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TRENDS IN DESIGN AND OPERATION OF UFAD BUILDINGS

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ABSTRACT

In this draft report we provide preliminary details of results from our web-based questionnaire survey tool used to collect design and operational information on existing UFAD buildings. This project makes up part of CBE’s overall UFAD Case Studies project dedicated to learning about how UFAD buildings perform in actual practice. Fifty buildings were selected from our database of about 300 UFAD projects in North America. Invitations were sent to project team members to complete the web-based survey; responses were received from 39 projects over a period beginning in November 2003 to August 2005. Although the sample size is too small to gauge how representative these results are, it does indicate that for the most part UFAD buildings are operating reasonably well. The results also suggest a “typical” UFAD building which is outlined in the Summary and Conclusions section.

PROJECT BACKGROUND AND INTRODUCTION

Underfloor air distribution (UFAD) systems are rapidly becoming established as a standard option for design of mechanical systems in new and retrofit situations. This is because UFAD systems have significant potential for improved comfort, indoor air quality, energy use, and simplicity of operation. Although considerable work has been done to develop underfloor technology over the past decade, research has focused on specific technical aspects rather than practical implementation and integration issues. These practical issues, the lack of well developed design methodologies, and limited product offerings has served as a barrier to wider implementation of these systems in the US. We initiated the UFAD case studies project in 2000 to supplement research efforts by providing useful information on actual performance of these buildings.

Initially we conducted a series of Project Profiles and two in-depth Case Studies. When we found that there were a few hundred UFAD projects in North America, we began developing a database of UFAD projects to help focus our case studies work. However, it became apparent that we could not obtain a broad enough sampling of projects with the limited resources using out previous approach. In an attempt to leverage the opportunities contained in the database we developed our current strategy of using survey techniques to query design team members for these projects. It was hoped that this strategy would lead to an understanding of trends in real-world UFAD installations and help us to ascertain how these buildings were performing in relation to how they were designed. Additional information about CBE’s research in this area can be found at http://www.cbe.berkeley.edu/underfloorair/.
OBJECTIVES

The key objectives of this element of our UFAD cases studies project are to gain broad based knowledge of design and performance issues in a systematic manner to assess how UFAD systems actually perform in practice in relation to how they were designed. Out of this assessment we expect to identify “lessons learned” so we can provide feedback to the design engineering and buildings operations community.

APPROACH AND METHODS

UFAD CASE STUDIES

The overall goal of CBE’s UFAD case studies project is to develop a better understanding of how underfloor air distribution (UFAD) systems work in actual practice, to document the various approaches to system design, and to identify barriers to implementation of UFAD systems. We study how designers of existing projects have addressed practical issues as well as trends in design and construction practices. We attempt to extract “lessons learned” out of these studies. This information and its analysis will be useful for designers and researchers alike. For this work we use a variety of procedures including:

1. UFAD MASTER DATABASE. Maintain and update a list of UFAD projects by contacting industry sources who have information about UFAD projects, either completed or those near occupancy. To assist with this, we provide a web-based project submission form on our CBE website.

2. UFAD BUILDINGS WEB-BASED QUESTIONNAIRE. Obtain contact information for project team members and request that they fill out a web-based questionnaire that covers key building parameters. Follow up with team members to expedite completion of database information. Conduct analyses of the questionnaire results to identify trends and characteristics of UFAD projects. Identify projects that are candidates for further study; e.g., office buildings that are occupied and could provide useful insight into UFAD design, construction, cost and performance issues. This element of our overall UFAD cases studies is the focus of the remainder of this report.

3. PROJECT PROFILES. Prepare a snapshot of system design and operations based on a limited set of interviews and a visit to the building.

4. CASE STUDY REPORTS. These are in-depth case studies based on a detailed study of a building including interviews, measurements, and an occupant satisfaction study.

QUESTIONNAIRE DEVELOPMENT

The first phase of the case studies project concentrated on developing a database-list of UFAD buildings in North America, focusing on basic details such as size, year constructed, owner, etc. Buildings were added to this list from various sources, including other research institutions and equipment manufacturers.

In 2003 we began development of a web-based questionnaire to be used to survey selected buildings in the database. The development of questions was reviewed with CBE partners and other industry contacts. This included a request for case study participants to submit drawings and there was a general desire for more specific information on cost and operational data.

What was initially envisioned as a short online survey evolved into a much longer document that covered the specifics of building construction, operational and design data about the mechanical systems, and details about the operational performance of the building. It became clear that no single person would be able to answer all of the questions, so the survey was divided into four parts. Sections were developed for four key members of the design and operations team: Architects, electrical engineers, mechanical engineers and operations managers. Participants to be surveyed would be drawn from the database of UFAD projects. After early attempts at using Microsoft Access to host the questions, we decided to move the survey over to the CBE survey format used for occupant surveys.

The Architectural section includes questions pertaining to the design of the building’s structure, cost of the building, and the use of the space (percentage tenant space, percentage served by UFAD etc.)
The Mechanical Section features questions that cover the design details of the tenant portions of the UFAD system as well as basic questions about the central system. We include additional questions about the design of the plenum, air distribution and access flooring. Like the other sections, comment test boxes are provided to allow for an expanded description of the system if the questions were not specific enough to cover a situation in a particular building.
The Electrical Section is similar to the Mechanical section, but is much shorter, covering only basic electrical and telecom information for tenant spaces. Included are questions about design loads for lighting and power, types of lighting, and details on cabling/wiring.

The Operations Section is written for someone familiar with the day-to-day operation of the building. Often completed by the building manager, this section focuses on how well the building functions and relies on the familiarity of the participant with occupant feedback. This section also asks what types of post-occupancy evaluation have been done, and asks about the availability of energy data and the potential of the building for future study. There are several boxes for comments in this section, allowing participants ample space for explaining situations that exist in their buildings. It is worth noting that many of the questions in this section are set up with a 7 point ranking scale that ranges from thumbs up (no problem) to thumbs down (serious problem).

![Operations Section](image)

**Figure 3: Opérations section question examples**

**IMPLEMENTATION**

**BETA TESTING**

In fall of 2003, and the end of the primary development phase, we conducted a beta test of the questionnaire to help fine tune the questions, test response performance, and refine contact management procedures. Initial invitations were sent out to potential participants affiliated with six buildings that CBE was already familiar with. These responses began to come in but the number was significantly lower than had been anticipated. In early 2004 we initiated a more concerted effort to increase response rate. Through repeated follow up phone calls the number of responses was increased and these results were presented at the March 2004 CBE meeting. Based on these responses we revised some of the questions.

**CONTACT MANAGEMENT**

During the beta test and subsequent revisions, we began using ACT! Contact management software to track the various people involved with each building. While far from perfect, this system allowed for connecting people involved with the same buildings. A key feature of this software was the ability to post the contact database file on a server to provide access by multiple team members in a seamless manner. Unfortunately, a subsequent upgrade of the ACT! Software created serious problems for sharing
information between users. We continue to use ACT! to host the UFAD database-list and project contacts. ACT! does allow porting of information to Excel that facilitates collection of database characteristics.

**PROJECT SOLICITATION**

Upon completion of the ACT! setup we populated it with basic building information and initiated active collection of project data using the questionnaire. We selected buildings from the master UFAD list based on a set of criteria that included date of construction, size, and a representative sample of various system manufacturers. Preference was given to larger projects and those built most recently to get a better sense of the current state of UFAD.

Beginning with buildings with complete contact information, additional projects were continually added to the case study project. It quickly became clear that finding current contact information for each building was much more difficult than we anticipated. In many cases, people familiar with projects had left the firm and had no forwarding information. In other cases, neither the architects nor the engineers were familiar with the operations personnel, or the person that they did know was only involved with the project until the building opened. Many larger companies were nearly impossible to penetrate, and security concerns led many building owners to prevent the sharing of any information. In most cases, there was one person willing to share information, usually the architect or mechanical engineer. Initial feedback was meager, and follow-up phone calls seemed to be the key to increasing the number of responses. In many cases, the participant agreed to take part, but had simply forgotten to fill out the answers online.

**REPORTING TOOL AND DATA EXPORT**

As the amount of data grew, it became apparent that the CBE Reporting Tool was not going to be adequate for examining the responses as it did not provide for a way to look at individual buildings. The limits in reporting format and its emphasis on cumulative data (as opposed to collecting info on individual buildings) needed to be circumvented. A procedure and associated tools were developed by the CBE Survey group that allowed us to bring the raw data into Microsoft Excel. This allowed for various methods of data sorting that enabled the isolation of individual building responses. The Excel data could also be placed into pivot charts and tables for presentation purposes.

We also developed a Flash-based web page that displayed UFAD buildings on an interactive map of North America. Upon rolling over dots on the map, a window appears that displays the building’s name and square footage. A time slider at the bottom of the map enabled the user to see the progression of UFAD implementation. This page is posted as a part of the CBE underfloor site; a link is also provided for submitting additional projects for inclusion in the database.

**DATABASE CHARACTERISTICS**

The overall database is currently comprised of about 300 projects. This database includes varying amounts of information depending on the project, but we attempted to collect location information and square footage whenever possible.

For the active survey projects (those that were solicited to participate in the web-based questionnaire), we focused primarily on buildings over 50,000 square feet that had been constructed in the last five years. From the master list, we identified approximately 50 buildings to target for the active survey. We received responses to one or more of the questionnaire sections from 34 buildings. By section it broke down as follows: Architecture - 20, Electrical - 10, Mechanical - 20, and Operations - 13.

Figure 4 displays the distribution by state for buildings over 50,000 square feet, as well as indicating the fifty buildings identified for the active survey (not all buildings appear in the results as we were unable to obtain responses from every project). This figure shows that the active survey building population was somewhat representative in terms of location.
QUESTIONNAIRE RESULTS

ARCHITECTURE
This section covers the buildings major design characteristics. Key points from the architecture section are as follows:

GENERAL
- Out of 25 responses, 20 were office buildings (including call centers).
- 64% of buildings were steel framed construction. For the concrete framed buildings, 32% used tensioned concrete slabs.
- Three quarters of the respondents (18 out of 24) indicated that their building was new construction.
- For 88% of responses, over 90% of the net floor area was owner-occupied.
- For 64% of responses, over 80% of the floor area was served by UFAD.
- Few architects responded to questions about churn rates, but those that did respond reported low numbers (either less than 10% or 10-19%).

The following figures indicate that most buildings are open plan with a minimum of private offices:
- For 88% of responses, interior private office area was less than 20%
- For 82% of responses, perimeter private offices area was less than 20%

BUILDING SIZE AND COST
The following table shows responses to questions about building occupancy and size. Cost data showed a range of $70-$200/Gsf with 50% in the range of $70-$120/Gsf (N=14). HVAC costs (excluding controls) ranged from less than $8/Gsf to over $15/Gsf (N=11).
### Building design occupancy

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-499</td>
<td>38%</td>
</tr>
<tr>
<td>500-999</td>
<td>42%</td>
</tr>
<tr>
<td>1000-1499</td>
<td>8%</td>
</tr>
<tr>
<td>1500 and greater</td>
<td>12%</td>
</tr>
</tbody>
</table>

### Gross Building Floor Area (x1000 SF)

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 100</td>
<td>30%</td>
</tr>
<tr>
<td>100-249</td>
<td>40%</td>
</tr>
<tr>
<td>250-499</td>
<td>20%</td>
</tr>
<tr>
<td>Over 500</td>
<td>10%</td>
</tr>
</tbody>
</table>

Figure 5 shows floor to floor and ceiling height responses. Note that most buildings have floor to floor heights of 14 ft and greater, and room heights (floor to finished ceiling) of 10 ft 6 inches and under.

**Floor to Floor and Room Heights**

![Floor to Floor and Room Heights](image_url)

*Figure 5: Floor to floor and room height distribution (N=25)*
Figure 6: Number of floors distribution (N=19)

Figure 6 shows a distribution of number of floors; 3 to 6 story buildings make up the majority (74%).

One interesting finding is shown in Figure 7, use of acoustical treatments. The results indicate that 35% of buildings use an exposed/open ceiling but only about 14% of those buildings include acoustical treatment on the exposed slab. This is particularly noteworthy considering the fact that CBE occupant surveys consistently show poor results for acoustical performance.

Figure 7: Acoustical ceiling treatments (N=20)
Figure 8 shows a breakdown of reasons for choosing a UFAD building. Occupant benefits, ease of configuration, low energy use, and requested by owner are the predominate reasons cited.

**Reasons for Using UFAD**

- Supports green (LEED) design intent
- Requested by owner/developer
- Low energy consumption
- Ease of reconfiguring building space/services
- Occupant benefits
- Company image of owner/developer
- Solution in high ceiling space
- Marketing advantage to potential tenants
- Positive experience with previous UFAD Building
- Supports green (LEED) design intent
- Other

![Bar chart showing reasons for choosing a UFAD design](image)

*Figure 8: Reasons for choosing a UFAD design (N=20)*

**MECHANICAL**

In this section we focus on details of the HVAC system design. The most significant results are indicated in the following list:

- 80% of the building designs exceeded state energy standards/ASHRAE 90.1 (N=20).
• 47% of the system cooling sources were direct expansion, 42% were water cooled and 11% used cooling towers only (N=19).

• 47% used a packaged rooftop AHU, while 37% used floor-by-floor AHUs and 11% used a central built-up system (N=19).

• Approximately 85% of the 19 buildings had more than one supply shaft.

• 95% of the 19 projects used VAV control at the AHU.

• Almost 75% used VAV cooling at terminal units (N=22).

• Only 21% of projects used plenums under 14”, while 47% had plenums over 18” in height.

• 75% of projects used only the primary cooling coils (i.e., no mixed or return air bypass) at the central plant for dehumidification (N=20).

• In no cases were sprinklers required in the plenum. However, code officials mandated plenum smoke detectors in 11% of projects and dictated diffuser materials in 25% of the projects.

• 71% of projects did nothing to control water in the supply plenum, while 2 used only moisture detectors and 3 used a combination of moisture detectors and floor drains (N=17).

• Only 22% of projects used aligned carpet tiles (N=18).

Other results are shown in the tables below. Figure 9 indicates that a high proportion (84%) perimeter systems use VAV control. Figure 10 shows a breakdown of perimeter terminal equipment types and indicates that many systems use series fan powered VAV boxes. Also indicated is a low usage of fan coil units (FCU), contrary to our perceptions. Figure 11 shows a breakdown of interior diffuser types which indicates a high proportion of swirl diffuser systems. This is probably not representative of the UFAD project population since this sample lacked a representative proportion of York systems which do not use swirl diffusers.

**Perimeter Zone Control**

![Pie chart showing perimeter zone control](https://escholarship.org/uc/item/7kd8f9vb)

*Figures 9: Perimeter zone control (N=19)*
Perimeter Zone Terminal Equipment

![Perimeter Zone Terminal Equipment Diagram]

Figure 10: Perimeter zone terminal equipment breakdown (N=23)

Type of Diffusers (Interior Zone)

![Type of Diffusers Pie Chart]

Figure 11: Interior zone diffuser type (N=22)

Figures 12 and 13 show results related to plenum distribution and zoning. Plenum air distribution methods were evenly split between non-ducted and some form of ducted distribution (i.e., air highways (20%), or sheet metal ducting (30%)). Figure 13 shows that 78% of supply plenums use 2 or more independent pressure controlled zones. These are typically used to support interior zoning using swirl diffuser but could also be used to support private office and conference room zones. Systems that use one zone can be York systems where plenum zoning is not required since damper/diffusers can be...
controlled in groups to provide zoning options or a single zone interior, one commonly used approach in many open plan buildings.

**Figure 12: Supply plenum air distribution strategies (N=19)**

**Figure 13: Supply plenum independent pressure zones (N=18)**
ELECTRICAL
There were a very small number of responses to this section; some key findings are:

- 90% of the projects used pendent mounted direct and/or indirect overhead lighting. This may not be too surprising given that about 50% of projects included an exposed slab/open ceiling configuration.
- 50% used conventional conduit in the plenum, while the rest used a modular wiring system (N=10).
- 90% of projects had electrical wiring completed by an electrical contractor, versus having the wiring done by the access floor contractor (N=10).
- 50% of projects used a fiber optic cable backbone (N=10).
- 80% of projects used cable trays to run wiring in the plenum (N=10).

OPERATIONS
We consider the operations section key to understanding how a UFAD building is performing. Besides the questions aimed at understanding how operators experience with UFAD differs from their experience with conventional buildings, respondent comments often provide additional useful insights. Some of these are included in Appendix A. Highlights of responses to this section are included in the list and charts below.

- 90% of projects had an interior setpoint between 72 and 74 degrees in the interior zone (N=9).
- All projects had perimeter setpoints between 72 and 75 degrees (N=10).

These setpoints are typical of those used in conventional buildings. These two findings indicate that buildings most likely are not being operated with consideration for stratification. Especially in the interior, with setpoints in this range, any significant degree of stratification is likely to result in cool temperatures in the occupied zone (below 67 inches standing, and 42 inches seated). Figures 14 and 15 show responses related to how well the building was commissioned and how well trained operating personnel are. Fifty percent of the responses suggest that a formal commissioning process was not used or only functional tests were performed. Furthermore, Figure 15 indicates that a high proportion of operators are not properly trained in the principles of UFAD systems. This can be a serious problems since UFAD systems are markedly different that conventional systems in many areas important to comfort and energy performance.

What level of commissioning has been accomplished?

- Yes, and the level of training was adequate. 29%
- No, training was inadequate 71%

Were you and/or your staff trained in the principles of UFAD technology?

- independent commissioning 50%
- contractor or operations personnel 50%

Figures 14, 15: System commissioning and operator training (N=14)
Figures 16 and 17 show responses to a series of questions about how the building is operating with respect to typical issues of comfort, energy use, and maintenance. These questions were posed in a way to identify the degree to which these issues differ from conventional buildings from the operators’ perspective based on their experience. Each question was scored on a 7 point scale. In Figure 16 the mean of the responses indicate, except for problems with zoning equipment that in general UFAD buildings compare favorably to conventional buildings with respect to these issues.

![Figure 16: How UFAD compares to conventional buildings (-3= much worse, 3 much better). The black diamond indicates the mean response and the blue bars indicate one standard deviation above and below the mean (N=13).](image)

Figure 17 rates questions related to issues that have been cited in the literature as being problems somewhat unique to UFAD systems. Supply plenum leakage at construction joints and air flow distribution were the only ones that are shown that might indicate problems based on the mean values. These are known issues for these systems and measures are being taken in design and research to address them.

![Figure 17: Operator responses to seriousness of problems deemed to be unique to UFAD systems (-3= serious problem, 3= no problem) (N=12) The black diamond indicates the mean response and the blue bars indicate one standard deviation above and below the mean.](image)
ANALYSIS AND DISCUSSION

Several issues about the data presented above should be noted. First of all, these results should be considered preliminary since we have not yet done an exhaustive evaluation of the data in terms of logical inconsistencies and other possible respondent errors. We have found occasional errors for some of the projects we know well. Also, for several projects we have additional information in our files from previous contacts with building team members that have not been incorporated into the results.

Another issue is that no building had all four sections filled out, therefore there is an element of inconsistency in the results. This means that each section should be considered on its own independent of the others. We wish to also note that responses should be considered anecdotal since the accuracy of the factual information has not been verified. The anecdotal nature of these results will vary depending on the topic since many are based on factual information. However, for the operations section the responses might be considered the most anecdotal since there are based less on factual information and detailed studies than on opinions of operations personnel. On the other hand, these responses were derived from personnel living with the building day-to-day as opposed to an outside evaluation based on a short visit. When the mean values are considered only a few issues appear to be “problems,” e.g., zone equipment, maintenance, construction joint leakage, and thermal distribution problems. However, the raw variance of these results is quite high compared to the mean which, through further analysis, might provide a different perspective.

Finally, the low response rate compared to the Master Database population indicates that these results may not be representative of the total population of UFAD projects. The representativeness varies depending on the item, as noted above in relation to the fact that we know that the proportion of York systems (~18%) is not consistent with their estimated proportion in the installed base of about 40%.

However, despite these reservations, the results do provide some valuable insight into certain trends and add an important perspective to some perceptions about the performance of UFAD systems cited in the literature. To our knowledge, there are no other studies conducted in the systematic manner that this one has been; most reports are highly anecdotal and based on individual buildings or an even smaller sub-population than this one. The results presented here should be considered “tendencies” rather than established “trends.”

SUMMARY AND CONCLUSIONS

There are a number of noteworthy findings from the questionnaire results. Starting with architectural issues, we were surprised to find steel framed buildings in such high proportion (64%). Most of the buildings were owner occupied and had over 80% of their area served by a UFAD system. The results for exposed ceilings indicate that architects are taking advantage of the opportunities to “open” the ceiling although the lack of acoustical treatments may indicate a indoor environmental quality (IEQ) problem since acoustical performance of most office buildings are relatively poor. There was no indication of whether wall height was saved for these open ceiling designs.

We were also surprised to see the degree to which packaged heating and cooling equipment was used, especially floor-by-floor units. However, since most of the buildings in this sample were 6 stories or less, the use of packaged units vs. central built-up systems is not unusual.

For electrical there was a high proportion of pendant lighting systems, although this is partly due to the fact that at least 35% of the projects used an open ceiling which would favor pendent lighting. It is noteworthy however, that 90% of the electrical systems were installed by electrical contractors, indicating union labor rates. This is apparently true even though 50% of the systems used modular wiring systems where it is possible to have access floor or other non-union labor perform the installation.

The operations sections responses provide some interesting insights. These questions were crafted to address issues that have been cited in the literature and among professionals as concerns about UFAD technology. Although, the operations response rate was relatively low, and the responses are mostly anecdotal, there were no overall negative surprises when the mean responses are viewed. The variance
however is a concern which presents a new perspective on what issues might be considered problems. More study of this issues is warranted.

The thermostat setpoint responses, in our view, indicate that they are being specified based on overhead system experience. This could lead to problems if significant stratification occurs because the lower occupied zone temperatures may be close to our outside of the ASHRAE Standard 55 comfort envelope.

**TYPICAL UFAD BUILDING**

If we were to conjecture a typical UFAD building based on the questionnaire results it would consist of the following elements:

- Owner occupied office building greater than 250K Gsf, 3-6 stories in height with 10-20 % floor area for private offices.
- Steel frame structure with 14-15 ft floor to floor height and about 10 ft finished floor to ceiling height. Hung ceilings with pendant overhead lighting and modular wiring, contractor installed.
- Supply plenum 14 inches high, with no distribution ducting, 2-6 pressure control zones, cable trays for voice and data distribution, and no sprinklers or moisture detection or management devices. Carpet tiles offset as opposed to aligned.
- Rooftop or floor by floor packaged heating/cooling units with VAV control serving swirl diffusers in the interior and fan powered boxes in the perimeter ducted to linear bar grille diffusers, or a York Flexsys system.
- The building would be commissioned by a combination of contractor and operations staff; the operations staff would likely not be trained in the principles of UFAD.
APPENDIX A – SURVEY COMMENTS

ARCHITECTURAL SECTION

- The UFAD system has been a major disappointment. Construction costs were higher. We have had higher energy costs, difficulty in maintaining the proper pressure, temperature. Requires significant intervention to run the system. New construction requires special attention to reduce leaks, maintain pressure. Only real benefit has been ease of reconfigurations.

- In conjunction with suspended direct/indirect lighting, the building configuration has been very comfortable for the user.

- The 2-story library was built over a single level under-building parking garage. The UFAD space allowed steel column base plates to be bolted to 12-inch thick formed and poured-in-place concrete first floor slab that provided 3-hour area separation with minimal concern for impact of structure on floor finishes and column enclosures.

ELECTRICAL SECTION

- The furniture system was existing 3 circuits. We used pre-fabricated flex cable with hard connections to furniture whips and data only floor boxes for work station voice and data. All cable was Giga bit cat VI.

- Generally, 2 types of power was supplied to each workstation, one UPS and one standard power with an average of 2 workstations on each UPS and standard power circuit for an average of 1 circuit per workstation.

MECHANICAL SECTION

- Floors 3 - 12 were primarily open office and used an open floor plenum with swirl and linear diffusers ducted from VAV’s with reheat on the perimeter. Floor 13 is the executive floor and all offices and conference rooms walls ran underfloor. These rooms primarily were served by series fan powered VAV’s with electric reheats discharging into the floor plenum and delivered through swirls. The two senior executive’s suites were served by a fan coil unit.

- This building was designed in 1998 and completed in early 2000. Design drawings are currently not available. This building was the first of its kind particularly in LA area. Water detection was used only around the areas where we had coffee stations. The ground floor restaurant area used an overhead system. Main conference center areas were served by UFAD and supplemented by overhead heat pumps to address cooling loads.

- A lot of air leaked from the supply plenum to the ceiling either through partitions or through expansion joints. This caused an inefficient operation of the fans producing high energy cost. Leakage was over 20%. There were very few complaints after the system was balanced.

- This project converted the ground floor of a six story parking garage to office space. Primary air conditioning systems are air-cooled DX split systems with the indoor units sitting on the raised floor, and the outdoor units on the top parking level. There were two interior zones, one fed by six AC units, and one fed by one AC unit; there was, on average, one air input per 14,000 square feet.

- Initial challenge balancing system due to some choke points in the plenum which resulted in being unable to maintain plenum pressure to a few areas. Booster fan used in plenum to overcome problem.
OPERATIONS SECTION

- We currently have three UFAD systems operating and one under construction. I believe given the right application the UFAD positive points definitely outweigh the negatives and the learning curve issues. I am a firm believer in the system.

- I have a comparative schedule of values for our project that highlights the bid costs for building our space sustainable vs. traditional. (UFAD with demountable walls vs. ceiling hung fan coils and gypsum wallboard)...You are welcome to this information. Also, our project was awarded the Energy Star Rating for High Performance Buildings and The USGBC LEED-CI certification.

- There are too many things to list now but if I had more time I am sure I could add more problems I have had.

- This is an 8 story building with only the top floor having UFAD. In the first year and a half of operation, the UFAD floor has consistently used more energy that the rest of the building (Even accounting for the roof load and its reduced footprint.) It has produced similar levels of comfort. We are currently negotiating for the construction of a three story, 180,000 sf office space with UFAD. It should be completed in about 18 months.

- Our UFAD system is common to both the interior and perimeter zones; hence, zoning is difficult. Furthermore, the lack of local re-heats for the perimeter has caused many complaints of hot/cold conditions throughout the building.

- I would be interested in the cost/benefit analysis of a raised floor system. Again, I was not here in the design phase so I do not know what benefits were identified. I believe that having a raised floor system takes longer to install that above ceiling systems (t-bar ceiling goes in faster than the floor system), so persons wanting to install this type of system should allow additional time for installation.