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A Comprehensive Review of the IEQ and Energy Savings Impact of Dynamically Varying Air Change Rates in Labs and Vivariums

The greatest single approach for reducing energy use in vivariums is to reduce or vary the room air change rates.

In the last few years, the concerns about global warming and the interest in reducing an organization's carbon footprint have increased significantly, as well as concerns over the cost of energy and the increasing volatility of energy prices. For most organizations, facilities have the greatest impact on carbon emissions and energy expenditures and as such have been receiving increasing scrutiny with regard to reducing energy usage. For organizations such as universities, pharmaceutical companies, and other life sciences organizations, labs and even more so vivariums are at the top of the list regarding energy usage. A recurrent theme from a recent conference on vivarium facilities was that the greatest single approach for reducing energy use in vivariums was to reduce or vary the room air change rates. Thus, the safe reduction or variation of air change rates in vivariums and also labs represents for most life sciences organizations the greatest single method for reducing their energy consumption and carbon footprint. Unfortunately, heretofore very little objective data has been available on the environmental and energy savings impact of both reducing and varying air change rates in labs and vivariums. This article attempts to address this data gap with the results of a major research study that generated a significant amount of objective data on the indoor environmental quality (IEQ) conditions of labs and vivariums that are using dynamic control of air change rates.

Before reviewing this study, it is important to first understand how air changes can be safely reduced in both labs and vivariums. One proven approach that was discussed in a previous article in *ALN Magazine*[1] is by dynamically varying air change rates based on the air quality level or "air cleanliness" of the lab or animal rooms.

In a large majority of labs (particularly life sciences labs) and vivariums, the air flow is often dictated by the minimum air change rate for the space, which might be 12 to 20 ACH in a vivarium or 6 to 12 ACH in a lab room. Although high thermal loads or the heavy use of fume hoods or animal racks with heavy makeup requirements can sometimes drive the room airflow rates, oftentimes it is the minimum ventilation rate that determines the air flow. However, if the air in these rooms is "clean" or free of any harmful or irritating contaminants that the minimum air change rate is intended to dilute, then a high air change rate is not needed, at least for when the air is clean.

As such, one approach that has been shown to effectively and safely vary air change rates in labs and vivariums is to sense the quality of the air for such contaminants as volatile organic compounds (VOCs), ammonia, plus some other chemical vapors and odors, as well as particulates. When the room air is free of these contaminants, then the air change rate in the vivarium can be reduced to, for example, 6 ACH, or if it is a lab room to for example 4 or even 2 ACH.

In order to economically and reliably accomplish this sensing of environmental conditions in many labs and vivarium rooms within a facility, the aforementioned article in *ALN Magazine*[1] described a sensing architecture known as multiplexed sensing. With this approach, one central set of sensors is used in a multiplexed fashion to sense not one but many different rooms or areas. Thus instead of placing multiple sensors in each of the rooms to be sensed, this networked system routes packets or samples of air sequentially in a multiplexed fashion to a shared set of sensors. Every 40 to 50 seconds, a sample of air from a different area is routed through a common air sampling backbone consisting of a hollow structured cable to the centralized set of sensors, known as a sensor suite, for measurement. These sequential measurements are then "de-multiplexed" for each sampled area to create distinct sensor signals used for traditional monitoring and control. Typically 15 to 20 areas can be sampled with one set of sensors approximately every 15 minutes depending on the requirements for those spaces.

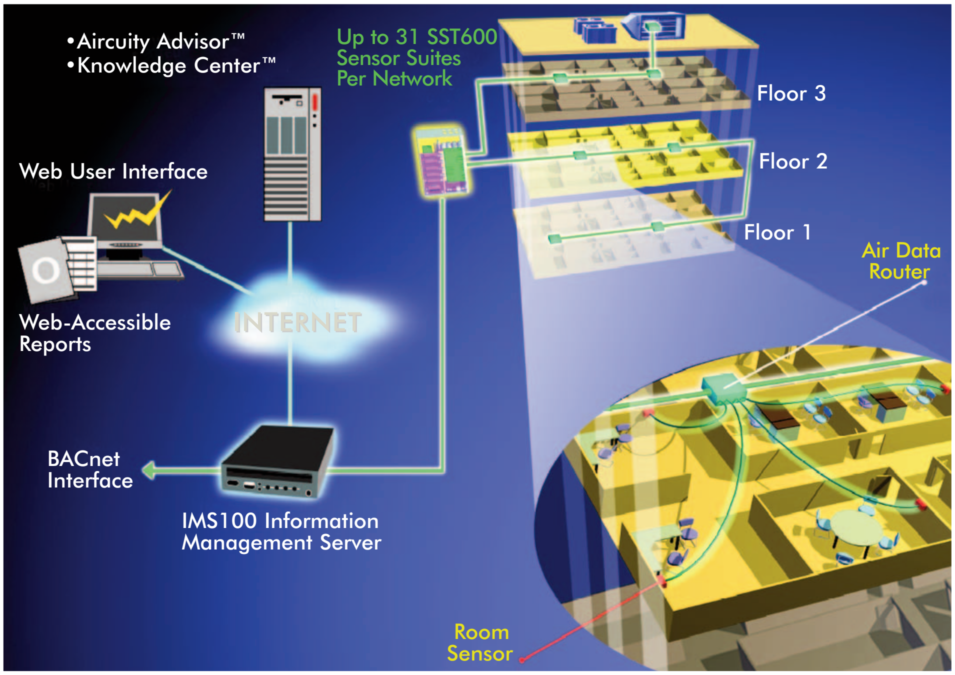


Figure 1: Facility-wide Sensing Architecture

This multiplexed sensing approach (Figure 1) can measure almost any air parameter of interest. For laboratories, the use of a photo-ionization detector type (PID) of Total Volatile Organic Compound (TVOC) sensor is very beneficial for accurately detecting literally hundreds of commonly used laboratory chemicals that can volatize and become a safety concern. Additionally, other non-organic compounds such as ammonia, which is of interest in animal rooms, can also be detected with a PID sensor. Other TVOC sensors such as metal oxide (MOS) sensors can also be used in addition to the PID sensor for even broader detection of chemical contaminants. Combining this sensor with a laser-based particle counter allows the identification of particles which can be used as a proxy for animal allergens in a vivarium as well as for detecting aerosol vapors. Finally, other sensors such as carbon dioxide sensors and more importantly accurate dewpoint or humidity sensors can also be used to sense the lab and vivarium rooms for other control and monitoring purposes.

Methodology and Background of the Study and Data Analysis

In addition to being used for control purposes, the multiplexed sensing system of Figure 1 also sends its sensing data to a password protected website to be archived and made available for review and analysis purposes by facilities and other qualified personnel. One use of this information is to assess the environmental and energy savings impact of dynamically varying air changes in a specific facility. However, in order to get a broader view of the efficacy of this concept across not just one, but many facilities; a comprehensive research study was undertaken to analyze the archived data from many different lab and vivariums sites.

This study was conducted using environmental data from 18 different lab and vivarium sites across the U.S. and Canada. Of these sites, six were from the East Coast, seven from the Central U.S., three from the West Coast, and two from Canada. These sites consisted primarily of life sciences and biology-related areas as well as a smaller amount of chemistry and physical sciences lab areas. Three of the above sites involved animal facilities which were broken out as a separate group. Almost all of the lab facilities involved spaces with moderate or low density of fume hoods. In all, over 300 lab and vivarium rooms were involved in the study providing a large cross-section of different lab room environments that were analyzed.

Regarding the scope of the study, approximately 1,500,000 operating hours of lab data and about 100,000 hours of vivarium data were analyzed. Put in other words, if only one lab room was studied versus over 300, this amount of operating hours would have spanned over 18 decades. The data from the various sites was for different lengths of time depending on when the site came online. In general, data was analyzed for lab operation in a range starting in the early fall of 2006 and continuing till early January of 2009. In total, over 20 million sensor values were collected and analyzed including data on TVOCs, particles of a size range of 0.3 to 2.5 microns, carbon dioxide, and dewpoint (absolute humidity). Specifically, this article will focus only on the

Figure 2: Average TVOC Level Percentages over Threshold (1.5M hours of Lab Operation)

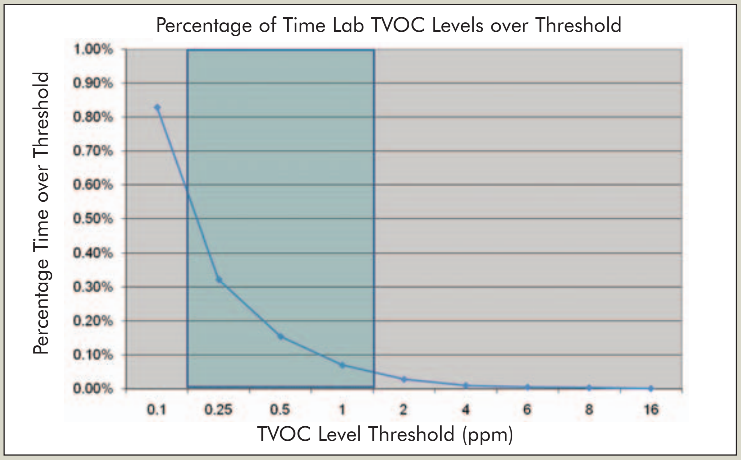


Figure 3: Typical Control Relationship between TVOC Values and Commanded Airflow

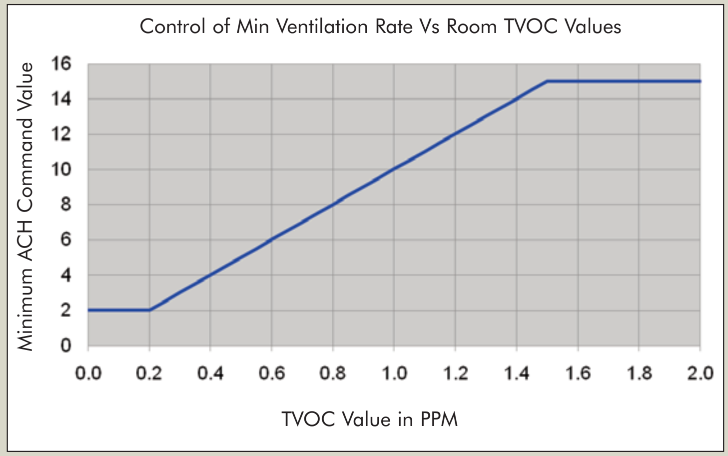


Figure 4: Number of Short TVOC Events per Week for an Average Lab Area

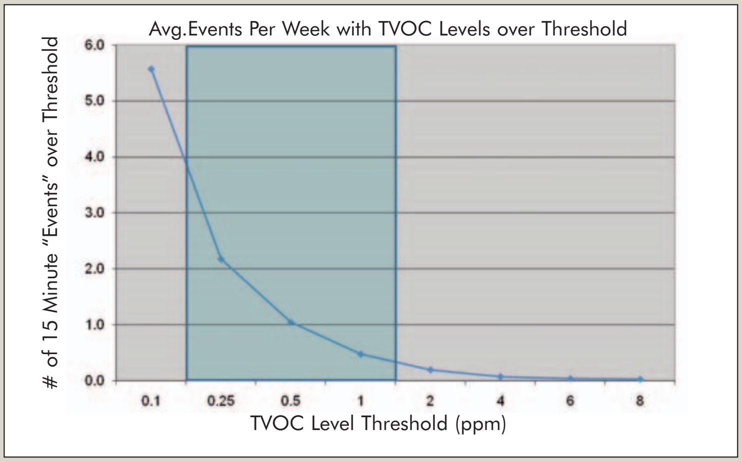
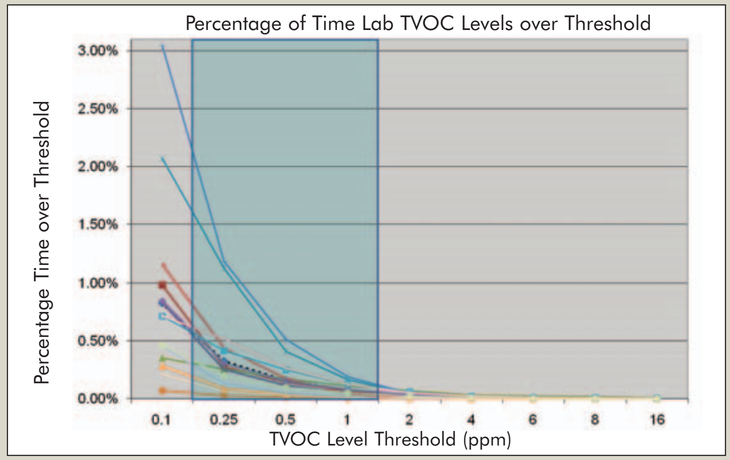


Figure 5: Average TVOC Level Percentages for Multiple Lab Sites (1.5M lab hours)



data collected on TVOCs and particulates since this data is most directly related to the dynamic control of air change rates.

For both particles and TVOCs, most measurements were taken as differential measurements of the room conditions minus the environmental conditions of the supply air feeding the lab or vivarium. This was done to significantly reduce potential effects of any sensor drift as well as to subtract out any impact of the outdoor conditions on the measured room conditions. Since all measurements were taken using a multiplexed sensing system, the measurements of both the room conditions and the supply air feeding these rooms were taken with the same sensor, thereby creating an accurate differential measurement.

To simplify the analysis, all sensor data was put into bins representing the number of counts or times that a parameter exceeded a specific threshold level corresponding to that bin. For example, the TVOC data was sorted into nine bins representing the number of times or counts that the threshold values of 0.1 PPM, 0.25 PPM, 0.5 PPM, 1 PPM, 2 PPM, 4 PPM, 6 PPM, 8 PPM, and 16 PPM were exceeded respectively. The data was then normalized based on the total number of data points or counts to generate the percentage of time the data exceeded the bin value thresholds. When these values are graphed, they form a cumulative graph showing the percent of time that each bin value was exceeded. Note that on average, a data value is usually taken about every 15 minutes, so four counts or data values typically represent an hour of elapsed time.

Regarding the average air change rates of the labs involved, generally the typical "clean" or minimum rate was between 2 and 6 air changes based on the specific site involved. When significant levels of TVOCs or particles were sensed, the commanded purge rates of air flow typically were between 12 and 16 ACH based again on the site involved. Regarding the vivariums, the reduced flow rates varied between 6 and 10 ACH when the rooms were sensed to be "clean" and the commanded purge rates when significant contaminants were sensed varied between 15 and 20 ACHs. Note that airflow rates higher than the minimum flow rates mentioned above may have also occurred occasionally even if the lab rooms were "clean" due to VAV fume hoods that may have been opened or cooling loads that demanded additional airflow.

Review of the Lab Room Data

Figure 2 shows a graph of the average TVOC levels over all of the lab locations representing about 1,500,000 hours of operating data. As mentioned

Figure 6: Percentage of Time that Small Particle Levels Exceed Threshold (1.5M lab hours)

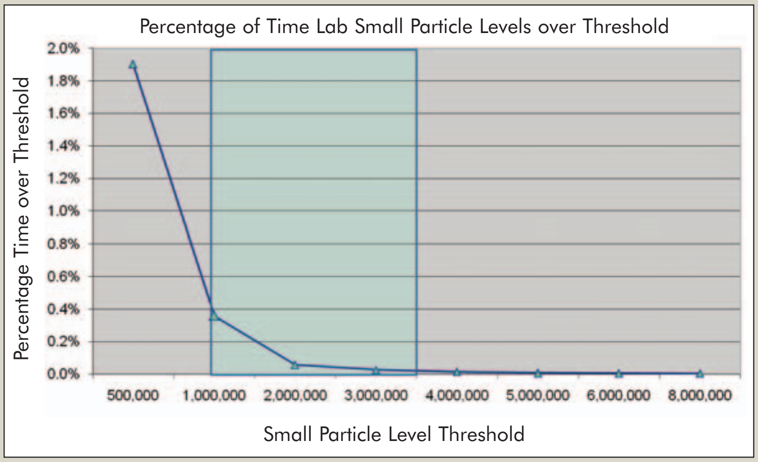


Figure 7: Percentage Time Particles Graph for Multiple Lab Sites (1.5M Operating Hours)

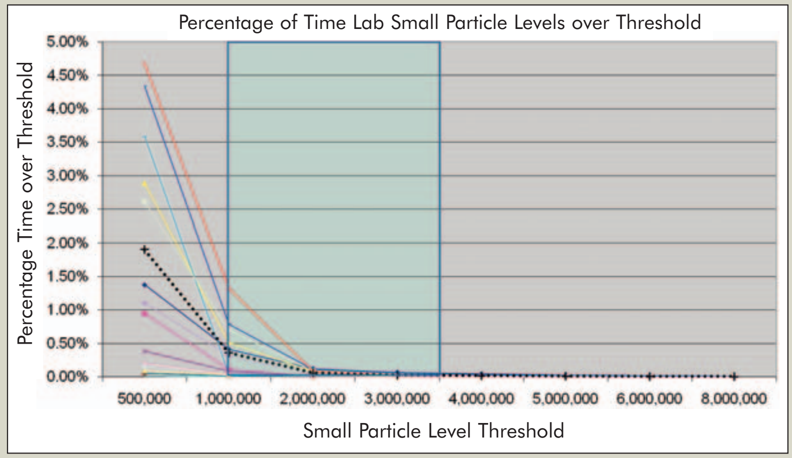


Figure 8: Average TVOC Level Percentages for Multiple Vivarium Sites (100K Hours)

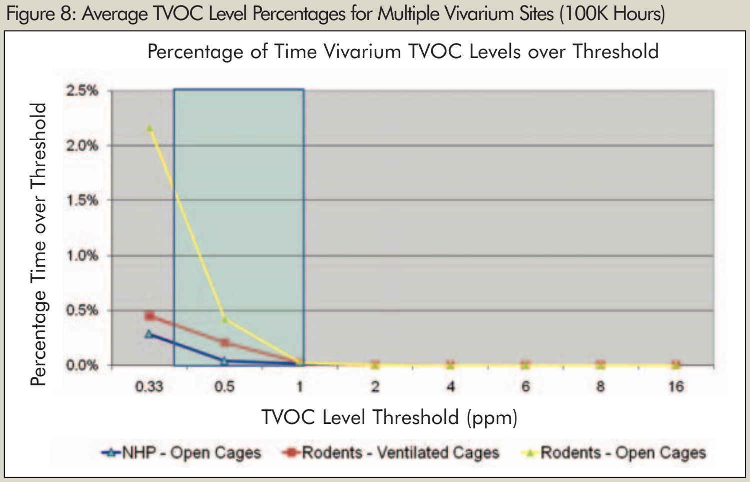
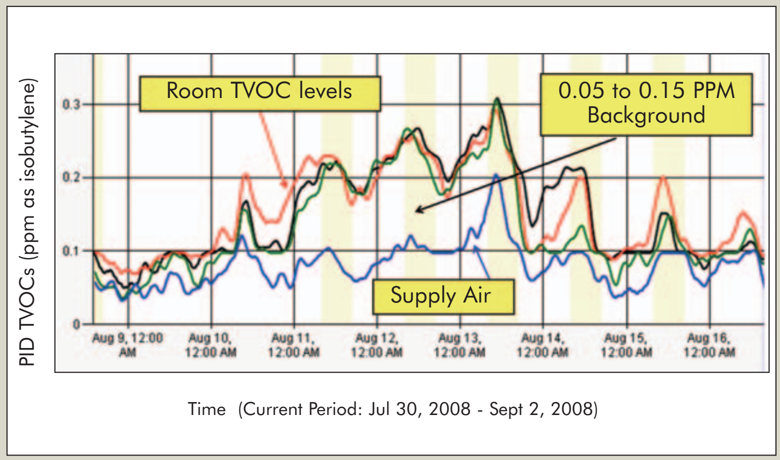


Figure 9: Typical Background TVOC/Ammonia Levels for Non-Ventilated Rodent Cage Rooms



previously, this is a cumulative graph so that the value of 0.84% at 0.10 PPM means that on average this is the amount of time that a lab location has a TVOC value greater than or equal to 0.1 PPM. Since this represents the average, some locations can be much higher than this and others potentially near zero. However, the average gives a good idea of the potential energy savings across all these different locations.

The highlighted green area on the graph in Figure 2 represents typical values for where the dynamic control of air changes operates in a proportional control fashion. For the indicated example, below about 0.2 PPM, there is no override of the room airflow. At 0.2 PPM[2] and above, the override of the minimum air change rate starts to occur with a maximum command value of 15 ACH reached when the sensed TVOC value reaches 1.5 PPM. This typical control relationship between the sensed TVOC values in a room versus the generated command for the minimum ventilation rate is shown in Figure 3.

As can be seen in Figure 2, labs are typically “clean” of most chemical contaminants about 99.5% of the time. As such, this means that energy can be saved by operating at reduced minimum air change rates up to about 99.5% of the time in labs at least with respect to the TVOC sensor.

Looking at this same data in another light, Figure 4 takes the data of Figure 2 and displays it in terms of approximately how many TVOC events occur in an average week in one of the lab room locations. Most TVOC events where chemical vapors are sensed in a lab room typically vary in duration from about 15 to 90 minutes, although the more common small events are often 15 to 30 minutes long. For the purposes of the graph, the total amount of time that the average TVOC event lasts was assumed to be 15 minutes. Therefore for events over about 0.2 PPM, there are typically about four of these events or about one hour of total time per week on average that the TVOC sensor senses over 0.2 PPM.

To demonstrate the variations in this data between different sites, Figure 5 shows the same TVOC graph but with each of the lab sites shown as a separate line with the average curve shown by the black dotted line. Note that even at the site with the greatest amount of TVOC activity, the dynamic control concept can still save energy about 98% of the time with almost four hours of time during which the minimum room ACH rate is safely increased to respond to TVOC based events.

Another parameter that can cause an increase in the minimum air change rate is an increase in particles in the lab due for example to a reaction that may go out of control or an acid spill that causes an evolution of smoke or an aerosol into the lab room. Figure 6 shows a graph of the average level of 0.3 to 2.5 micron particles that exceeds a background level of the lab room's supply air. Typically about 1.0 million[3] particles a cubic foot (pcf) is used as the threshold for increasing the minimum air change rate.

As can be seen in Figure 6, the average lab room is above the 1 M pcf threshold almost 0.4% of the time or about 30 minutes a week on average. If this amount of time is added to the amount of time that TVOCs are above the control threshold, this comes to total of almost 1.0% of the time. In other words, energy can be saved by a total of up to about 99.0% of the time taking into account both TVOC and particle contaminants.

To provide more detail on the variation in particle data across sites, Figure 7 shows the same data but with the individual sites represented by separate lines. The average value across all sites is shown as the black dotted line for reference. This data shows a similar level of variation compared to the TVOC data. Again however even with the worst case site in terms of the sum of the TVOC and particles percentages, the largest total is still about 2% or 3.5 hours a week.

Review of the Vivarium Room Data

For vivariums, data was collected on three sites that had effectively worst case conditions for dynamic control of air changes. These consisted of one site with open, unventilated rodent cages, another with ventilated rodent cages that were exhausted into the vivarium room, and finally a site with non-human primates (NHP) housed in open cages. The total data of these three sites consists of about 100,000 operating hours.

Figure 8 shows the individual TVOC data for the three sites. As might be expected, the highest TVOC levels were for the rodents in the non-ventilated cage racks. Interestingly, the NHP rooms were the cleanest in terms of TVOCs and ammonia. Note that the multiplexed sensing system also responds to ammonia at a response factor of approximately 10 to 20. In other words, a value of 0.1 PPM from the PID TVOC sensor if generated solely by ammonia would represent a level of about 1 to 2 PPM. A typical control range for vivariums would range from about 0.4 PPM to 1 PPM corresponding to a command for 6 ACH and 15 ACH, respectively. As such, this shows the opportunity to save energy in these vivariums is very high, with the worst case site, the non-ventilated rodent cages potentially requiring extra airflow on average only 1.5% of the time, at least based on TVOC levels.

Specific TVOC data for a few of the rooms with rodents in non-ventilated cages is shown in Figure 9. The difference between the blue supply air line and the red, green, and black room TVOC lines represents the TVOC/ammonia levels in those rooms created by the animals. The gradually increasing TVOC/ammonia level in these rooms starting at about August 9 followed by a decrease in the levels at about August 14th and 15th shows the increase in TVOC and ammonia levels between cage changes. If the increase with respect to the supply air levels was solely related to ammonia, this might correspond to a variation in ammonia levels of up to about 1.5 to 3 PPM.

The next set of data as shown in Figure 10 is the data for particles across the different vivarium sites. Overall, the average levels are again low for all cases at no more than about 1.2% for the NHP rooms, so again the ability to reduce air changes when the air is clean and has low levels of particulates occurs about 99% or more of the time on average, providing a significant opportunity for energy savings from lower air change rates.

Figure 11 shows some of the specific site data from the non-human primate rooms that points out the reason for the high particle levels in this facility. Note how the indicated particles spikes match up in time and in room location (different colors) with the large dewpoint/humidity spikes. This information indicates that the cages were being cleaned during these periods, throwing a lot of particulates into the air as a result. Automatically increasing the air change rates during the cage cleaning process helps keeps particle levels lower and clears the room more quickly of excess particles, animal dander/allergens and moisture. Additionally, this also allows lower air change rates for the far majority of time that the cages are not being cleaned.

Finally, Figure 12 shows some other interesting site data, namely the impact of filtered laminar flow benches on cleaning the air and reducing room particle levels. As can be seen in the graph, there are periodic drops in particle counts caused by turning on the laminar flow benches for either animal cage changes or work on the animals.

Summary and Conclusions

The largest and most comprehensive study to date of the impact of varying air change rates on lab and vivarium IEQ conditions and energy savings was recently completed. This study involved about 1.5 million operating hours of recorded data representing over 20 million sensor values from over 300 lab spaces and 18 sites. For laboratories, on average the lab IEQ conditions of low TVOCs and low particulates permitted the substantial reduction of air change rates approximately 99% of the time. Put in other words, the average laboratory room saw about 1.5

Figure 10: Percentage of Time Particles Exceed Threshold for Multiple Vivariums (100K hours)

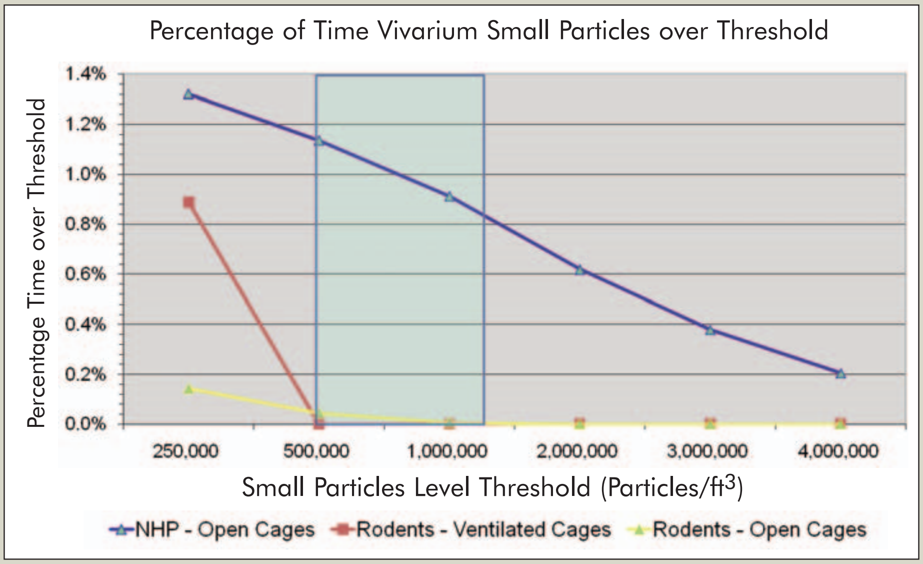


Figure 11: Impact of NHP Cage Cleaning on Room Particle and Dewpoint/Humidity Levels

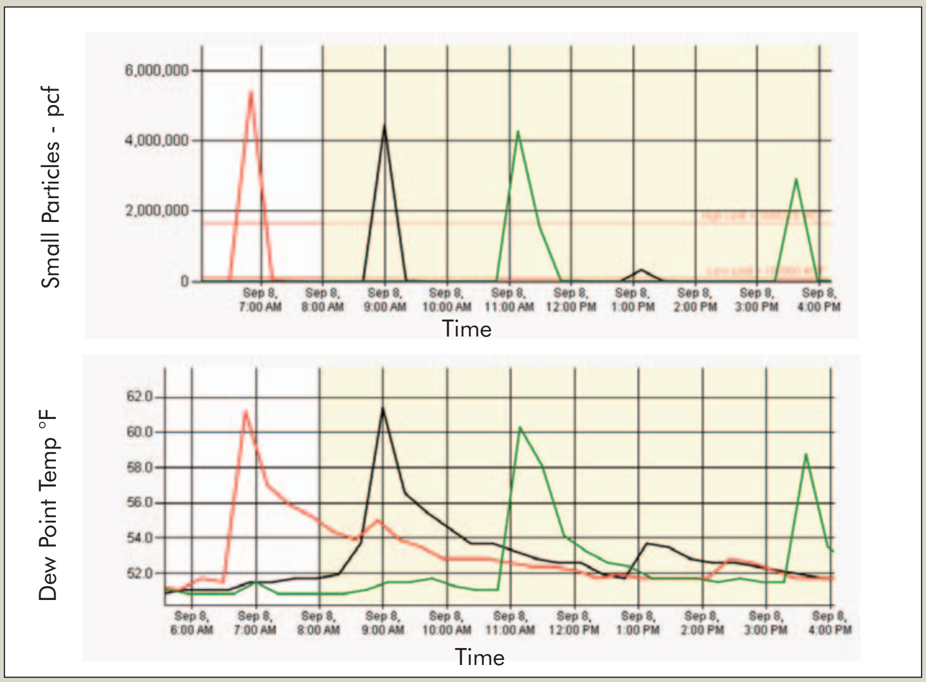
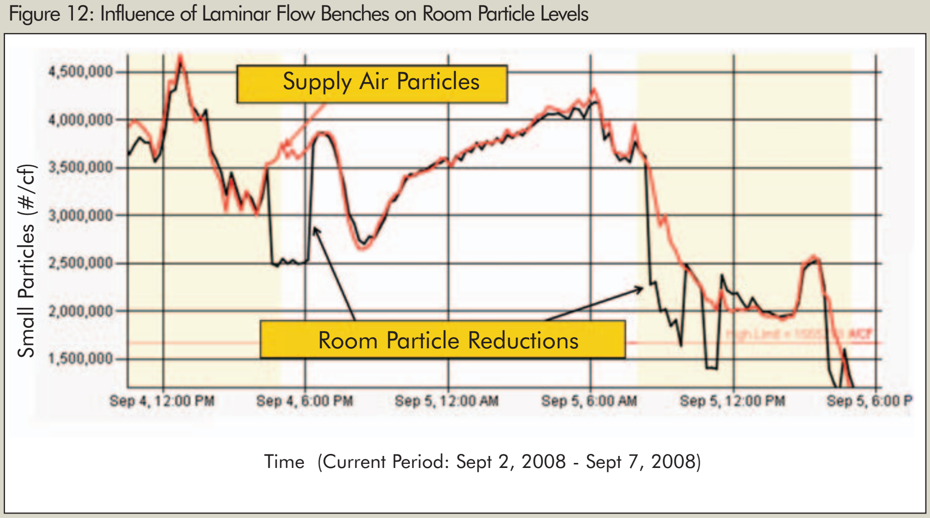


Figure 12: Influence of Laminar Flow Benches on Room Particle Levels



hours a week of IEQ conditions that required increasing the room air flow from its minimum value.

For the three types of vivariums studied, similar to labs, the IEQ conditions of low TVOC and particulate levels occurred about 98.5% of the time, again safely allowing for substantial energy savings for all but about 2.5 hours a week when higher flows were required.

With the current challenges many organizations are facing concerning reducing their carbon footprint and their usage of energy, this study provides ample evidence of the significant contribution that the dynamic variation of lab and vivarium air change rates can make towards safely meeting these goals.

References and Additional Information

1. *"Dynamic Variation of Laboratory Air Change Rates: A New Approach to Saving Energy and Enhancing Safety,"* ALN Magazine, November/December 2008.
2. Note that with respect to the TVOC values used for ACH control, the referenced 0.2 PPM minimum threshold level corresponds to the average limit value for the LEED EQ3.2 of the LEED® NC (New Construction) credit for flush-out of an office building after construction which is based on certain EPA and State of Washington requirements. This is a conservative threshold when used with labs for control of air changes since the study data in this article shows primarily infrequent short term exposures of TVOC events verses a constant level of VOCs from off-gassing of construction materials.
3. Again as a point of reference, the particle requirement for the LEED EQ3.2 average value threshold for flush-out after construction is about 1.6 million particles per cubic foot (pcf). Setting the minimum control threshold level at 1 million pcf provides a conservative threshold level for the ACH control approach.

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