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Evaluating Economizer Use in Data Centers

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ABSTRACT

An emerging technology to alleviate rising energy demands for data centers are economizers, which turn off the power consuming chillers and bring in outside air for cooling. However, contaminants in outdoor air can lower the reliability of the electronics through corrosion, which can negate any energy savings. This experiment seeks to determine if the indoor air quality of economizer systems is suitable for data center use. The mass concentrations of the particulate matter were measured both inside and outside of the data center, using aerosol instruments. Particles were captured using collection filters, to identify their chemical properties. It is shown that indoor particle concentrations rise when the economizer is operating, due to bringing in outside air. However, the concentrations are well below the ASHRAE standard, which confirms that economizer use does not pose a risk for the servers in a data center.

INTRODUCTION

Background Information

With the growth of the modern era of information technology, data centers are in high demand. Data centers are large rooms with rows of servers that serve an important role in storing information. The equipment in data centers generates an enormous amount of heat. The energy consumed in maintaining the data center interior at an operating temperature is enormous. This amounts to approximately 60 TWh/year, which is a major fraction of the country's carbon footprint [1]. Complicating this issue, data centers must run 24 hours a day, increasing their energy usage to 1.5% of the total electricity generated in the United States, and government projections predict it will increase further [2]. Chillers are a significant energy consumer in data centers, consuming a quarter of the energy use of a data center, with costs up to $100,000 per year [3] [4]. A major way to cut energy costs is to find a more effective way to cool the data center. With the current energy and environmental problems, there is increasing concern for ways to conserve energy.

Air-Side Economizers

A novel building design to reduce energy consumption is to use air-side economizers. The Lawrence Berkeley National Laboratory (LBNL) is investigating the effectiveness and cost implications of economizer technology. Economizer systems turn off the power consuming chillers and use large amounts of outside air as the cooling medium. The resulting reduction of chiller operating hours lowers the energy costs. This solution is not available at all times of the day, as data centers need to be maintained below 68° F and within 40-55% relative humidity [2]. When the outside air is cool enough, the HVAC (heating, ventilating and air conditioning) system chillers circulates only 15% of inside air, with the remaining fraction coming from outside air [5]. Economizing has varying levels of effectiveness at different climates. In cities with cooler climates like San Francisco, more hours of the year are available for economizer use. Since data centers also run during the cool night, this method is feasible even at warm weather climates. Figure 1 shows the layout of a typical economizer based data center. The conventional data center layout consists of computer-room air-conditioning (CRAC) and air handling units (AHU) that circulate air and force them through plenums [5]. An economizer based data center is different in that when the outside ambient temperature is cool enough, the economizer brings in outdoor air for cooling. The economizer relies on an energy management and control system (EMCS) to control when the economizer starts running [5]. Other considerations include managing the flow of air. Separators prevent the mixing of hot and cold air, which can make heat transfer to the cooling medium less effective. The resulting isolated hot and cold aisles of server racks reinforce the air flow.

Particulate Matter

An issue with economizer systems is that air in urban areas contains contaminants. Particulate matter (PM) in air can potentially lower the reliability of the electronic components in the data centers, which can negate any energy savings. Particles can short out circuits and corrode the metal contacts. Factors that induce corrosion include: relative humidity, temperature, and particle concentrations [6]. Hygroscopic or water absorbing molecules, such as sulfates and nitrates, deliquesce when the critical relative humidity (CRH) is reached [7]. The deposition of these molecules on the electrical parts can lower the electrical resistance between conductors [8]. The size of the particles is also considered. Particles are to be separated into three bins of different sizes for analysis: ultrafine particles represent particles less than 0.1 μm in diameter, accumulation particles represent particles between 0.1 and 2.0 μm in diameter and coarse particles represent the particles greater than 2.0 μm in diameter [9]. The coarse particles are not of concern because they are effectively filtered out in buildings. The ultrafine and accumulation particles with diameters less than 2.0 μm are of greater concern because they can get through the filters and are usually hygroscopic in nature. These hygroscopic particles can degrade surface mounted chips (SMCs) by creating bridges between conductors [8]. An effective filtering system is needed to remove the pollutants, though greater filtration efficiency may increase costs. The air-side economizer concept thus uses HVAC filters with varying MERV (minimum efficiency reporting value)

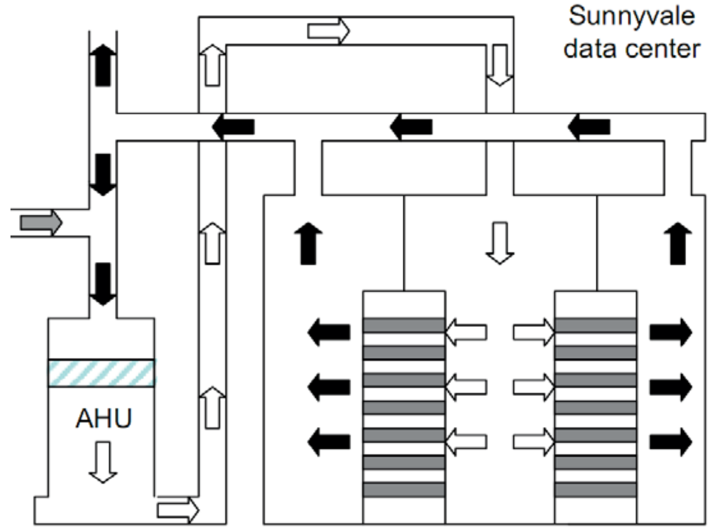

Figure 1: An economizer based data center uses separators to create hot and cold aisles. The white arrows represent cold air flowing through the cold aisles, while the black arrows represent warm air flowing through the hot aisles. The grey arrow represents outside air which is brought in for cooling when the economizer is operating. The air handling unit (AHU) moves air through the system [5].

ratings to solve this problem. Currently, the industry is wary of the technology because there is no published data on the effects of economizer use on indoor particle concentrations. This experiment seeks to confirm economizers as a viable technology.

MATERIALS AND METHODS

Aerosol Analysis

Experimental runs were done at an economizer based data center in Sunnyvale to find out the impact of economizers on indoor air quality. One of the approaches of this study is to collect data on the physical aspects of the particles, such as concentrations. An aerosol data collection setup consists of a piping apparatus to draw air from both outside and inside the data center to be collected for analysis. The hardware consists of copper tubing with airtight brass fittings. Metallic tubing is chosen in place of plastic tubing because plastic tubing contains static electricity which can attract the lightweight particles. Air is vacuum pumped through the aerosol setup, which is controlled electronically by a LabView virtual instrument. A solenoid valve switches between air inside and outside the data center every ten minutes. The larger particles are eliminated with centripetal force before they reach the instruments, because they can be effectively filtered out in HVAC systems. A rotameter measures the flow rate, which must be a constant 25 l/

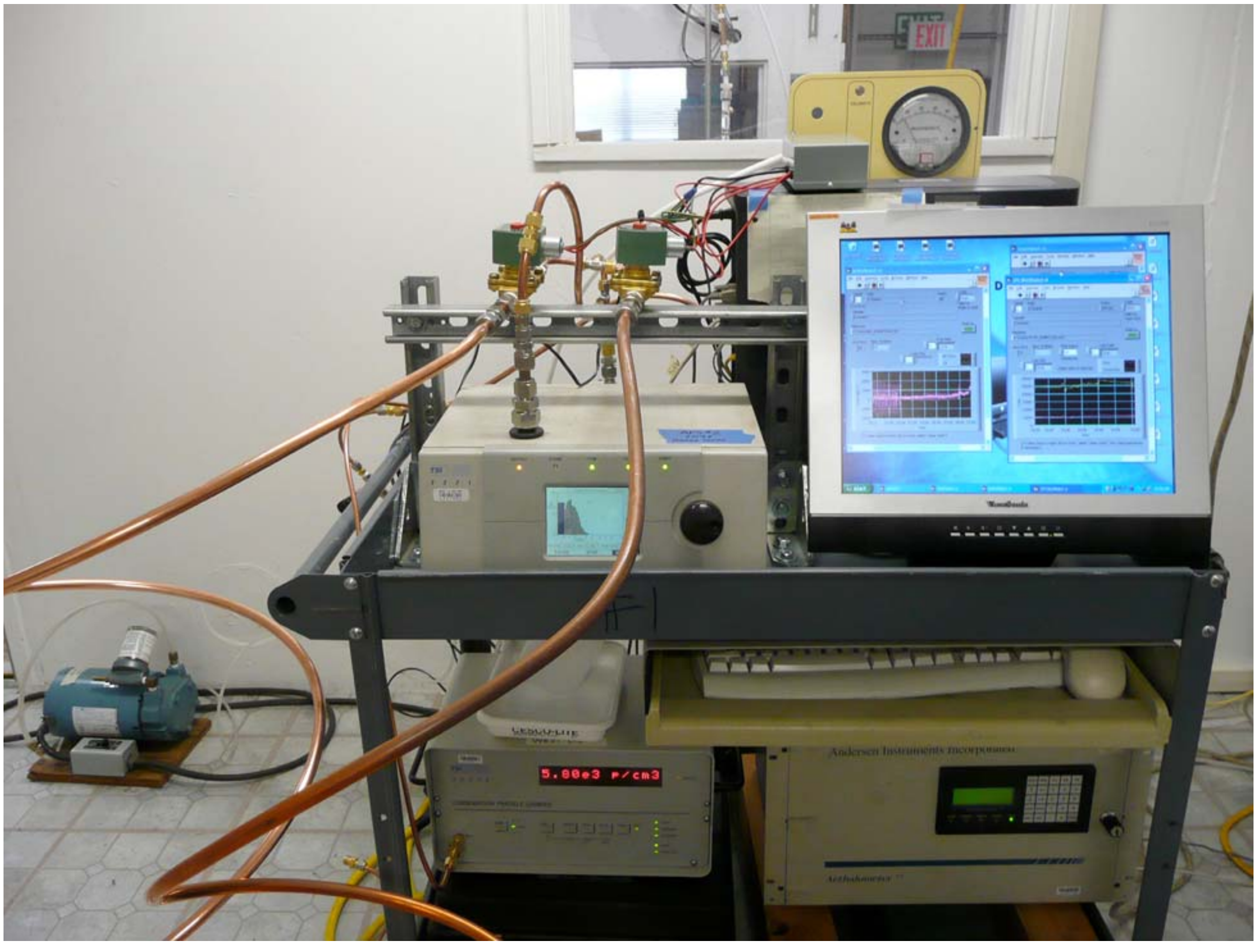

Figure 2: The aerosol setup with the APS, CPC and aethalometer instruments on a cart. One copper pipe draws air from outside the data center, while the other draws air from inside the data center.

min, which is the value needed to eliminate the larger particles. A Magnehelic pressure gauge measures the pressure difference, which should be less than 8 inches of water. The air is then pumped into the optical measurement devices used to measure the concentration and sizes of the particulate matter.

Instrumentation

A Magee Scientific AE22 aethalometer, TSI 3321 aerodynamic particle sizer (APS), TSI 3022A condensation particle counter (CPC) and two Met One 237AB optical particle counters (OPC) are used to count and identify the particulate matter of various size ranges. Figure 2 shows the instrumentation setup, which fits onto a cart. The devices have different detection and accuracy ranges. The aethalometer measures the concentration of black carbon and organic carbon in the air. The instrument has an accuracy of 5%. The APS and the OPC provides size resolved data with counts of the number of particles within different size bins of a certain time period. The OPC collects data from multiple size ranges less than 5.0 μm, with the smallest size range for all particles less than 0.3 μm. The APS collects data from multiple size ranges less than 7.774 μm, with the smallest size range for all particles less than 0.523 μm. It has an accuracy of 10%. The CPC is able to count smaller particles less than 0.02 μm in diameter. The instrument outputs real-time number concentration. The error count of the CPC is proportional to the square root of the overall count. Measurements of particle concentrations are to be collected both inside and outside the data center to check the efficiency of the filters. Indoor concentrations measured when the economizer is operating, are compared to the indoor concentrations measured when the economizer is not operating. To supplement the instruments, temperature and relative humidity sensors are used to analyze the indoor environment of the data center.

Chemical Analysis

In addition to concentrations, the chemical makeup

Figure 3: The particle collection setup. One setup is placed outside the data center; the other setup is placed inside the data center. Each setup has two filter and denuder pairs. The small circular disks hold the quartz filters. The long metallic tubes wrapped in tape hold the denuder and the series of Teflon, nylon and cellulose filters.

of the particles is to be determined. A separate "filter" setup is used to collect the particles in the air for chemical analysis. These filters are not the MERV filters in the HVAC systems, but a separate item used to collect PMs for chemical analysis. A pump forces air through the setup, with the larger particles eliminated before it enters the filters. The flow rate is controlled by needle valves and a rotameter. In each setup, the air is diverted into two flows. One pathway involves filtration by one annular denuder, followed by Teflon, nylon and cellulose filters. The denuder has a honeycomb structure coated with magnesium oxide on one side and citric acid on the other side. The apparatus is used to absorb nitrate, sulfate and ammonium gaseous compounds in the air. This prevents the gaseous from affecting the masses from being counted as particles. These ions are of interest because they are hygroscopic in nature. After the denuder captures the gases, the series of Teflon, nylon and cellulose filters are use to collect specific particulate species. The nylon and cellulose filters are downstream of the Teflon filter and are used to collect any of the particles that have converted to gaseous form. The other pathway consists of two quartz filters. The quartz filters are "pre-baked" to eliminate the initial carbon residue. This setup captures all carbon containing particulate matter. One filter captures the carbon particles, while the other captures the vapors. The carbon vapor counts are subtracted from the overall carbon counts to prevent the vapors from being counted. Teflon washers are used to hold the fragile filters in place. There are two filter setups, one to sample air outside the data center, and one to sample air inside the data center. This is done to find the relationship between the outdoor and indoor air. Each filter setup has two denuder and quartz filter pairs to collect data. A solenoid valve switches between the pairs, depending on whether or not the economizer is operating. This is done so there is data for both operating modes. Figure 3 is a photograph of the two filter setups, each with two denuder and quartz filter pairs.

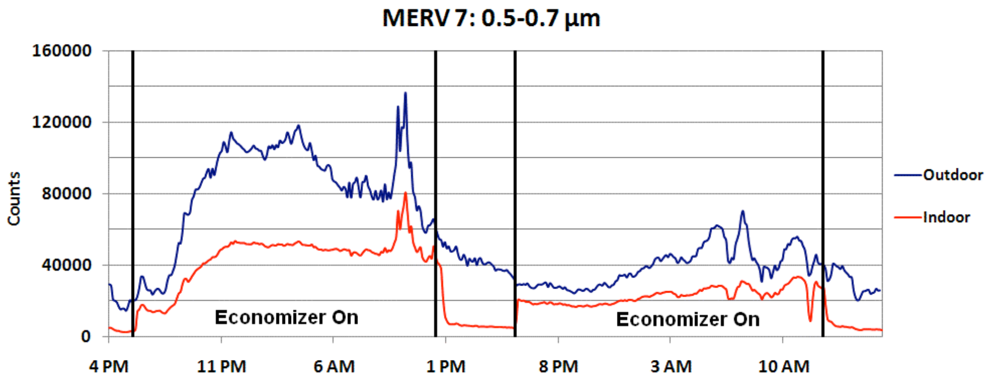

Figure 4: Counts for indoor and outdoor particles with a diameter between 0.5 to 0.7 µm from 7/30/08 to 8/1/08. The black vertical line indicates changes in the economizer mode. "Economizer On" refers to when the economizer is running.

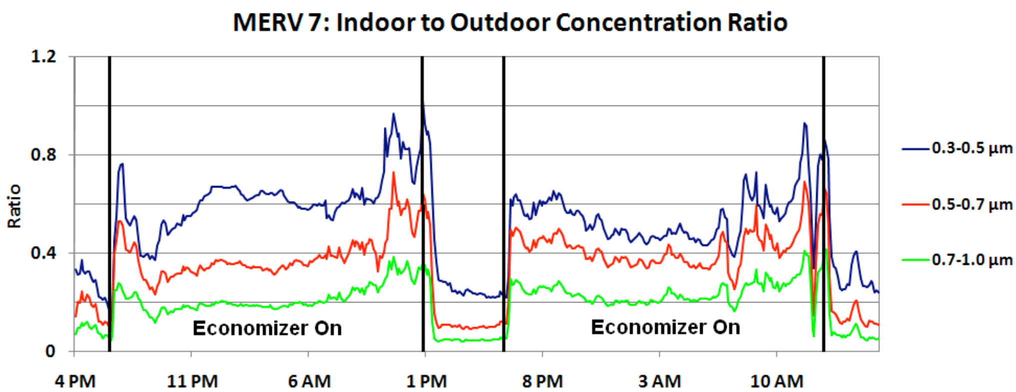

Figure 5: Indoor to outdoor concentration ratio for 7/30/08 to 8/1/08. The black vertical line indicates changes in the economizer mode. "Economizer On" refers to when the economizer is running.

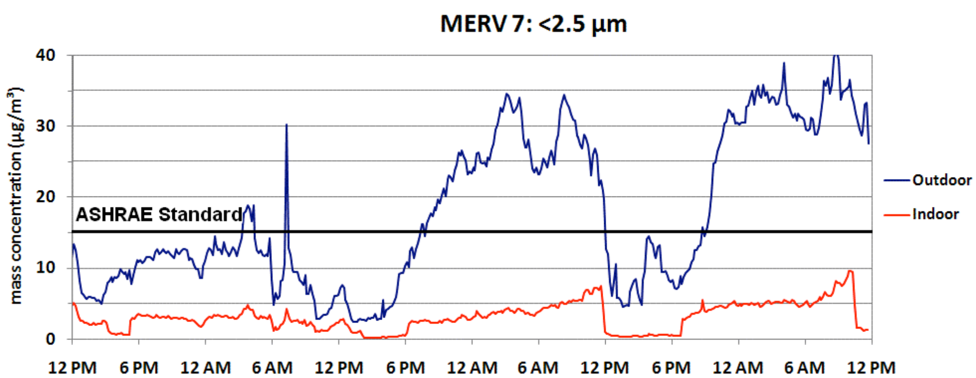

Figure 6: Indoor compared to outdoor mass concentrations. The data was collected from 8/8/08 to 8/11/08. The ASHRAE standard for particulate matter under 2.5 µm in diameter is shown on the graph as a black horizontal line (15.0 µg/m³).

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Filter Procedure

To measure the carbon content, the quartz filters are heated in a thermo-optical analyzer. This converts the carbon compounds into carbon dioxide, which is counted by an instrument. The collection filters will be measuring air quality when HVAC filters with a MERV rating of 7, 11 and 14 are used. The air will be sample for a week for each HVAC filter. The collection filters are collected every two days and refrigerated to preserve them. They are sent to a company for ion chromatography analysis to find out the ionic species in the particulate matter. Ammonia will be measured by sonicating the Teflon filters in a deionized water bath and then measuring the voltage of the bath to find out the concentration ions.

RESULTS

Instrument Data

The economizer is in use from approximately 6 pm to noon in a typical summer day in the Sunnyvale when the outside temperature is desirable. In Figures 4 through 7, a black vertical line indicates a change in the economizer mode. Figures 4 and 5 display data from the same time period (7/30/08 to 8/1/08) for comparison. Figure 4 compares the counts for indoor and outdoor air while a MERV 7 filter is in use. Figure 5 compares the indoor to outdoor ratio for different size ranges. From Figures 4 and 5, the relationship between indoor and outdoor concentrations is determined for each economizer mode. Figure 6 compares the mass

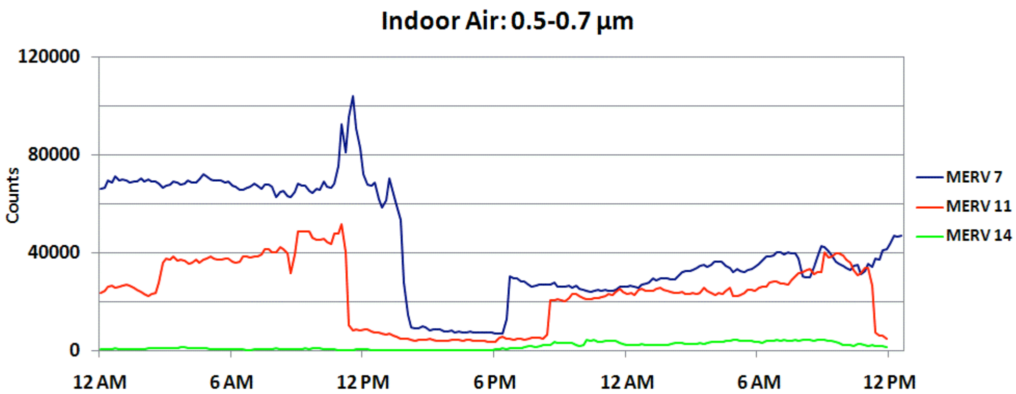

Figure 7: Comparison of indoor counts for different MERV filters. Each filter was used for a week each, which is why the economizers operate at different times of the day.

concentrations inside and outside the data center. The concentrations are compared to the air quality standard to find out if economizers pose a reliability risk for data centers. To convert particle counts to mass concentrations, the mass of the particles and the sampling volume of the instrument was calculated. The mass of each particle was obtained by using the geometric mean diameter to calculate the volume of each particle. The volume of each particle is multiplied with the density of the particles to calculate the mass. The sampling volume of the instrument was determined from multiplying the inlet flow rate by the sampling period. Figure 7 compares the indoor concentration counts for different MERV filters. The effectiveness of different MERV rated filters are determined from this graph. The data for each filter was measured approximately a week apart, so temeperature fluctuations resulted in different times when the economizer begins operating.

DISCUSSION AND CONCLUSION

Particle Concentrations

Outdoor concentrations are dependent on various factors, including emissions, which are usually lower during the night compared to during the day. However, outdoor concentrations generally rise during the night, due to the inversion layer. This creates a layer of relatively suppressed convection, which inhibits air circulation. Thus, the particles are trapped in the smaller layer close to the ground, which increases mass concentrations. When the economizer is running in Figure 4, particle concentrations of indoor air increase due to the economizer taking in outside air. At times when the economizer is not running, indoor particle concentrations are lower, due to air being circulated and filtered repeatedly. This gives an indication of the performance of conventional data centers. Figure 5 shows that for the larger particles, more of the outdoor particles are filtered out before the reach inside the data center. Thus, the larger particles are filtered more efficiently than the smaller particles.

Filter Efficiency

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) sets standards for data center particle concentrations. Even though indoor concentrations are higher during economizer use, as compared to when the economizer is not in use, the concentrations shown in Figure 6 are well below the minimum ASHRAE data center air quality standards for fine particulate matter smaller than 2.5 μm diameter, which is 15.0 μg/m³ [10]. Thus, economizers are shown to be suitable for data center use, and do not pose a risk for the electrical components. Figure 7 shows that higher rated MERV filters are more effective at removing outdoor particles than the lower rated MERV filters. The data in Figure 6 was collected while the weakest filter in the study (MERV 7 rated) was installed in order to account for the worst case scenario. Thus, more powerful filters are more effective, but not necessary when a weaker filter can still meet the ASHRAE standard. Also, higher costs for the higher rated filters can cut into energy savings and is not advised.

Further Work

After data from the ion chromatography study is completed, the group will begin chemical analysis of the particulate matter. The ventilations conditions of the data center are of interest to the study. SF_6 gas is released in the data center as a tracer to measure the air exchange rate. A portable ambient air analyzer is used to track the air exchange rate by collecting the concentrations in a fixed location and calculating the change over time. The effects of electronic circuit corrosion are to be studied with corrosion coupons. The coupons are pieces of exposed metal which will be hanging from the ceiling of the data center. After significant corrosion, they will be sent to a company for analysis. The ultimate goal of the study is to create a model of the cost implications of installing an economizer system. From the results of the research, the group hopes to predict the cost savings at different climate zones. By quantifying the cost savings, the group hopes to strengthen the argument for installing economizers.

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