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NEW APPROACHES TO SLASH LABORATORY & COMMERCIAL BUILDING ENERGY USE & IMPROVE IEQ

GORDON P. SHARP
Chairman, Aircuity, Inc.
55 Chapel St., Newton MA 02459, USA
gsharp@aircuity.com

ABOUT THE AUTHOR

Gordon Sharp, chairman of Aircuity Inc., has over 25 years of experience and 25 patents in energy efficiency, IEQ (Indoor Environmental Quality), and laboratory controls. As founder and CEO of Phoenix Controls, he led this laboratory airflow controls leader that was acquired by Honeywell in 1998. In 2000, Gordon founded Aircuity, a smart airside energy efficiency company. Gordon is a MIT BSEE and MSEE graduate, ASHRAE Distinguished Lecturer, and Executive Vice President and a Director of I2SL, the International Institute of Sustainable Laboratories. He is also a voting member of ASHRAE Standard 170 on Healthcare Ventilation, and ANSI Standard Z9.5 on Laboratory Ventilation.

ABSTRACT

In the face of significant energy costs and concerns over global warming, buildings are receiving increasing scrutiny to reduce their carbon footprint and cut their energy expenses. For many buildings and particularly in laboratory facilities, outside air is the largest single driver of both energy efficiency and indoor environmental quality (IEQ). This paper will discuss and provide case studies of a demand control approach for laboratories that can reduce laboratory building energy use by 50 per cent while also improving its IEQ. A cost-effective approach for implementing this method through direct, real time sensing of laboratory room air quality will also be described. Additionally, the results will be shown for the largest study ever done of laboratory IEQ conditions covering over 1.5 million hours of laboratory operation. Finally, this demand control concept can also be applied to other types of facilities such as office buildings, educational facilities, public buildings and healthcare facilities.

INTRODUCTION

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.

Specifically, this paper will focus on the results of research that represents what is believed to be the largest study ever done of laboratory IEQ conditions covering over 1.5 million hours of laboratory operation from labs and vivariums that employ demand based control of air change rates or real time sensing and control of Laboratory IEQ. In total over 20 million sensor values were collected and analysed including data on Total Volatile Organic Compounds (TVOC’s), particles of a size range of 0.3 to 2.5 microns, carbon dioxide, and dewpoint (absolute humidity). This study of over 300 laboratory areas at 18 different facilities indicates that although laboratory events occur on a regular periodic basis requiring an increase in air change rates to purge levels, on average, air flow can be maintained at minimum levels of 2 to 4 Air Changes per Hour (ACH) for over 97 to 98 per cent of the time while still providing excellent IEQ.

1. METHODOLOGY

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 laboratory 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, often times 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 (VOC’s), ammonia, plus some other chemical vapors and odours, 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 4 to 6 ACH for example, or if it is a laboratory room to 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, a novel sensing architecture known as multiplexed sensing was used in this study. 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 centralised 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. A variety of different types of sensors can be used to analyse the air samples for multiple air parameters. Figure 1 shows an example of the architecture of the multiplexed sensing system used to implement the study.

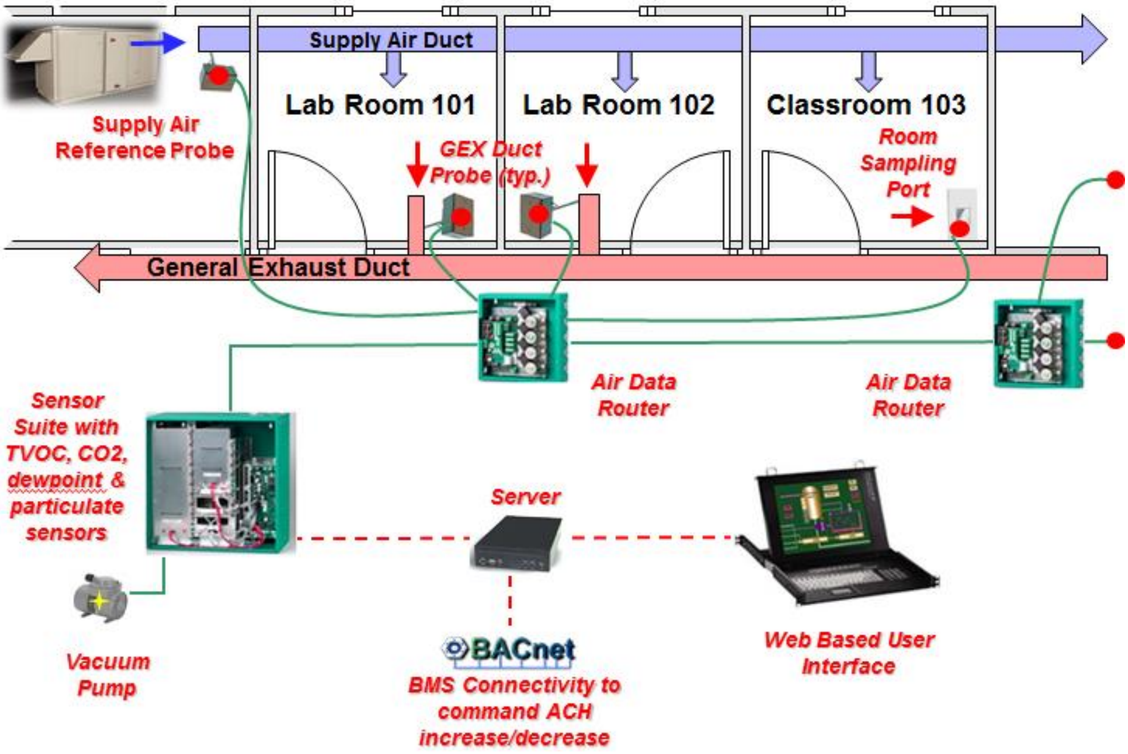


Figure 1. *Multiplexed sensing architecture for Demand Based Control*

In addition to dramatically reducing the number of sensors needed to implement this concept such as by a factor of 15 to 20, this multiplexed sensing concept has another advantage over using individual sensors. Typically for controlling the laboratory room space airflow and IEQ, it is best to look at the contaminant levels in the room differentially. In other words, we typically want to subtract the contaminant levels seen in the supply airflow from the exhaust or room levels. Thus, if the supply airflow particle levels were high for example, then we would not erroneously call for more supply flow which would just pump more particles into the room from the supply system. Dilution ventilation only works to dilute the contaminants generated in the room itself. A significant benefit of using the multiplexed sensing approach is that it can measure differential contaminant or parameter levels much more accurately and reliably than individual sensors. This is because using two different sensors, one for the room or exhaust and another for the supply levels can actually double the sensor drift errors since one sensor could drift negative while the other could drift positive, thereby doubling the error. With a multiplexed sensing system the same centralised sensor is used to measure both the supply contaminant levels as well as the room levels. Any offset drift error of the sensor will be the same for both measurements since the sensor is the same for both measurements. Therefore when the differential is taken and the supply level is subtracted from the room level, the offset drift error of each measurement is cancelled out. Thus, the multiplexed sensing architecture can generate much more accurate differential measurements compared to using individual sensors.

This research study was conducted using environmental data obtained from the above multiplexed sensing system from 18 different laboratory and vivarium sites representing over 300 laboratory and vivarium rooms across the US and Canada where dynamic control of air change rates was employed. These sites consisted primarily of life sciences and biology related areas as well as a smaller amount of chemistry and physical sciences laboratory areas. Three of the above sites involved animal facilities which are not reported on in this paper.

Regarding the scope of the study, approximately 1.5 million operating hours of laboratory data and about 100 thousand hours of vivarium data were analysed. Put in other words, if only one laboratory room was studied vs. 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 total, over 20 million sensor values were collected and analysed including data on TVOC's, and particles of a size range of 0.3 to 2.5 microns which are both reported on in this paper as well as carbon dioxide, and dewpoint (absolute humidity).

All particle and TVOC measurements were taken as differential measurements of the room minus the environmental conditions of the supply air feeding the laboratory 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. The data was then normalised based on the total number of data points or counts to generate the percent 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.

2. RESULTS

Figure 2 shows a graph of the average TVOC levels over all of the laboratory locations representing about 1.5 million hours of operating data. As mentioned previously, this is a cumulative graph so that the value of 0.84 per cent at 0.10 PPM means that on average this is the amount of time that a laboratory 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.

As can be seen in Figure 2, labs are typically "clean" of most chemical contaminants about 99.2 per cent of the time. As such this means that energy can be saved by operating at reduced minimum air change rates up to about 99.2 per cent of the time in labs at least with respect to the TVOC sensor. Looking at this same data in another light, on average TVOC events occur for about 1.5 hours a week or over 3 per cent of a typical 40 hour work week.

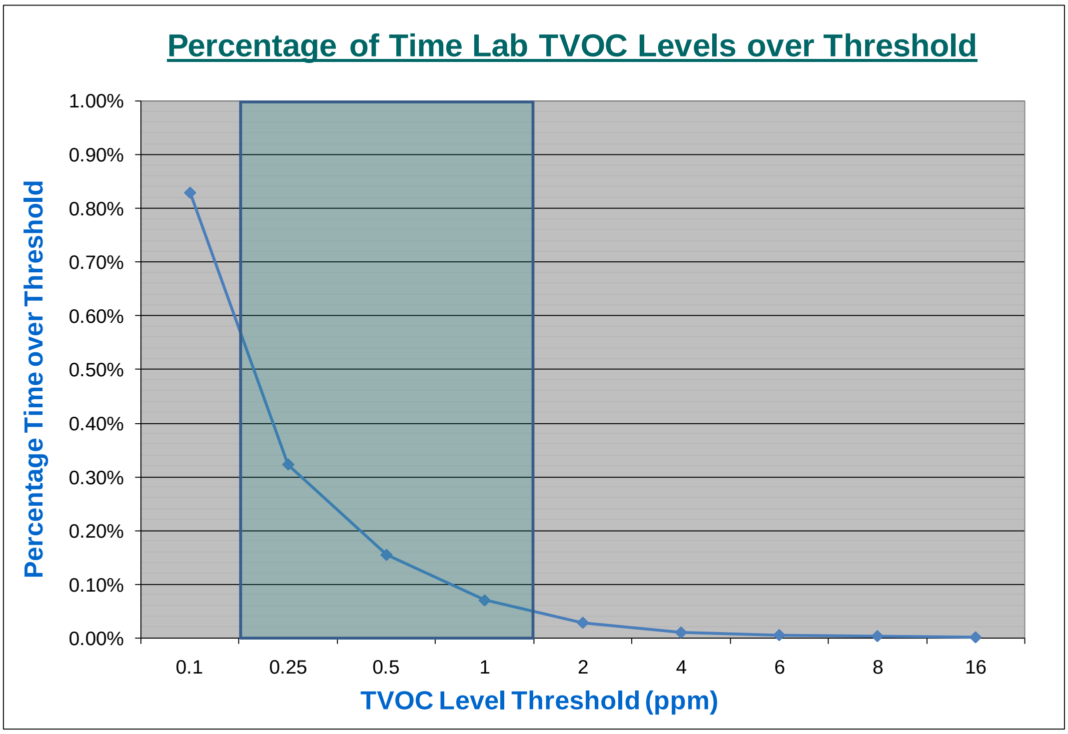


Figure 2. *Average TVOC level percentages over threshold (1.5M hours of laboratory operation)*

To show the variations in this data between different sites, Figure 3 shows the same TVOC graph but with each of the laboratory 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 97 per cent of the time with almost 6 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 laboratory 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 laboratory room. Figure 3 shows a graph of the average level of 0.3 to 2.5 micron particle counts (PM2.5) that exceeded a background level of the laboratory room’s supply air for all the different sites of the study. Typically about 35 million particles per cubic metre (pcm) or 1 million particles per cubic foot (pcf) is used as the threshold for increasing the minimum air change rate.

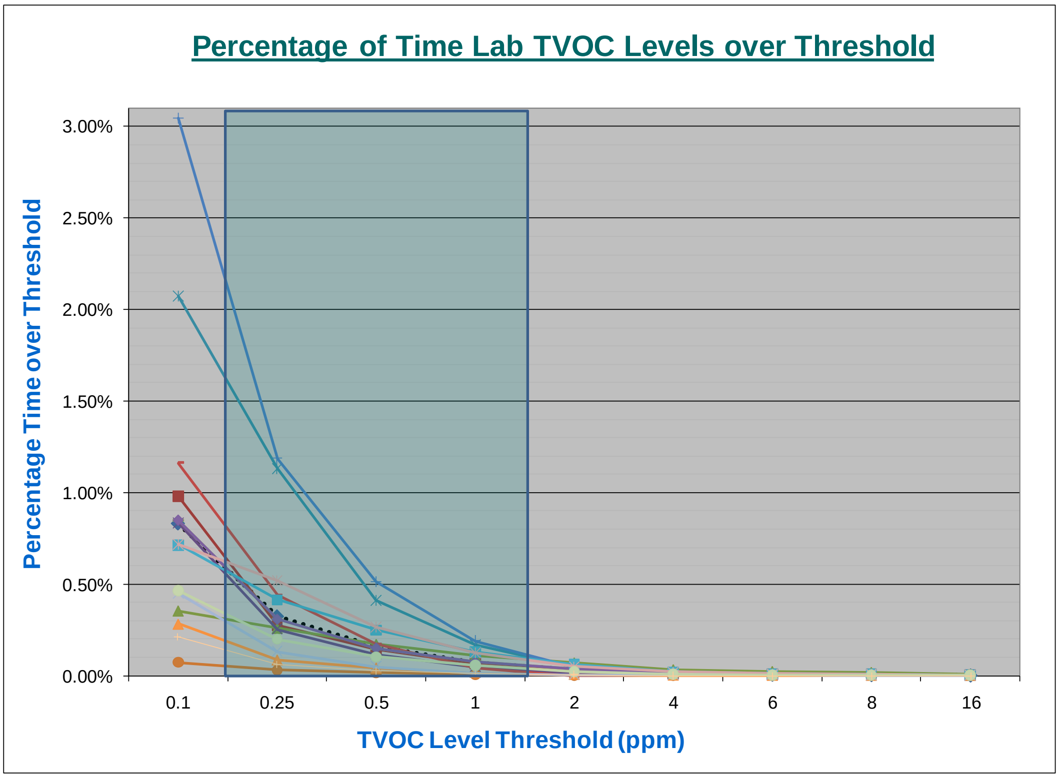


Figure 3. *Average TVOC level percentages for multiple laboratory sites*

As can be seen in Figure 4, the average laboratory room, indicated by the dotted black line, is above the 1 million pcf threshold or 35 millon pcm almost 0.5 per cent of the time or about 30 minutes a week on average. The individual sites show a range of values from near zero up to about 1.5 per cent of the time that flow should be increased based on a particle event. If this amount of time is added to the time that TVOC's are above the control threshold, this comes to total of about 1.2 per cent of the time on average or for some sites 2 to 3 per cent of the time. In other words, minimum air change rates of between 2 to 4 ACH can be achieved from 97 per cent to in excess 99.0 per cent of the time due to the presence of either TVOC or particle events occurring on average up to about five hours a week.

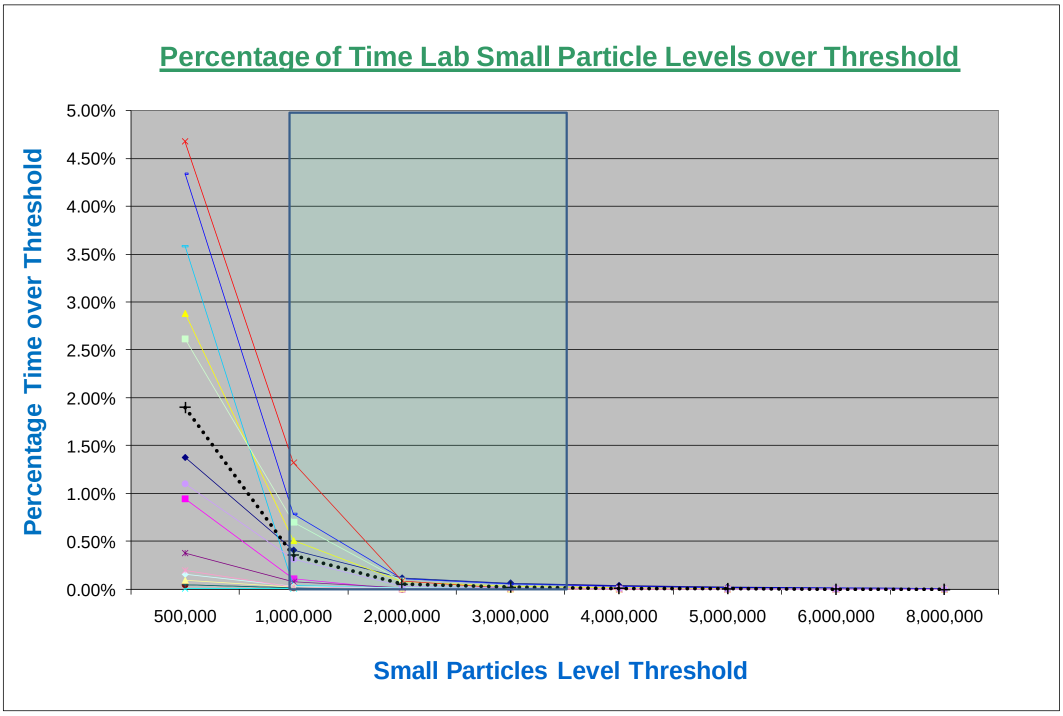


Figure 4. *Percentage of time that small particle levels exceed threshold*

3. CASE STUDIES

One case study of demand based control and multiplexed sensing is the Biodesign A & B buildings at Arizona State University in Phoenix, Arizona. These highly acclaimed facilities were R&D Magazine's Laboratory of the Year in 2006 and also achieved USGBC's (US Green Building Council) LEED Platinum certification. The building was initially designed with a minimum ventilation rate of 12 ACH. It was decided to reduce the air change rate by a factor of 3 down to 4 ACH using demand based control when the laboratory air is clean, and to increase the airflow to about 16 ACH when contaminants are sensed in the lab. This was successfully tested in a pilot project in 2007 and then implemented in 2009 in over 200 laboratory spaces and another 90 vivarium spaces. The net result of this 2009 retrofit was an energy savings of approximately $1 million annually for this approximately 35 thousand gross square metre facility. Figure 5 shows the reduction in airflow that was achieved upon implementing the demand based control in about 10 laboratory areas at ASU Biodesign Institute. Some variation in total airflow can be seen from day to day but the total average savings is quite significant with an excellent payback.

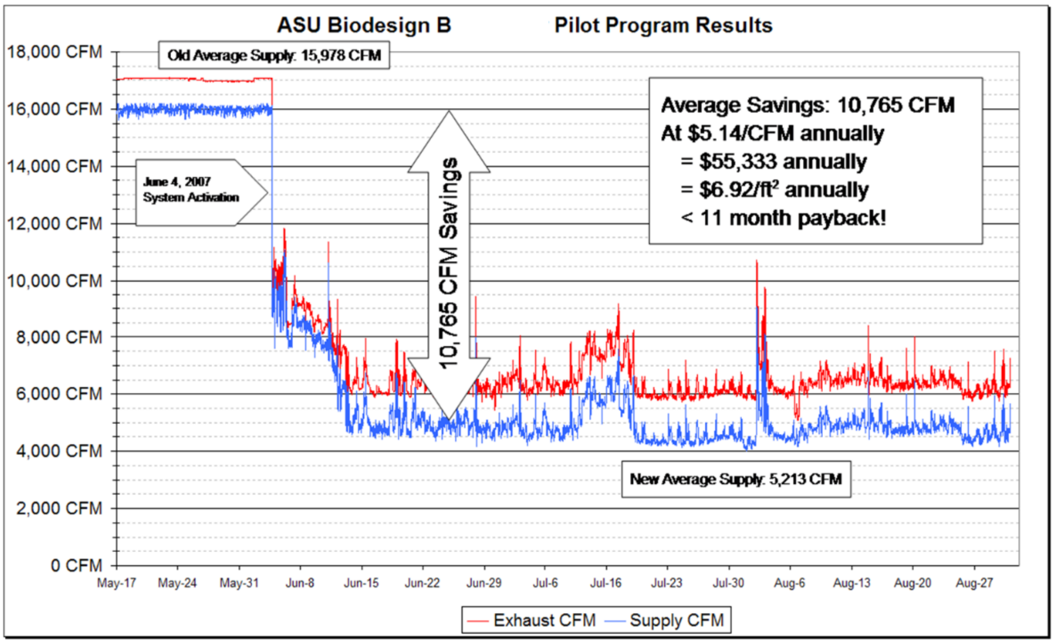


Figure 5. *Representative flow reduction from demand based control at the ASU Biodesign Institute*

Furthermore not only was energy saved but as shown in Figure 6 the IEQ of the Biodesign Institute was improved as well due to the increase in the purge airflow rates when contaminants were present in the laboratory areas. This can be seen in the lower amounts of time that various TVOC thresholds were exceeded when demand based control (dynamic ACH control) was used versus a constant minimum airflow rate of 12 ACH. Thus demand based control proved both significant energy savings and improved IEQ.

In addition to safely saving energy in laboratory and vivarium facilities, multiplexed sensing technology is also being used in non-laboratory facilities at Arizona State University such as in their offices, classrooms, library, sports arena, student centre and many other buildings where the demand control of outside air is important to save energy. In total, Arizona State University has implemented this technology approach in over 25 laboratory and non-laboratory buildings.

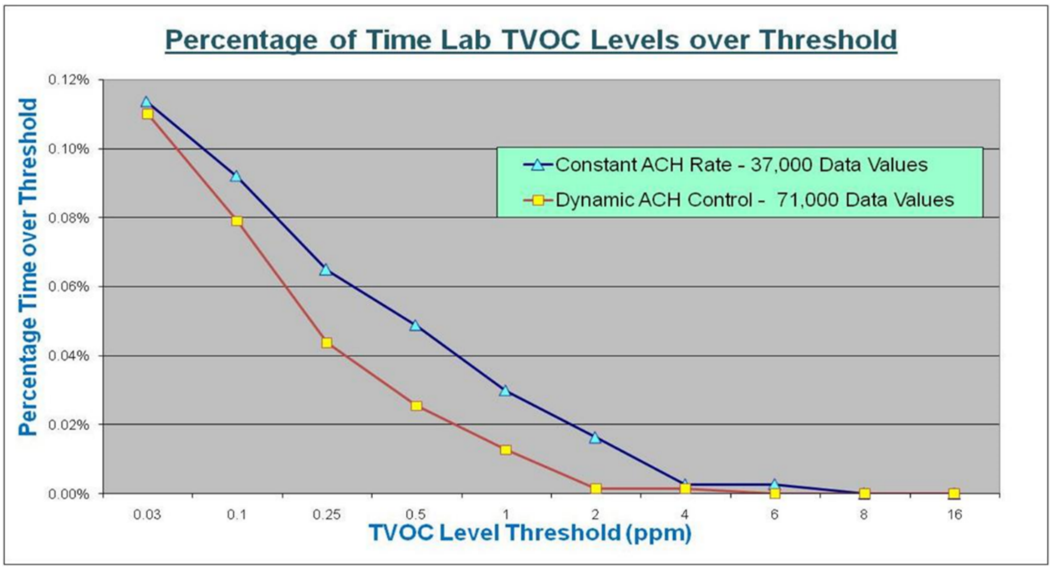
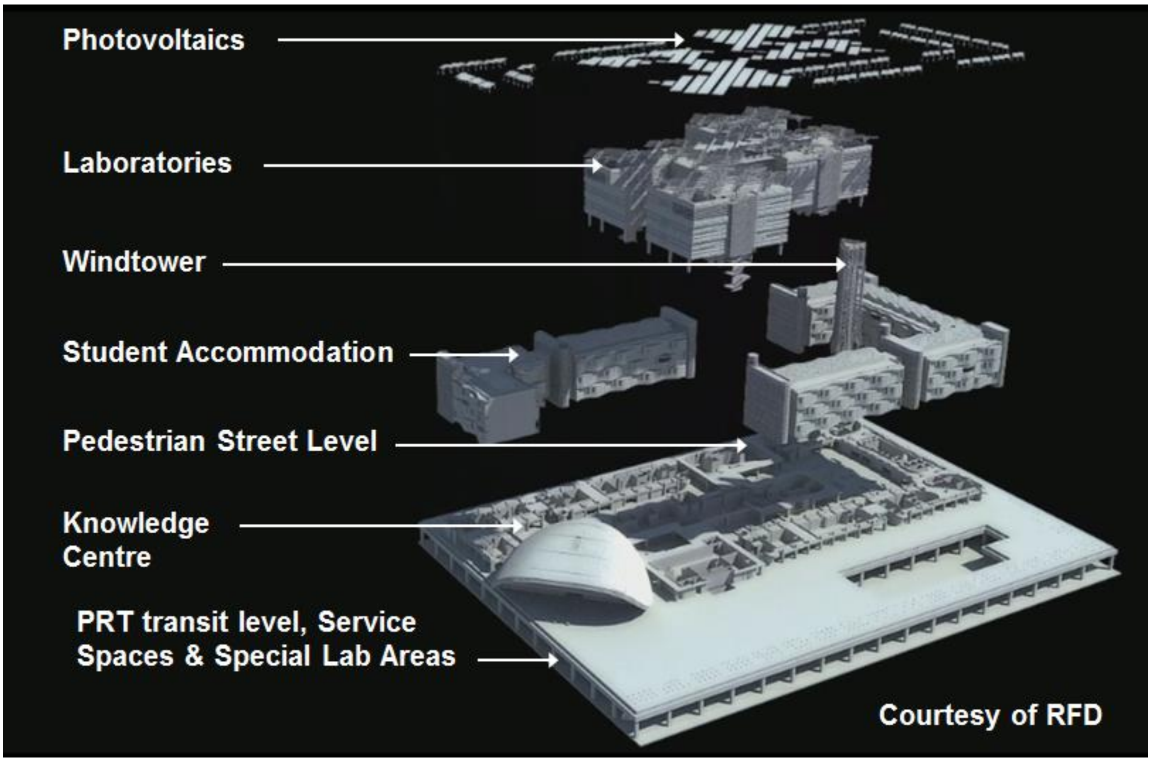


Figure 6. *Improved IEQ in the form of lower TVOC levels from demand based control (dynamic ACH) versus a constant airflow*

A second case study of demand based control is the Masdar Institute of Science and Technology or MIST which is located in Masdar City in Abu Dhabi, UAE. Designed to be one of the world's most sustainable facilities with a near net zero carbon footprint, the MIST 1A and 1B buildings comprise mixed use lab, office, classroom, and residential space over about 150 thousand sqm. The MIST 1A part of the facility is shown in Figures 7 and 8. The region experiences severe climate with both very high temperatures and very high humidity levels.

Figure 7. *MIST 1A views - Courtesy of Fosters and Partners*

MIST used demand control in its classrooms and office areas to reduce ventilation based on determining occupancy by sensing carbon dioxide. In the MIST labs, demand based control is being used in conjunction with either chilled beams or fan coil units to reduce laboratory air change rates to 2 ACH day and night when laboratory air is sensed to be clean. When contaminants are sensed purge airflow rates of as high as 14 ACH are commanded to provide greater dilution than a fixed minimum ACH rate of 6 to 8 ACH for safer operation. The lab's VAV (Variable Air Volume) fume hoods were initially designed to go as low as 150 l/s when the sash was closed, but due to the new ANSI Z9.5-2012 standard a VAV fume hood min of 45 l/s was used to further increase energy savings.



Courtesy of RFD

Figure 8. *Further detail of MIST 1A laboratory spaces*

Demand based control is providing high impact energy savings for the MIST 1A and 1B facilities of approximately 9,000MWh per year while also enhancing laboratory and non-laboratory area IEQ. Additionally, the reduction in laboratory and office airflow volumes reduced the project's HVAC capacity requirements creating a significant reduction in first or capital costs. This was achieved though downsizing the main HVAC capital equipment such as air handlers, exhaust fans, chillers, heat recovery systems, etc. Finally, the reduction of about 9,000MWh/year of energy use translated into 4 MW less of solar photovoltaic panels required to approach net zero energy capacity. This solar photovoltaic panel capital savings was alone in excess of $20 million.

CONCLUSIONS

The largest and most comprehensive study to date of the impact of varying air change rates on laboratory and vivarium IEQ conditions and energy savings was completed using a multiplexed sensing approach in buildings that implemented demand based control. This study showed that although particle and TVOC events occur upwards of a few hours a week and require high ventilation rates, much lower flow rates can be utilised with an automatic ACH rate control system for well over 97 per cent of the time. With the current challenges many organisations are facing concerning reducing their carbon footprint and their usage of energy, this research and the related case studies provide ample evidence of the significant contribution that the demand based control of laboratory air change rates can make towards safely meeting these goals.

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