Data Center Airflow Management Retrofit

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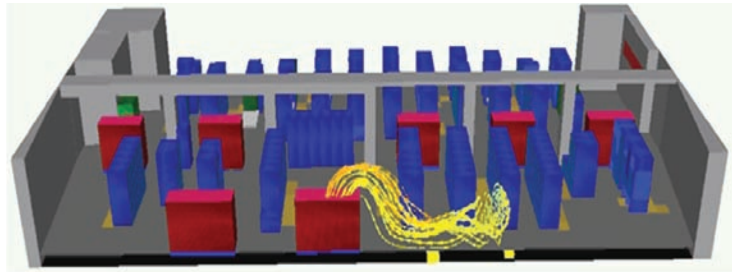

Figure 1

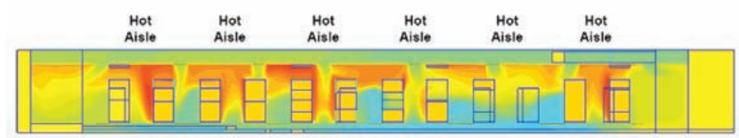

Figure 2

Figure 1: Data center CFD model of return airflow short circuit (Courtesy: ANCIS)
Figure 2: Data center CFD model - airflow cross section (Courtesy: ANCIS)

As data center energy densities, measured in power-use per square foot, increase, energy savings for cooling can be realized by optimizing airflow pathways within the data center. Due to constraints from under-floor dimensions, obstructions, and leakage, this is especially important in existing data centers with typical under-floor air distribution. Fortunately, airflow-capacity can be improved significantly in most data centers, as described below in the airflow management overview. In addition, a generalized air management approach is provided listing measures to improve data center airflow. This case study bulletin presents air management improvements that were retrofitted in an older legacy data center at Lawrence Berkeley National Laboratory (LBNL). Particular airflow improvements, performance results, and benefits are reviewed. Finally, a series of lessons learned gained during the retrofit project at LBNL is presented.

Airflow Management Overview

Airflow retrofits can increase data center energy efficiency by freeing up stranded airflow and cooling capacity and make it available for future needs. Effective implementation requires information technologies (IT) staff, in-house facilities technicians, and engineering consultants working collaboratively. Together they can identify airflow deficiencies, develop solutions, and implement fixes and upgrades.

Identifying airflow deficiencies

Data center operators can benefit from airflow visualization models created by using computational fluid dynamics (CFD). Understanding airflow within data centers is complicated because under-floor air distribution and unguided pathways often result in unintended turbulences and vortices. These turbulences and vortices limit cooling capacity and waste energy. A CFD model of the data center can help identify detrimental airflow short-circuits, mixing, imbalances, and hotspots. Examples of CFD modeling at LBNL are provided in Figures 1 and 2.

Airflow visualization can also be achieved by using wireless monitoring sensor technology. Visualization is provided by real-time thermal mapping software that uses temperature and pressure data from properly deployed wireless sensors. The thermal map gives continuous feedback to the data center operator to initially optimize floor tile outlet-size and location and to subsequently identify operational problems. Wireless sensors are a lower-cost alternative to hard-wired sensors and can be relocated easily when a data center is modified. A companion case study technical bulletin is available regarding the application of wireless sensors at LBNL, see DOE Wireless Sensors Improve Data Center Efficiency Technology Case Study Bulletin.

Another visualization technique is thermal imaging. This technique uses infrared thermography to provide immediate visual feedback to identify performance deficiencies. However, thermal imaging cannot be used for continuous monitoring.

Developing solutions

Many airflow deficiencies can be expected in legacy data centers that have gone through numerous modifications, rearrangements, and refreshes of sever equipment. Air leaks, obstructions, perforated tile locations, cable penetrations, and missing blanking plates can cause poor air distribution that can be remedied with low-cost solutions. In certain situations, customized solutions with more extensive construction costs can still have acceptable payback periods because they can free-up existing cooling capacity.

Implementing fixes and upgrades

Generally, "fixing what's broke" makes the most energy and economic sense in

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legacy data centers. The challenge is achieving this goal without having to rebuild the entire data center, though this sometimes can be the best economic solution. Investing retrofit funds in passive components such as sealing leaks under the floor, repairing ductwork, replacing floor tiles, and adding blanking-plates are usually beneficial and cost-effective solutions.

Generalized Approach to Airflow Improvement

Each of these measures will contribute to increasing the cooling capacity of your existing data center systems and may help avoid the complexity of installing new, additional cooling capacity.

Identify common airflow problems

- Hot spots
- Leaks
- Mixing
- Recirculation
- Short circuiting
- Obstructions
- Disordered pathways
- Turbulence
- Reverse flows

Fundamental Repairs

Complete basic maintenance before initiating more complex repairs.

- Remove or relocate as many obstructions to airflow under floor as practical.
- Fix under-floor air leaks primarily at cable and pipe penetrations and under racks.
- Install missing blanking plates and side panels in server racks.
- Re-locate tiles to balance under floor flow.
- Fix or replace leaking or broken floor tiles.

Develop Retrofit Solutions

- Determine chiller and cooling tower system capacity.
- Study airflow patterns with a visualization tool/method.
- Develop designs to optimize airflow circulation.
- Consider establishing a return air path with an overhead plenum.
- Add/connect ductwork from computer room air conditioner (CRAC) unit air intake to overhead plenum.
- Included isolation dampers in air intake ductwork.
- Prepare servers for possible down-time.

Commissioning

Thoroughly commission the air management installation including:

- Confirm point-to-point connections of temperature sensors.
- Ensure airflow leakage around floor tiles is minimized.
- Verify server airflow temperature at IT equipment inlets.
- Check air temperature at server inlets and outlets for differential temperature (ΔT).
- Confirm isolation damper operation at CRAC air inlets (returns).
- Check for leaks at cable penetrations in floor.
- Review and test new control sequences for CRAC units.

Additional Measures

Operators of data centers using under-floor air distribution should consider and implement additional appropriate energy-efficiency measures including:

- Increasing data center setpoint temperature.
- Optimizing control coordination by installing an energy monitoring and control system (EMCS).
- Disabling or broadening control range of humidification systems that can have unintended, simultaneous operations.
- Consider installing barriers, e.g., curtains, for hot/cold aisle isolation.

Retrofit Experience at LBNL

At LBNL, many common airflow problems existed that were exacerbated by airflow deficiencies particular to this 40-year old data center. Existing perforated tiles were inefficiently arranged, causing airflow from under-floor outlets to be misdirected. In addition, low volume flow rates were noted in certain sections of the data center resulting in hotspots (see Figure 3). Notably, supply tile outlet size (known as tile free-hole area) and location optimization was enhanced by using wireless temperature monitoring devices[1] and associated visualization software. In this data center, hot air short circuiting through the racks was widespread. To limit this situation, LBNL installed server rack blanking-plates and recommends using side-panels. In addition, LBNL used brush-type seals around cabling to mitigate this air-leak pathway. The combination of air management best practices implemented at LBNL improved airflow and under-floor air pressure.

Figure 3: Before retrofit auxiliary fans cool hot spots

[1] *See Technical Case Study Bulletin on wireless sensor monitoring at URL.*

Figure 4: Return duct from plenum to CRAC unit

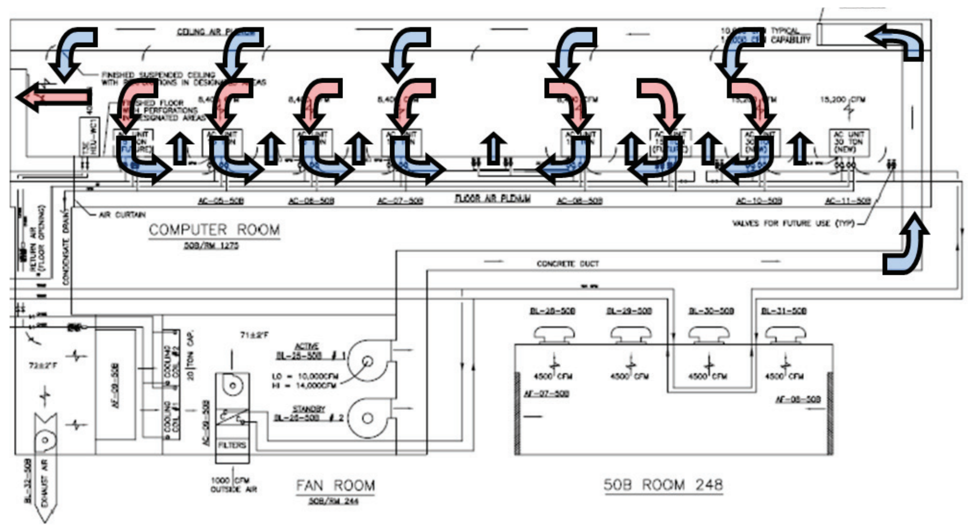


Figure 5: Airflow before retrofit (red arrows=hot; blue arrows=cold)

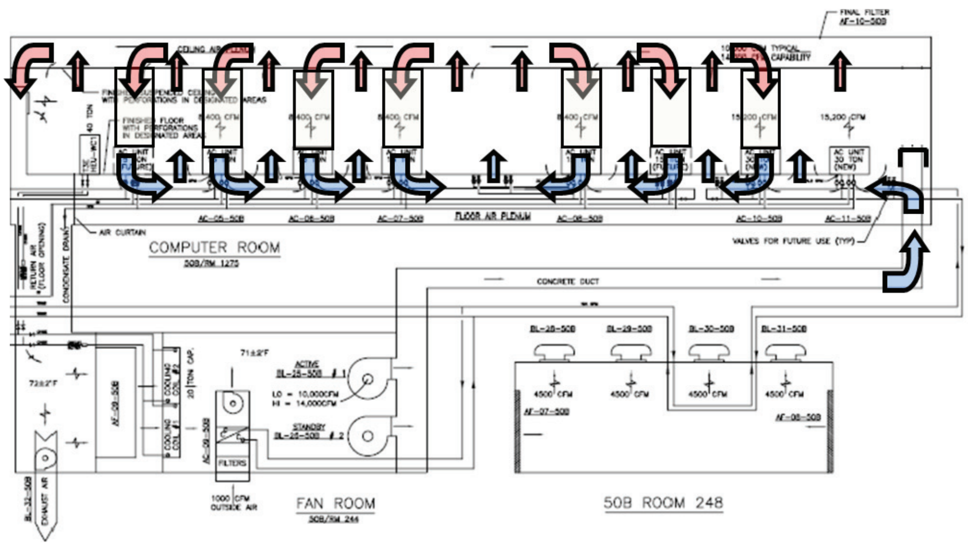


Figure 6: Revised airflow with return plenum (red arrows=hot; blue arrows=cold)

Cooling Arrangement and Problems Identified at LBNL

- Cooling was provided by 7 down-flow CRAC units with under-floor supply.
- Supplementary cooling was also supplied overhead, mixing with hot server return air.
- Server racks were missing blanking panels at inlets and between racks.
- Too many perforated floor tiles lowered under-floor pressure limiting distribution.
- Air-flow mixing and short-circuiting created hotspots.
- CRAC units were simultaneously humidifying and dehumidifying wasting energy.

Retrofit Solutions

Completed basic repairs:

- Patched under-floor leaks.
- Added blanking panels in racks.
- Sealed cable penetrations in floor.
- Rebalanced air distribution.
  - Removed supply outlets in hot aisles.
  - Reduced floor tile opening in cold aisles.

Implemented main retrofits:

- Converted false ceiling to hot-air plenum.
  - Ceiling plenum became return airflow pathway.
- Extended CRAC intakes into new overhead hot-air return plenum.
  - Duct CRAC units to ceiling plenum (see Figure 4).
- Redirected supplementary cooling to under floor.
  - Relocated existing overhead supply to under-floor plenum (see Figures 5 and 6).
- Installed isolation curtains.
  - Added strip curtains to hot aisles (see Figure 7).

Figure 7: Isolation air curtains with fusible links

Retrofit Results

Improved return airflow

A return plenum was created from an existing overhead ceiling that substantially improved hot air return to the CRAC unit intakes.

Eliminated short-circuit airflow

Airflow short-circuits were eliminated by adding ductwork at the top of each CRAC unit to connect to the newly configured hot-air return plenum in the data center's ceiling.

Reduced mixing

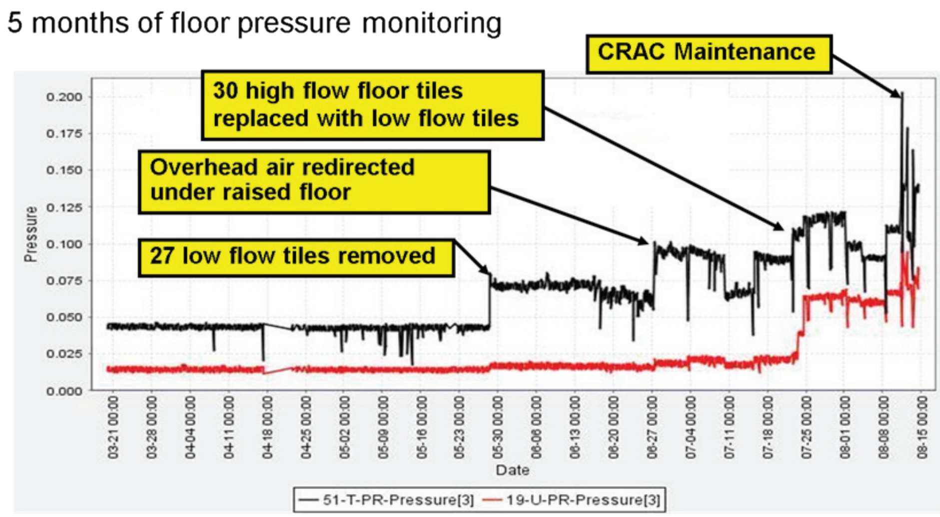
Cold and hot airflow mixing was significantly reduced by redirecting cooling air from an existing overhead supply system to the under-floor cooling plenum already in use by the CRAC units. Strip curtains improved isolation of cold and hot airstreams.

Optimized under-floor air distribution

Under-floor air distribution was examined and optimized for pressure and flow distribution. Installation of many wireless temperature and pressure sensors aided the optimization process (refer to DOE Wireless Sensors Improve Data Center Efficiency Technology Case Study Bulletin). The following improvements were made to the tile configuration (see Figure 8):

- 27 perforated floor tiles removed.
- 30 floor tiles converted from high- to low-flow.
- 4 floor tiles converted from low- to high-flow.

Figure 8: Floor tiles; before and after retrofit



Retrofit Benefits

The airflow management retrofit at LBNL resulted in many benefits. The benefits included some surprises such as freeing up 60 tons of stranded cooling capacity. This "excess" capacity allowed 30 tons of CRAC capacity to be used immediately for cooling new servers and the remaining 30 tons to be redundant. The following benefits were realized:

- Released 60 tons of stranded CRAC capacity initially.
- Increased cooling capacity by 21% (~150kW).
- Decreased fan energy by 8% .
- Raised CRAC unit setpoints 3°F warmer due to more effective cooling.
- Eliminated most hot spots.
- Turned off one 15 ton unit for stand-by operation.
- Created redundancy with one extra 15 ton unit; on-line but operating at minimum.
- Extend life of existing data center infrastructure.

Figure 9 shows a five-month history of improved under-floor airflow. Note the significant performance improvement resulting from CRAC maintenance that included tightening loose supply fan belts.

Retrofit Costs

The airflow management retrofit at LBNL corrected numerous air distribution deficiencies that may not be found in all data centers. The costs incurred were used to not only improve an unusual airflow arrangement but included repairing CRAC units, fixing dampers, moving chilled water pipes, and relocating fire sprinklers. Expenditures amounted to approximately $61,000 plus $4,100 for the airflow isolation curtains in this 5,300 square foot data center, which is slightly more than $12 per sq. ft. Depending on how the benefits listed above are valued, the airflow management retrofit results in a simple payback of 2 to 6 years.

Lessons Learned

The demonstration project at LBNL provided lessons learned that are applicable in many existing data centers. Most data centers will reduce energy use by implementing similar air management projects.

Maintain Airflow Devices

Regular preventative maintenance, inspection, and tune-ups are highly effective in reducing energy waste in data centers. A sizeable increase in airflow resulted from basic maintenance. In particular, LBNL facilities personnel found CRAC fan belts to be loose and slipping.

Manage Energy With Metering

The LBNL demonstration project clearly validated the old energy-use axiom "you cannot manage energy without monitoring energy." Adequate metering and monitoring are essential to providing reliable energy data and trends to sustain the performance of a data center.

Supervise Performance with EMCS

An EMCS, Building Automation System (BAS), or other monitoring system, should be used to gather air temperatures and to develop trend information prior to installing air management retrofits. Generally in a data center, an EMCS with centralized, automated, direct digital control can coordinate energy use of cooling systems such as CRAC units, maximizing performance of the data center. For example, one beneficial result of the airflow improvements at LBNL was a relatively large amount of excess cooling capacity created within the data center. The newly found capacity required coordinating existing CRAC unit operation to allow shutdown of redundant CRAC units. This was achieved by manual control of the existing CRAC units as no centralized control system was available. Standard CRAC return-air control methods, which are beyond the scope of this bulletin, can present a challenging situation.

Use Advanced Wireless Monitoring Devices

LBNL employed a wireless monitoring system to maximize energy savings. In conjunction with an EMCS, wireless monitoring devices can significantly enhance data collection at much reduced cost compared to hard-wired sensors and devices. At LBNL, monitoring temperatures and under-floor air pressures helped to identify improvement strategies.

Optimize Rack Cooling Effectiveness

Data center operators should consider the following items to maximize rack cooling effectiveness:

- Match under-floor airflow to IT equipment needs.
- Locate higher density racks near CRAC units; verify airflow effectiveness.
- Locate severs to minimize vertical and horizontal empty space in racks.
- Consolidate cable penetrations to reduce leaks.
- Load racks bottom first in under-floor distribution systems.
- Use blanking plates and panels.
- Eliminate floor openings in hot aisles.
- Establish hot and cold airstream isolation.

References

Hydeman, M. "Lawrence Berkeley National Laboratory (LBNL) Case Study of Building 50B, Room 1275 Data Center from 2007 to 2009." Taylor Engineering, LLC. December 2009.

Acknowledgements

Bulletin Primary Author:

Geoffrey C. Bell, P.E.
Lawrence Berkeley National Laboratory
One Cyclotron Road
M.S. 90-3111
Berkeley, CA 94720
510.486.4626
gcbell@lbl.gov

Reviewers and Contributors:

Paul Mathew, Ph.D.
Lawrence Berkeley National Laboratory
One Cyclotron Road
M.S. 90-3111
Berkeley, CA 94720
510.486.5116
pamathew@lbl.gov

William Tschudi, P.E.
Lawrence Berkeley National Laboratory
One Cyclotron Road
M.S. 90-3111
Berkeley, CA 94720
510.495.2417
wftschudi@lbl.gov

David H. Edgar
Lawrence Berkeley National Laboratory
One Cyclotron Road
Information Technology Division
M.S. 50E-101
Berkeley, CA 94720
510.486.7803
dhedgar@lbl.gov

For more information on FEMP:

Will Lintner, P.E.
Federal Energy Management Program
U.S. Department of Energy
1000 Independence Ave., S.W.
Washington, D.C. 20585-0121
202.586.3120
william.lintner@ee.doe.gov

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