare, intensity of lighting, contrast) in your work space.
	Daylighting	Do you find exposure to daylight would be beneficial for your overall productivity ?
		How would you describe the impact/ absence of natural daylight in or near your work space on your overall satisfaction with your work space? (Response dependant)
	Individual devices/ controls	Do you use any personal task lighting (e.g floor lamps, desk lamps) in your work space?
Office Layout, Materials, and Finishes	Furniture	How would you rate your satisfaction with the furniture (e.g desk, table, cabinet, chair, etc) in your work space?
	Layout	Please rate the effect your work space layout may have on your productivity levels or overall daily work performance.
	Materials and Finishes	How would you rate the materials and/or finishes(flooring, ceiling, walls, window coverings/blinds, etc) in or near your work space ?
	Individual devices/ controls	Do you have any plants in your work space? If you selected yes, briefly explain why.

Findings

Integrated Daylighting Simulations and Sun path

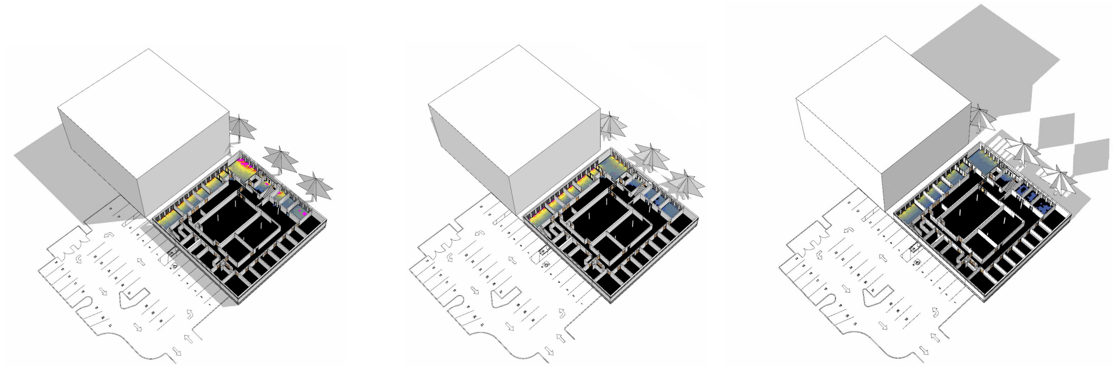

Figure 1. Sun path and daylighting illuminance simulation visualized for the first floor of parkmill for morning (10:00; left), noon (12:00; center), and afternoon (16:00; right)

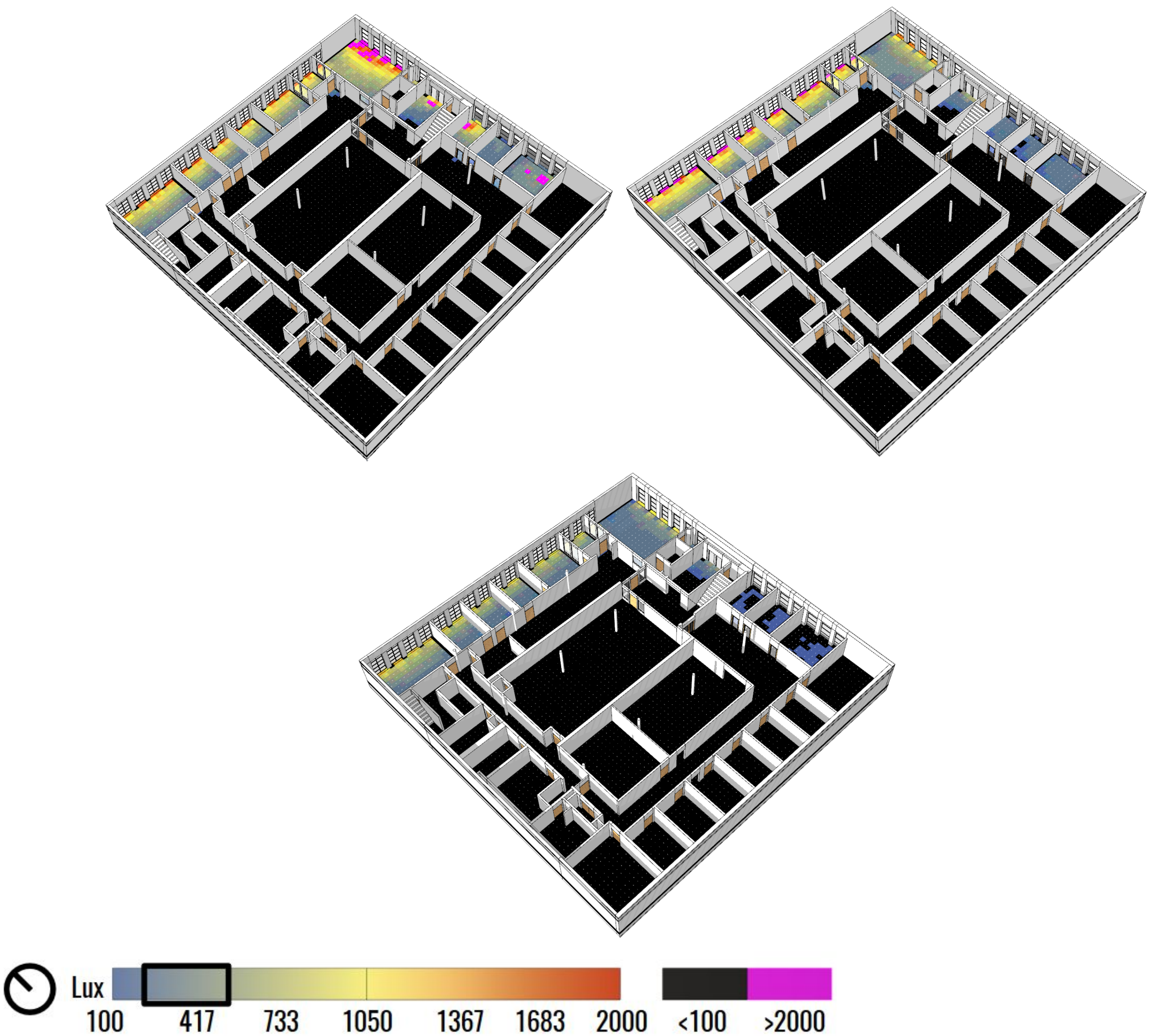

Figure 2. Detail of daylighting illuminance simulation visualized for the first floor of parkmill for morning (10:00; left), noon (12:00; center), and afternoon (16:00; right). Refer to the Intensity of illumination (in lux) scale provided by the DIVA plug-in with optimal intensity level ranging from 150-500 lux.

	Zone A				Zone B	
Space	Avg. Temp. (F)	Avg. RH (%)		Space	Avg. Temp. (F)	Avg. RH (%)
150A	75.5	41.3		107	75.5	40.6
150B	75.5	41.4		113A	78.1	38.7
150C	75.5	41.3		113B	79.1	37.2
101A	72.1	46.2		119	84	35
101B	72.3	45.6		123	80.4	37.5
141	74.9	41.6		184A	76.4	40.5
				184B	76.5	40.3
				184C	76.6	40.3
				185	74.7	43.1
				C104	77.1	39.5
Average	74.3	42.9			77.8	39.3

Table 2: A comparison between Zone A and B average temperature and Relative Humidity.

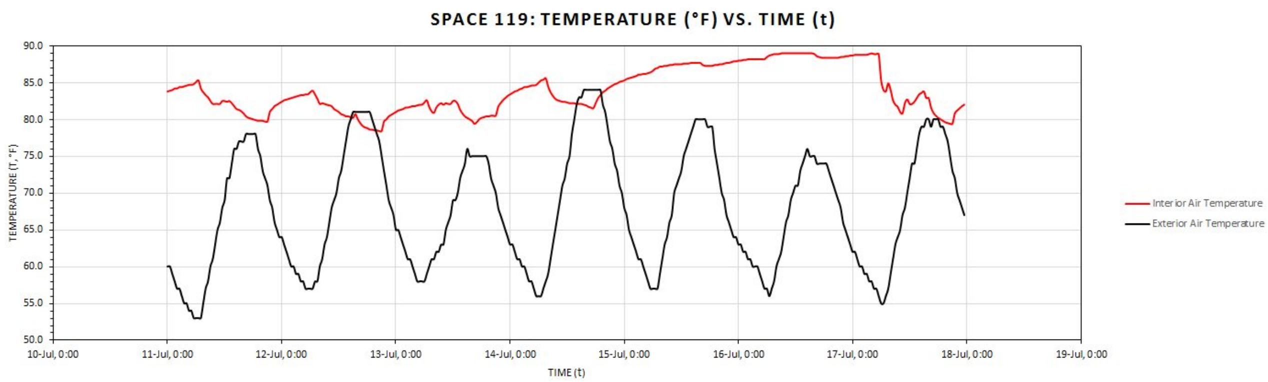

Fig. 7: Shows the highest temperature levels in space 119 during the study.

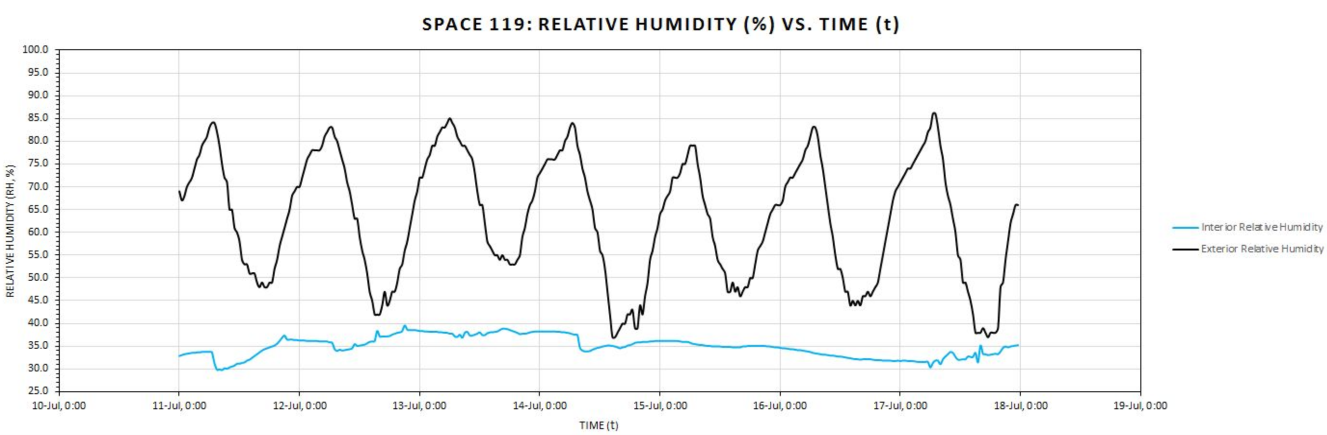

Fig. 8: Shows the relative humidity levels in space 119.

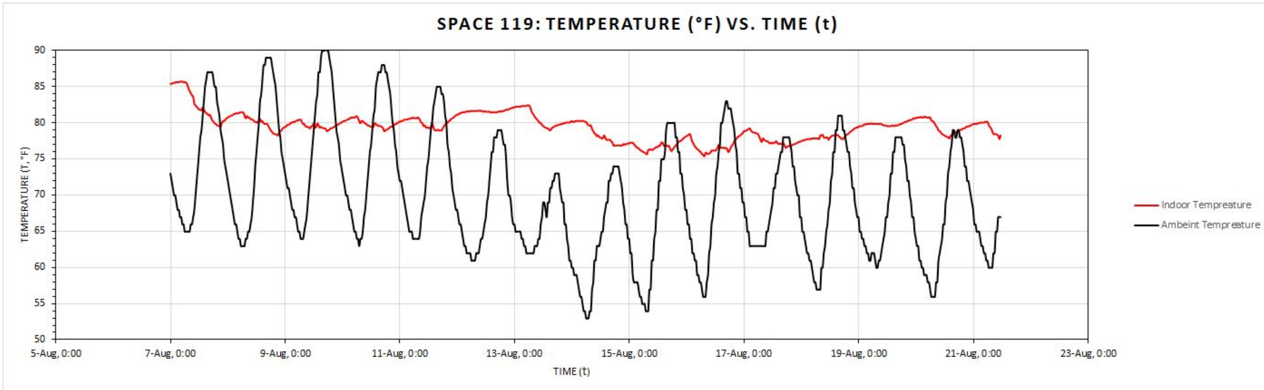

Fig. 9: Shows the temperature levels in space 119 before and after the duct cleaning.

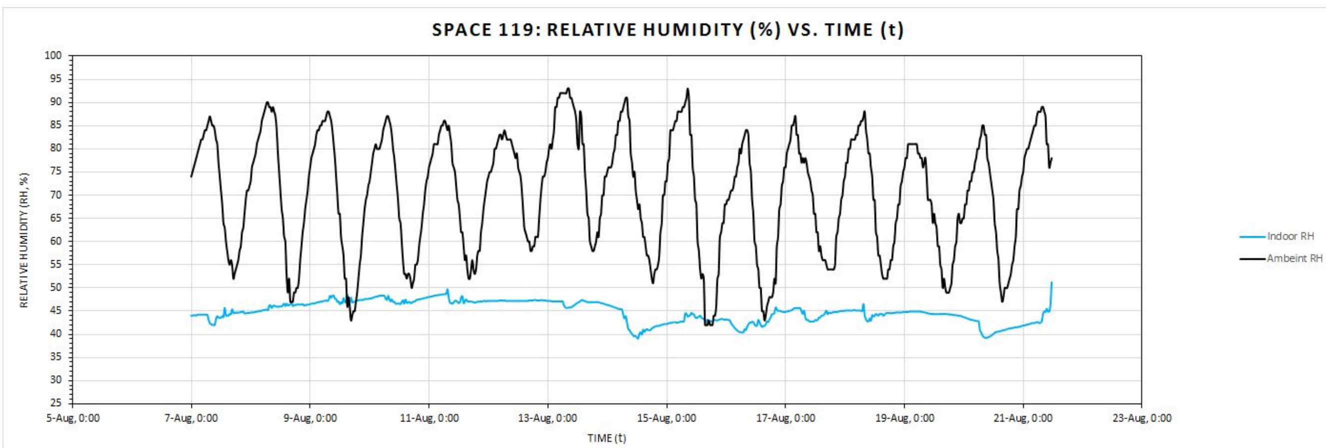

Fig. 10: Shows the relative humidity levels in space 119 before and after the duct cleaning.

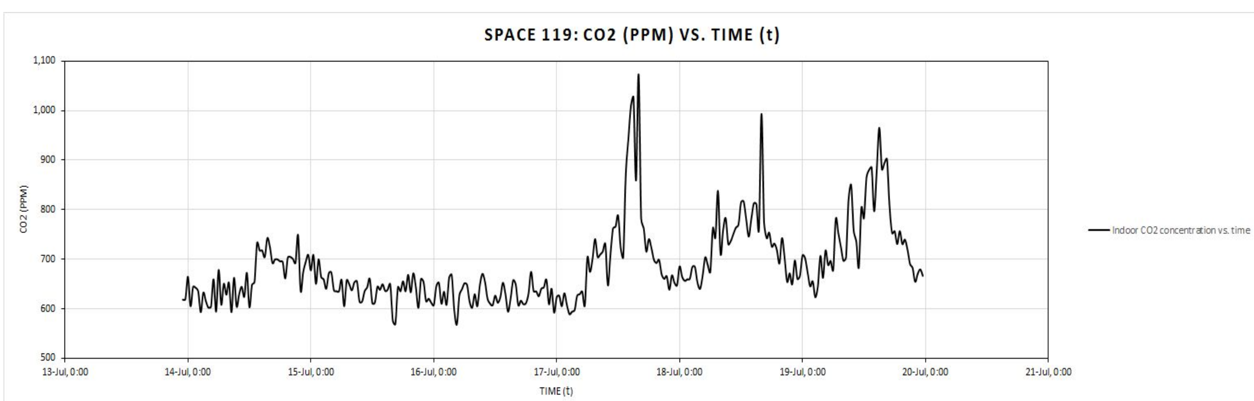

Fig. 11:: CO2 levels in space 119 before the duct cleaning.

HOBOs			
Space	**Temp, °F**	**RH, %**	**CO2, ppm**
113	80	41.83	836
119	**89.32**	**41.39**	**1,072.00**
150	77.2	49.26	790
184	75.9	51.06	747

Fig. 12: CO2 levels in different spaces of PKM.

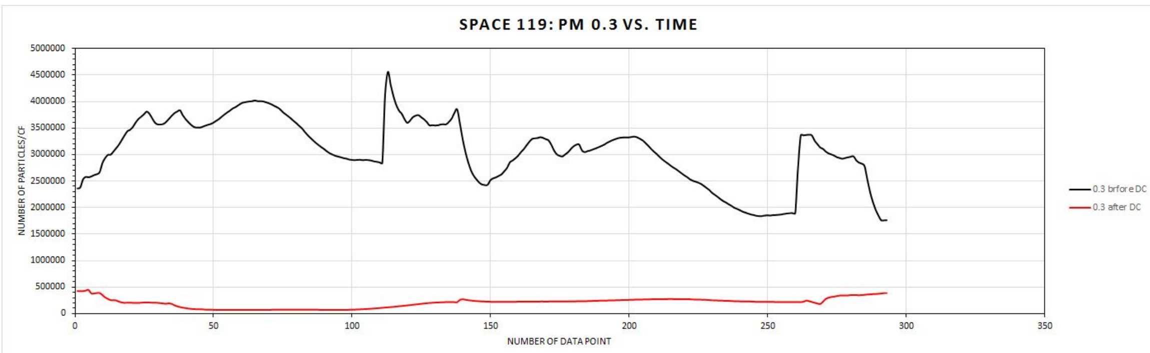

Fig 13: PM 0.3 concentration in space 119.

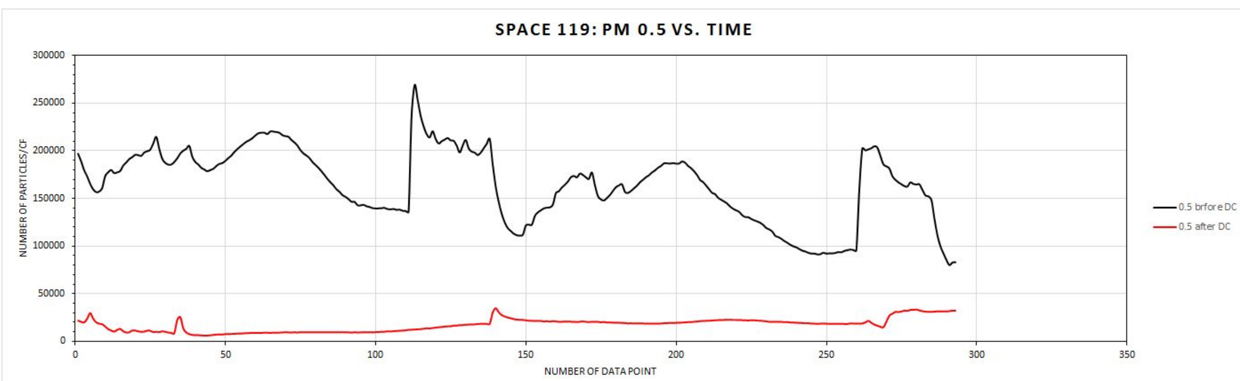

Fig 14: PM 0.5 concentration in space 119.

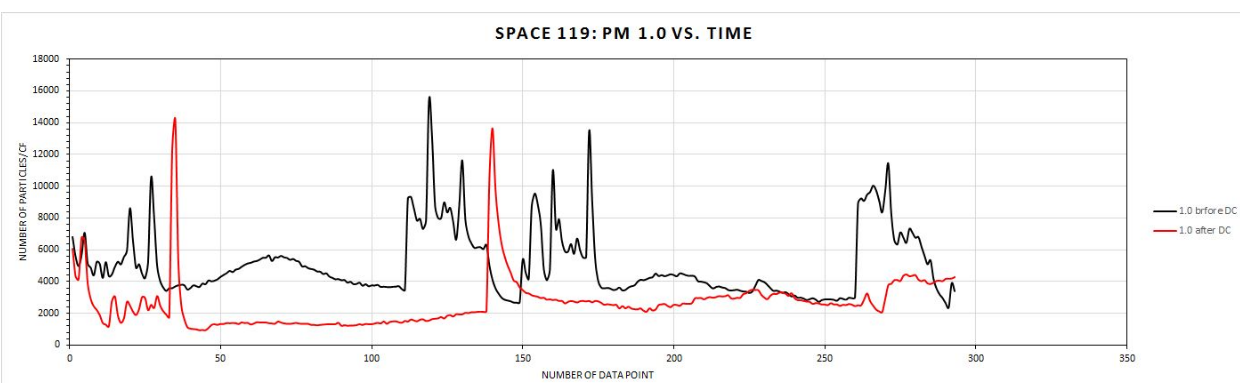

Fig 15: PM 1.0 concentration in space 119.

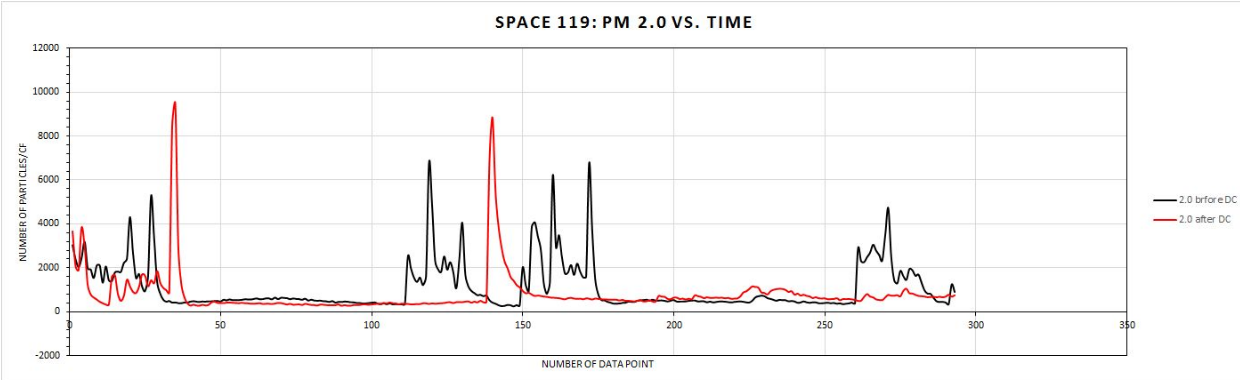

Fig 16: PM 2.0 concentration in space 119.

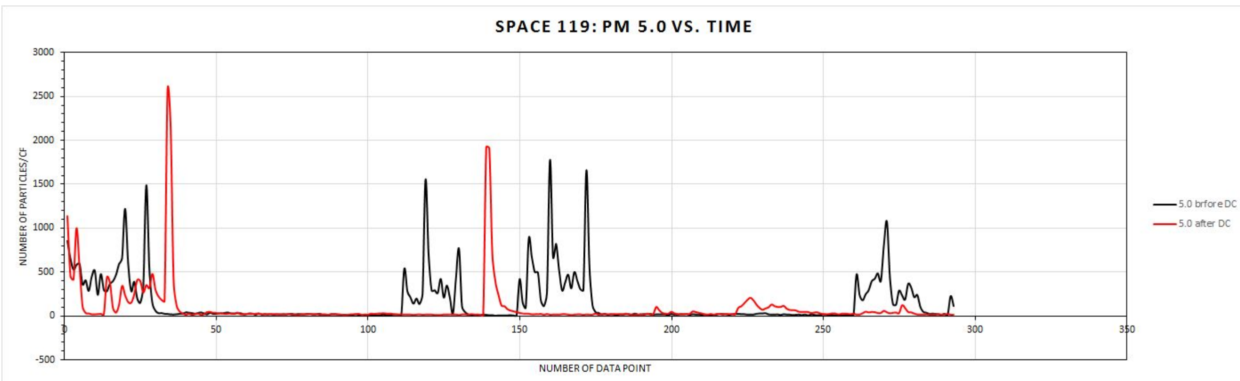

Fig 17: PM 5.0 concentration in space 119.

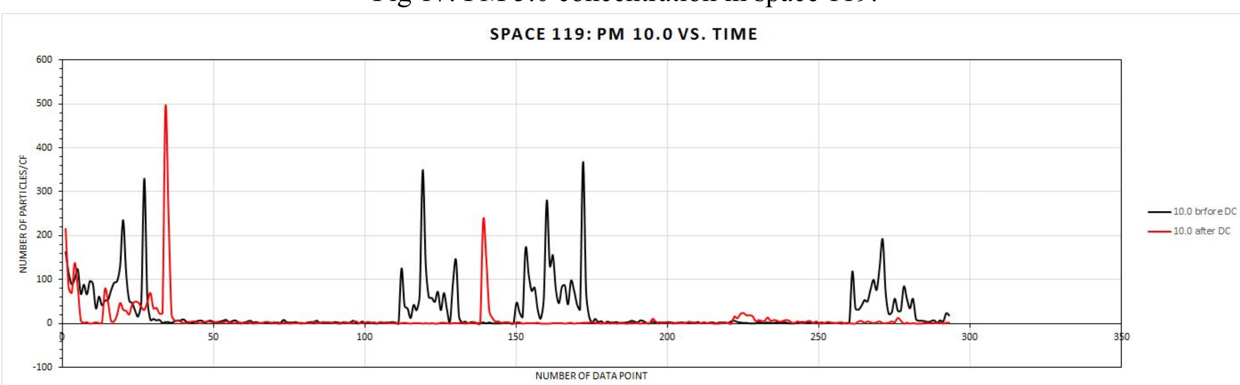

Fig 18: PM 10.0 concentration in space 119.

Discussion

After taking temperature and relative humidity readings before and after the duct cleaning process, we have not noticed any significant improvement in temperature and relative humidity after the duct cleaning. See Fig. 5,6,7, and 8. The Kestrel's readings also shows that the average indoor temperature in zone B is always much higher than zone B. The main reason for this temperature difference is the sun effect. Figure 2 shows the solar path on PKM building. It is obvious that the sun hits the walls of zone B more than zone A in a sunny summer day. The CO2 levels have not changed or improved due to duct cleaning. On the other hand, The PM data shows significant improvements in the indoor air quality. Figures 13, 14, and 15 indicates the high reduction of small particulate matters like PM 0.3, PM 0.5, and PM 1.0. This improvement may lead to significant occupant comfort improvement.

The duct cleaning improves the indoor air quality in occupied buildings. It is required by ASHRAE to inspect the ducts annually and clean them as needed. We have not noticed any improvement in indoor temperature, CO2 or relative humidity associated with the duct cleaning process. However, we have seen a huge improvement in the fine particulate matters (PM 0.3, 0.5, 1.0) after the duct cleaning. We have noticed that the amps readings have increased for the supply and return fans after the duct cleaning. Increasing the amps reading indicates that the energy usage will increase after the duct cleaning. This indicates that more ventilation after the duct cleaning.

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