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Energy Efficiency in Small Server Rooms: Field Surveys and Findings

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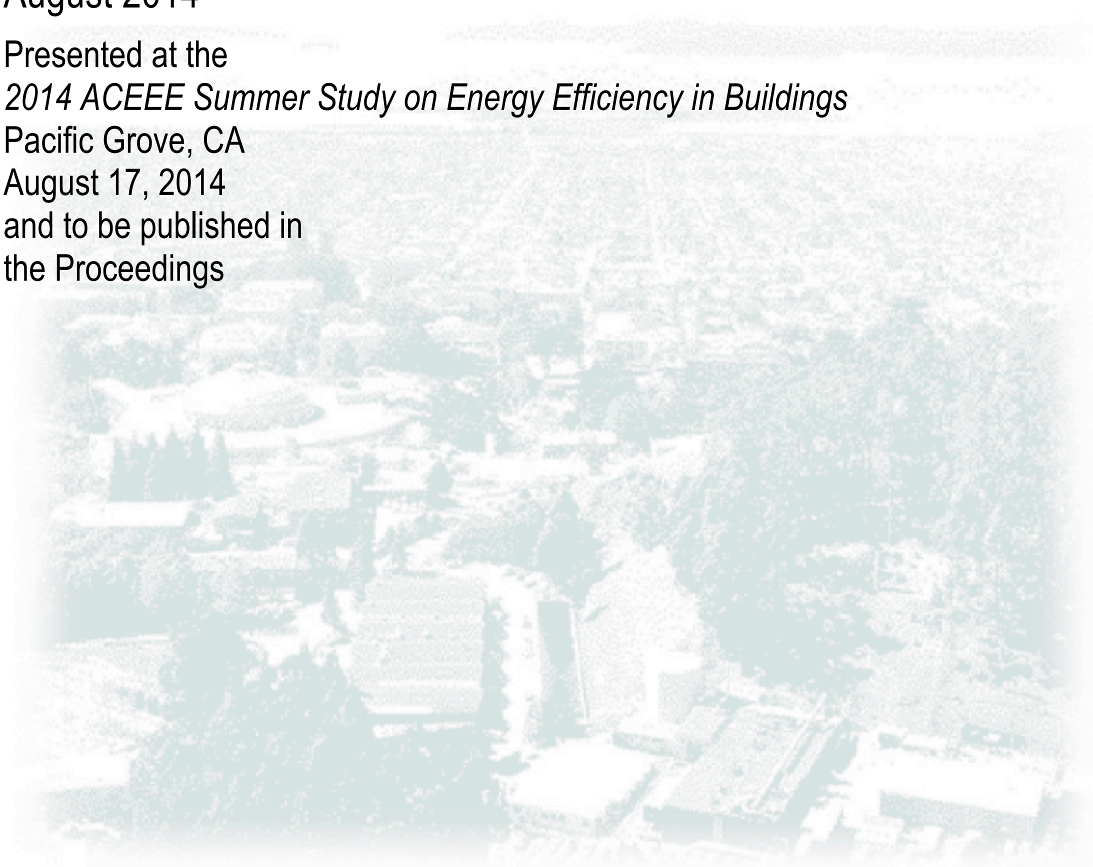

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ABSTRACT

Fifty-seven percent of US servers are housed in server closets, server rooms, and localized data centers, in what are commonly referred to as small server rooms, which comprise 99% of all server spaces in the US. While many mid-tier and enterprise-class data centers are owned by large corporations that consider energy efficiency a goal to minimize business operating costs, small server rooms typically are not similarly motivated. They are characterized by decentralized ownership and management and come in many configurations, which creates a unique set of efficiency challenges.

To develop energy efficiency strategies for these spaces, we surveyed 30 small server rooms across eight institutions, and selected four of them for detailed assessments. The four rooms had Power Usage Effectiveness (PUE) values ranging from 1.5 to 2.1. Energy saving opportunities ranged from no- to low-cost measures such as raising cooling set points and better airflow management, to more involved but cost-effective measures including server consolidation and virtualization, and dedicated cooling with economizers.

We found that inefficiencies mainly resulted from organizational rather than technical issues. Because of the inherent space and resource limitations, the most effective measure is to operate servers through energy-efficient cloud-based services or well-managed larger data centers, rather than server rooms. Backup power requirement, and IT and cooling efficiency should be evaluated to minimize energy waste in the server space. Utility programs are instrumental in raising awareness and spreading technical knowledge on server operation, and the implementation of energy efficiency measures in small server rooms.

INTRODUCTION

In the past, energy efficiency efforts and public attention have focused on large data centers, while small server rooms (usually housed in commercial buildings) have received little attention. A 2007 study conducted by the International Data Corporation (IDC) (Bailey et al.) revealed that 43% of volume servers in the U.S. are located in data centers (mid-tier and enterprise-class), which occupy 0.7% of all server spaces, and the other 57% of servers are housed in the remaining 99.3% of server spaces (server closets, server rooms, and localized data centers), in what are commonly referred to as "small server rooms". These data suggest that the energy efficiency of small server rooms is equally important as that of larger data centers.

Mid-tier and enterprise-class data centers are increasingly designed and operated with energy efficiency as a goal. Many of these servers spaces are owned by large corporations, and server operations comprise a core part of their business. In addition, larger organizations can dedicate resources to ensure efficient operation. Server rooms, however, are widely distributed in many different organizations, ranging from academic institutions and businesses of different sizes, to hospitals and government entities. Business or operational needs often drive the acquisition of additional servers, and because many organizations develop server rooms on an ad hoc basis, server spaces are shoehorned into existing available space. Rarely are they configured with energy efficiency as a primary objective.

This study investigated how IT equipment was deployed, powered, and cooled in small server rooms. Results of this research are intended improve the energy efficiency of existing server spaces, and guide the design and configuration of new server rooms. Major activities included:

1. Surveyed 30 small server spaces across a range of institutions.
2. Performed detailed assessments and energy measurements for four selected configurations.
3. Developed a list of efficiency measures and potential saving estimates that can be applied to server spaces with similar configurations in the “small server room” category.

SURVEYS AND PRELIMINARY ASSESSMENTS

SITE IDENTIFICATION AND SURVEYS

The first task of the study was to identify and survey server room sites, from which four configurations were selected for detailed assessments. Each site survey took approximately 20-30 minutes per space for the walk-through, and the following data were gathered: 1) a sketch of the room configuration, 2) background information about the closet/room; 3) IT equipment layout and utilization; 4) power conditioning, cooling systems and layout; and 5) any current barriers to energy efficiency improvements. To facilitate the data collection effort, the research team drafted a Server Room Assessment Protocol, which underwent several revisions and improvements throughout this study phase.

The surveys included a diversified range of institutions, including high-tech companies, academic institutions, health care, local governments, and small businesses. The research team recruited participants through a workshop at the 2011 Silicon Valley Leadership Group Data Center Summit, and supplemented this with existing contacts. The workshop was conducted in partnership with collaborators from Stanford University and the Natural Resources Defense Council (NRDC). Table 1 summarizes the final list of organizations and the corresponding number of server rooms included in the survey.

Table 1: Server Room Survey List

	Organization Type	Organization	Rooms/Closets Surveyed
1	Academic & Research	LBNL	6
2	Academic & Research	Stanford University	10
3	Healthcare	John Muir Hospital	1
4	High-Tech	Applied Materials	6
5	High-Tech	Intel	1
6	Local Government	City of Benicia	3
7	Local Government	City of Walnut Creek	2
8	Small Companies	Alfa Tech	1

Figure 1 presents the floor area distribution of the 30 server rooms surveyed. Most measured 500 square feet or less, with several over 1,000 square feet. The surveyed rooms exhibited significant variation in the number of servers, software applications, rack arrangement, and power and cooling schemes. Most spaces contained either dedicated cooling or a mix of dedicated cooling and house air, although a few spaces depended solely on house air for cooling. Dedicated cooling types ranged from wall mounted AC units and fan/cooling coils in smaller spaces, to Computer Room Air Conditioners/Handlers (CRACs or CRAHs) and roof mounted AC units in larger spaces. Some CRAC/H units utilized chilled water loops if the facility had a central chilled water plant. The spaces also relied on various backup power configurations - some servers were connected to a central Uninterruptible Power System (UPS), with others connected to rack-level UPS units. Some server rooms were connected to the building backup generators. Still other servers had no backup power at all. All server spaces surveyed were fed from electric utilities.

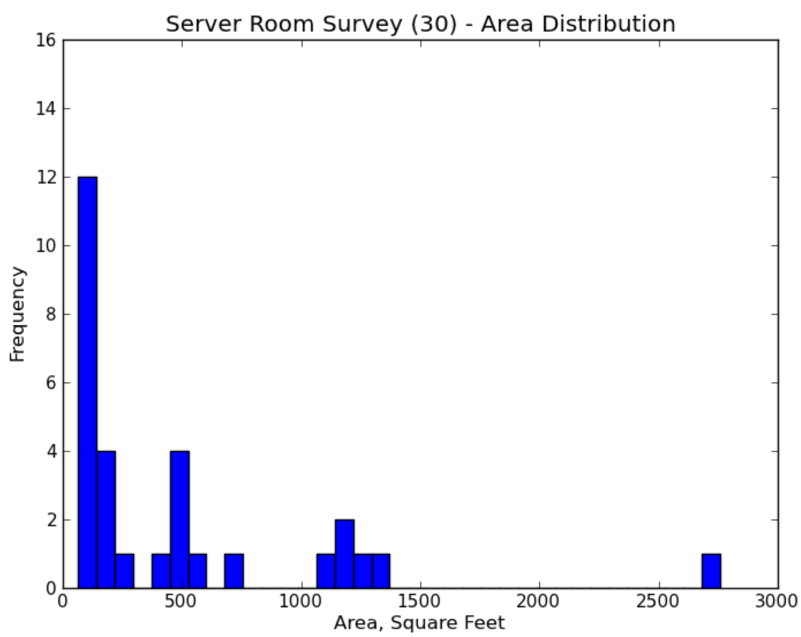


Figure 1: Server Room Survey - Area Distribution Histogram

COMMON EFFICIENCY ISSUES

The 30 server spaces we surveyed were not intended to be a representative sample, yet the research team observed a number of common issues and practices that were barriers to energy efficiency. These are described individually below; note that these issues are often linked and therefore discussed together when possible. Based on the configurations and efficiency issues observed, we developed a list of common efficiency recommendations targeted toward small server rooms in collaboration with Stanford and NRDC. One outcome of these efforts is the Improving Energy Efficiency in Server Rooms and Closets fact sheets – the abridged and detailed versions can be found at Delforge et al. (2012) and http://hightech.lbl.gov/documents/data_centers/fact-sheet-ee-server-rooms.pdf, respectively.

Most Small Server Rooms Were Not Designed To Operate As Server Spaces. Many of the small server rooms and closets started with just a few servers in a repurposed area. As the organization's computing needs gradually expanded, new servers were incrementally added, resulting in the current configurations. In other words, the rooms started out to be a temporary location for servers and were not designed to be server spaces. For example, many of the rooms had no hot/cold air separation - warm air exhausting from the servers was mixed with cooled air from the HVAC units, undercutting cooling efficiency. Sometimes, as a result of the limited square footage and legacy configurations, potential options for cost-effective upgrades were limited, and owners/operators saw no cost effective alternatives to operate the spaces more efficiently.

Principal-Agent Problem - Utility Bill Not Paid By Server Owner/Operator. Unlike large data centers, small server rooms are rarely sub-metered and therefore energy consumption cannot be easily measured. In most of the spaces we surveyed, the power bill was simply paid by the department or the larger organization, with little or no feedback on cost provided to the people who operate the equipment. In some cases (e.g. one server room in LBNL), even though server spaces were energy intensive, the energy bill was allocated on a per-square-foot basis and paid by the respective organization occupying the spaces. Since the energy costs were not seen by server owners, there was little incentive for efficiency improvements. Common in academic settings including Stanford and LBNL, the operator merely maintains servers for individual owners in the larger department and has limited authority on how server applications are run – the disconnect in operation and ownership often undercuts efficiency.

Business and Operational Needs Take Priority Over Energy Use/Efficiency. Servers in small server rooms usually support critical internal business or operational functions. Although server owners/operators understood that server room efficiencies would likely increase with changes in IT and cooling configurations, they also assumed that energy savings would not be substantial enough to fund up-front equipment purchases and labor costs. They did not find the configuration changes to be worthwhile, considering the uncertainties and risks. Since server owners may not directly pay the energy bill and in light of the barriers and uncertainties, owners preferred to maintain the status quo.

IT-Specific Observations. Because of resource constraints, many small server room operators did not have detailed records of their equipment inventory. Furthermore, due to the absence of a cost-effective and user-friendly platform to access utilization data, only one server space (out of 30) tracked server utilization rates over time. As a result, few server spaces had implemented high degrees of consolidation and virtualization (i.e. placing many applications on one physical server). Substantial reductions in IT energy use could be realized through consolidating under-utilized servers, identifying and shutting down unused servers, and virtualizing when appropriate (DiStefano 2009). Bigger organizations usually operate larger, central server spaces, but also have small server rooms. In most cases, servers in the less efficient, small server rooms could be moved to more energy efficient central facilities, though the following factors often prevented such centralization:

- The lack of incentives as discussed in "Principal-Agent Problem," above;
- Operators prefer to locate their equipment nearby for easy access, even though in some cases this is not necessary.

Some operators of small server rooms are using cloud computing to reduce server footprint. A number of server owners, however, elected not to use cloud computing, because of the following barriers:

- Cloud computing is not permitted for some government applications, including those related to municipal police operations.
- Organizations that deal with sensitive data, either personally identifiable information (PII) or personal health information (PHI), are reluctant to store these data outside of a facility that they own and control. This limits the type of consolidation or migration to the cloud that can be employed.
- Some organizations desire a high level of security for their file storage and applications, and are skeptical about the degree of cyber security that can be attained in cloud computing.

In organizations such as city governments, where the computational workload was relatively constant over time, typical refreshing of IT equipment enabled a reduction in the amount of IT equipment and overall energy use. Since modern equipment has significantly higher computational capability, the two city governments surveyed were able to host all of their IT services on fewer servers.

Cooling-Specific Observations. The research team made three observations related to cooling:

Low Operating Temperature

Most IT equipment sold today is designed to operate with inlet temperatures up to 80°F - or even higher (ASHRAE 2011). However, most server spaces visited by the research team were over-cooled and maintained a temperature of 74°F or lower, using unnecessary energy. The research team identified several underlying reasons: 1) there was a common misconception that server spaces should be kept at temperatures of around 72°F - and that colder is better; 2) operators were concerned that higher temperatures may not provide adequate buffer in the event cooling equipment fails in these relatively small spaces; 3) the owner and operator were not responsible for paying the energy costs, and over-cooling was therefore not a primary concern (principal-agent problem), and 4) the cooled air was sometimes poorly directed in small server spaces and resulted in local hot spots; to compensate, operators relied on extra cooling.

No Use of Free Cooling

All server spaces surveyed were located in the San Francisco Bay Area, where the climate is temperate, and outside air temperature is low enough to provide cooling for most of the year. However, a majority of the server spaces in the survey utilized dedicated closed cooling systems, without taking advantage of free cooling. This was partially because the rooms were not designed to be server rooms, and were served by existing building HVAC systems; cooling options were often restricted by the existing duct configuration. Typically, as server heat loads increased, dedicated cooling was added to offset heat loads without much consideration for efficiency. Adding an air economizer would potentially be cost effective in the long run, but the upfront cost and ductwork reconfiguration often served as disincentives.

No Hot/Cold Air Separation

Many small server rooms were not designed to operate as server spaces. As a result, some of them were too small to allow for air separation, and exhaust air from the servers mixed with cooler inlet air, requiring more cooling energy than necessary. The small square footage of some spaces limited the possible options for retrofit or room rearrangement. Physical barriers (e.g. plastic screen/curtain) to separate hot and cold air, and blanking panels to block off empty server spaces in racks could be installed to maximize hot and cold air separation.

DETAILED ASSESSMENTS

From the 30 surveyed server rooms, the research team selected four configurations for detailed assessments, with preferences given to spaces that broadly represented other room configurations and had the highest potential for efficiency improvements. Two other factors considered were 1) site access and 2) operators' interest in participating in further studies, as they would likely affect data collection quality for IT and cooling measurements, as well as for institutional data.

MEASUREMENT METHODS AND PROCEDURES

The main goal of the detailed assessments was to examine the infrastructure and IT systems in more detail. This included power measurements of IT, cooling, and other power consuming equipment in each server space. Data-logging power meters (Dent Elite Pro and the use of current transformers) were installed on the circuits that supplied power to the IT and cooling equipment, and the meters remained in operation for a period of one week, recording measurements at 15-minute intervals. In cases where time-series measurement of IT or cooling power use was not feasible due to metering equipment or site constraints, field researchers collected one-time measurements of the actual power feed, or power draw was estimated from equipment design information. Ideally, energy use would be measured over a longer period of time to capture seasonal and other operational variability, but this was not possible due to the scope of the study. However, since the selected sites had relatively constant IT power consumption throughout the year, and were located in a temperate climate zone, seasonal variation is not expected to vary significantly throughout the year. To determine the effectiveness of the cooling systems and whether the appropriate level of cooling was provided, field researchers collected spot measurements of room temperatures or reviewed existing temperature records.

In order to calculate the Power Utilization Effectiveness (PUE) for each site, researchers estimated power consumption or losses if measurements were not possible due to site constraints, for example, when more than one end use was supplied by a single circuit, which was the case for lighting. In addition to power measurements, we also collected information on organizational policies and server room operational practices, which often described the evolution of the server space and current operational schemes. This information was gathered through observations and in-depth interviews with the server room owners/operators, and included the following:

- Applications run on each server.
- Current virtualization, consolidation, and cloud computing schemes.
- Who owns and operates the servers?
- Is power separately metered, and who pays the energy bill?
- Are there any organizational guidelines or rules for starting a new server room?

- How did IT and infrastructure evolve to the current state?
- What cooling systems are employed?
- What equipment is on backup power and why is this necessary?
- Configurations and operational modes of UPS systems?

FINDINGS SUMMARY

Based on the above criteria, four server spaces were selected for further evaluation and their major characteristics are summarized in Table 2. Load measurements contributing to the calculation of site PUEs are summarized in Table 3 and illustrated in Figure 2. None of the server rooms was equipped with Power Distribution Unit (PDU). Electricity use was not separately metered across all four detailed assessment sites.

Table 2: Detailed Site Assessment Summary

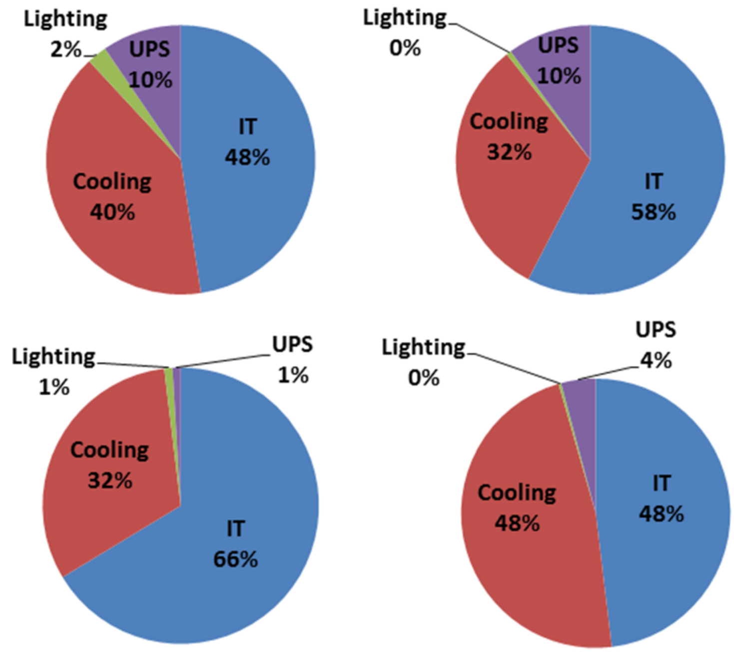
Description	Stanford 333 Bonair Siding	Stanford Alumni Center	LBNL Rm 90-2094	City of Walnut Creek
Area, square ft.	760	100	200	580
Raised floor	12”	none	none	none
No. of racks	12	3	3	23
Uninterruptible Power Supplies (UPS)	In rack (mostly A and B feeds)	In rack	Only a few equipment connected to individual UPSs	Main UPS for all equipment
UPS efficiency	0.85 (assumed)	0.85 (assumed)	0.9 (estimated)	0.92 (measured)
Cooling	3 split system units	Fan coil w/ house chilled water system	3 window mounted units	2 roof mounted package units
Supply Air Temperature, degF	42	65	Not measured	Not measured
Lighting	26 – 32 Watt, T8	4 – 32 Watt, T8	8 - 60 Watt, T8	17 - 54 Watt, T5
Lighting density, W/sf	1.1	1.3	0.51 [1]	0.21 [1]

[1] Assume lighting was on 10% of the year.

Table 3: PUE Breakdown

Power (Units in kW, except for PUE)	Stanford 333 Bonair Siding	Stanford Alumni Center	LBNL 90-2094	City of Walnut Creek
IT	10 [1]	10 [1]	6.9 [1]	15.1 [1]
Cooling	8.5 [1]	5.5 [2]	3.3 [1]	14.9 [1]
Lighting	0.5 [2]	0.1 [2]	0.1 [2]	0.1 [2]
UPS	2 [2]	1.8 [2]	0.1 [2]	1.3 [1]
Total load	21	17.4	10.4	31.4
PUE	2.1	1.7	1.5	2.1

[1] Directly measured. [2] Assumed or estimated.



Starting from Top Left (clockwise): Stanford University Bonair Siding, Stanford University Arrillaga Alumni Center, City of Walnut Creek, LBNL 90:2094.

Figure 2: PUE Breakdown

EFFICIENCY MEASURES AND POTENTIAL SAVINGS

Based on the assessments and energy measurements, a number of efficiency measures and their estimated annual savings were determined for each site, as shown in Table 4. The measures ranged from simple measures (e.g. server consolidation and identifying unused servers) to measures that would involve a higher initial cost but would generate energy savings over time (e.g. changing cooling to include "free cooling" using an air economizer). Electricity cost at LBNL was priced at $0.09 per kWh, while costs at the other three sites were assumed to be $0.12 per kWh.

Lawrence Berkeley National Laboratory - Bldg. 90, Room 2094

The room was cooled by three window mounted air conditioners that operated continuously at a constant setting. Room temperature was measured at 75 F. Cool air from the air conditioners and hot air from the IT equipment discharged into the same space, which lowered cooling efficiency. The research team suggested reconfiguring equipment in the room to achieve better airflow management. In addition, since the local climate is temperate, outside air could be used for cooling most of the year. Instead of operating three window AC units with compressors on at all times, one or more existing AC units could operate on fan mode. For short periods in the year when outside air temperature is not sufficient to cool the space, a maximum room temperature set-point can trigger an alert for IT staff to manually turn on the AC compressor.

A number of servers in the room were unused and could be turned off. Also, servers in the room were on average 10 years old (with reported utilization of 60-70%); an equipment refresh schedule could significantly improve computing and storage efficiency as funding become available. This could result in fewer machines providing the same functions with higher reliability. Prior to implementing improvements, organizational disincentives would first have to be resolved, by establishing server operation policies and eliminating the principal-agent problem. In summary, LBNL's Rm 90-2094 had substantial potential for efficiency improvements, including: server refresh; moving a portion of the IT equipment to a more centralized location; resolving organizational disincentives to encourage efficiency; IT and cooling equipment reconfiguration to improve airflow management; and the direct use of outside air to save cooling energy.

City of Walnut Creek Server Room

Server room temperature was set at constant 72°F at a specific location in the room; however, temperature varied throughout the room due to mixing of hot and cold air streams. Most of the equipment likely received adequate cooling, but a few hot spots were causing uneven cooling. Raising the temperature set-point by a few degrees could generate energy savings, given that airflow and hot spots in the room are reasonably well managed.

To better separate cold and hot air in the room, distinct hot and cold aisles can be created by reconfiguring the ductwork above the ceiling and rearranging server rack locations. The hot/cold aisles will improve airflow management, thus enabling higher temperature set-points. The research team also recommends installing a cooling system with built-in air-side economizer to make use of free cooling in the temperate climate. Either one of these efficiency measures will generate cooling cost savings; optimal efficiency will be achieved when both are implemented together. This is because the duct reconfiguration improves air management and thus allows for a higher supply air temperature, which in turn enables the cooling unit to operate on economizer mode for even longer times in the year (when temperatures go below the supply air temperature).

The City included energy efficiency when making IT purchasing decisions. Server equipment could benefit from further virtualization and consolidation; these practices were already part of the City's plan as new funding becomes available. The UPS in the room was operated in double-conversion mode at all times, which may not be needed for the IT applications in this space. Instead, the UPS unit could be operated in bypass mode for most of the year to reduce conversion losses.

Stanford University - 333 Bonair Siding Server Room

The server room housed a mixture of new and old IT equipment and UPSs, and some of the UPSs were not working properly. Researchers suggested maintaining an equipment inventory to better manage assets. This would enable the development of a prioritization plan to replace older, less efficient as well as critical equipment when budgets become available. The team also recommended further virtualization and consolidation of servers, and retiring older machines to improve the overall IT efficiency in the server room. All servers and storage equipment were connected to two redundant in-rack UPSs, and a backup generator was connected to the building. The research team questioned whether the UPSs and especially the power supply redundancy were really necessary, especially since some of the more mission-critical systems had already been moved to Stanford's central data center.

Cooling was provided by two or three split systems depending on the cooling load. Because of room configuration and location of the units, little could be done to significantly improve airflow management. We observed that two of the split units discharged cold air directly into the exhaust side of a nearby row of racks, mixing cold and hot air streams. Careful server rack and room reconfigurations may be able to improve airflow and reduce cooling needs, saving energy and money throughout the year.

Stanford University - Arrillaga Alumni Center Server Room

A study was launched to measure the PUE of this room several years ago. As a result of that study, efficiency measures were identified which included installation of a plastic curtain behind the server exhaust to better separate hot and cold air in the room - operations have since improved significantly. Other opportunities are available to further reduce energy use of the room. A portion of the server equipment could be moved to Stanford's central data center, although IT staff wanted to keep their equipment conveniently located. In addition, many of the servers were operated with a utilization rate below 25% and could be further virtualized and consolidated. The temperature in the room was maintained around 70-72F; raising the temperature set-point could easily generate energy savings.

Table 4: Energy Efficiency Measures (EEMs) and Estimated Annual Energy Savings

Energy Efficiency Measures	Stanford, 333 Bonair Siding	Stanford, Alumni Center	LBNL 90-2094	City of Walnut Creek
EEM-1 Turn off unused computers, virtualization, and consolidation[1]	25% IT energy use reduction - $2,600	25% IT energy use reduction - $2,600	25% IT energy use reduction - $1,400	25% IT energy use reduction - $4,000
EEM-2 Increase temperature set point.	With 1 unit off - $3,000	Not measurable	See EEM-5	See EEM-5
EEM-3a: Assume 50% removal of UPS	$1,300	$900	Not considered (low savings)	Not applicable (see EEM-3b)
EEM-3b: Switch from double conversion to bypass mode	Not applicable	Not applicable	Not applicable	$800[2]
EEM-4: Install lighting control	$300	Not applicable	Not applicable	Not applicable
EEM-5: Install air-side economizer	Not applicable	Not applicable	$2,000[3]	$11,600 (plus $8,700 PG&E 1st year rebate)[4]

1 Assume 25% energy savings, based on modest improvement in optimizing IT equipment configuration.

2 Energy savings assume UPS operates in bypass mode (0.4 kW) year around instead of double conversion mode (1.2 kW), which is the case for current operational scheme.

3 Assume current air conditioning units to operate in fan mode year around, consuming an average of 0.8 kW instead of 3.3 kW.

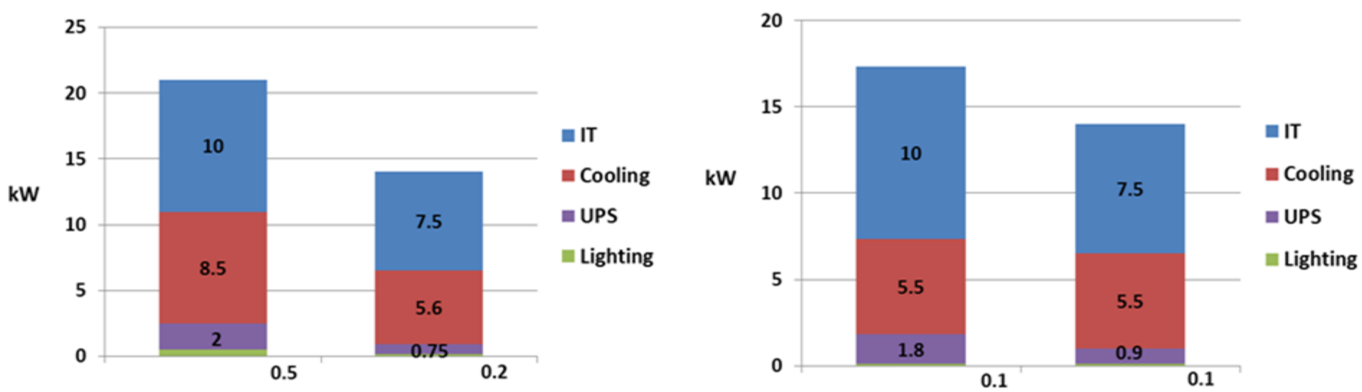
4 Estimated energy savings based on the following assumptions:

a) Two currently installed roof-mounted cooling units will be replaced with two new cooling units of the same capacity but with economizers.

b) Energy consumption of new cooling units based on units running in economizer mode 11 months of the year, estimated per climate conditions in Walnut Creek.

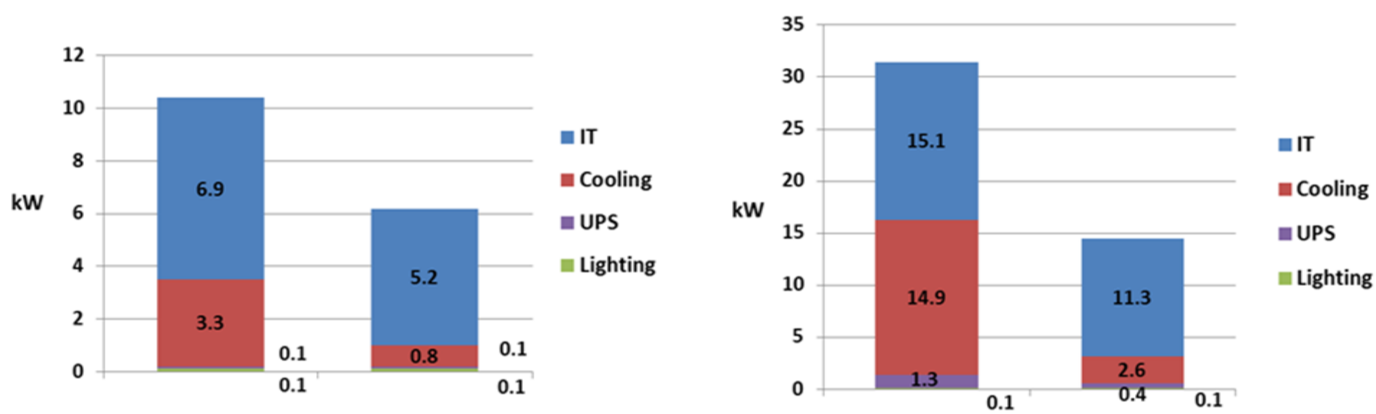
c) Estimated capital cost of $25,000 includes removal of old units and installation of two new units.

d) Customers in PG&E territories receive $0.09 per kWh for energy savings generated during the first year of operation after retrofit is in place - equivalent to about $8,700 for this retrofit (as of 2012).



Left to right: Stanford University Bonair Siding, Stanford University Arrillaga Alumni Center.

Figure 3: Current and Potential Average Power Draw (1)



Left to right: LBNL 90-2094, City of Walnut Creek.

Figure 4: Current and Potential Average Power Draw (2)

CONCLUSIONS AND RECOMMENDATIONS

The research team surveyed 30 small server rooms, which came in many different configurations. We concluded that the inefficiencies commonly observed in small server rooms are not limited by current technology, but rather due to following factors:

- Most small server rooms were not designed to operate as server spaces, with configurations that compromise energy efficiency and limit upgrade options.

- Few organizational policies are in place to create and promote efficiency incentives.
- Principal-agent problem: Owners of small server rooms often do not pay the energy bill directly, creating disincentives to achieve high efficiency.
- Lack of training and awareness in server room operation, which usually makes up only part of the responsible personnel's job descriptions (efficiency also not an objective).
- Owners and operators prefer to keep their equipment in close proximity for security reasons, even though centralized data centers may be more secure and reliable.

Consequently, there are many opportunities for efficiency improvements, ranging from simple, low-cost options to more intensive retrofits. The "Improving Energy Efficiency in Server Rooms and Closets Fact Sheet" developed as part of this study (Delforge et al. 2012) describes some of the efficiency opportunities available for small server rooms, and also separately lists the measures based on difficulty of implementation. The solution for each space depends on the specific configuration, which involves factors such as room size, IT and cooling equipment specs and layout, and local climate. While energy savings potential in any particular small server room may be small, the aggregated total energy savings potential on a national scale is very large due to the large quantity of servers that operate in these spaces.

Suggested future work includes efforts to raise awareness about server room energy efficiency and convey efficiency practices such as the ones listed on the Improving Energy Efficiency in Server Rooms and Closets Fact Sheet. In addition, vendor-based and open platform tools that track server utilization should be evaluated for their effectiveness to improve server management and reduce IT energy use. Finally, demonstrations or case studies of actual improvements - realized by consolidating and/or virtualizing IT equipment, improving power or cooling performance, or eliminating server closets via relocating equipment to central data centers or cloud operations - can serve to inform server room operators and provide assurance that these actions will not have a negative effect on their mission.

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