Benefits of Micro-Zone HVAC Systems

Of the three major utility systems available in most buildings – lighting, plumbing, and heating, ventilation and air conditioning ("HVAC"); HVAC is the only system that is often not controlled at the individual or room level. Generally, one finds light switches in every room, not one master light switch that controls all of the lights in the building. Similarly, water faucets are typically controlled by the individual users. Users do not have to cause the water to run everywhere in the building when they want water in one location. Most traditional HVAC systems, however, have one thermostat that controls many rooms (these multiple rooms comprise a single HVAC "zone"). Thus, one user often sets the thermostat to a temperature that every other occupant in the same HVAC zone has to accept.

In contrast, "micro-zoning" an HVAC system provides users individual temperature control in rooms, offices, or workspaces. These spaces are micro-zones. This is generically accomplished by: (1) providing a means to both monitor the actual temperature in each micro-zone and set the desired temperature for the micro-zone; (2) providing a means to control the flow of air into the micro-zone, often through the use of dampers that open or close to allow or prevent air flow; and (3) controlling the HVAC system so that it turns on or off as needed to supply either hot or cold air.

Numerous studies have shown that micro-zone systems provide two primary benefits: energy savings and increased comfort for the occupants. A compelling payback analysis can be made for micro-zoning by demonstrating the energy savings through significant utility cost reductions and increased employee productivity due to the improvement in employee comfort.

The remainder of this paper will summarize the energy savings and comfort benefits documented in previous studies and analyses.

Commercial Building Energy Consumption

Several government agencies and non-profit organizations have analyzed and documented the impact that the commercial building market has on our nation's energy consumption. The U.S. Department of Energy estimates that nearly 20% of energy use in the U.S. is dedicated to commercial buildings[1]. The U.S. Green Business Council (USGBC) estimates commercial building energy consumption to be 60% of total U.S. electricity usage[2]. These numbers are staggering. By way of example, in California where just 2% of commercial building energy use is dedicated to heating, that 2% translates into 82,832 GWh of energy consumed annually[3]. This is equal to the annual energy consumption of all of Belgium[4].

There is general agreement that HVAC systems account for the greatest share of energy costs within the commercial building market. The U.S. Department of Energy estimates that HVAC systems may consume up to 60% of the energy used in commercial buildings nationwide.

Energy Savings

"Micro-zoning" is a well established concept in HVAC system design that can lead to significant energy savings. Numerous micro-zone systems have been shown to reduce energy costs associated with heating, cooling, and ventilation. The following is a review of published information documenting concrete energy savings as a result of micro-zoning and micro-zone systems.

As the premier organization for national green building guidelines, USGBC formulated the LEED (Leadership in Energy and Environmental Design) green building criteria to rate and recognize energy efficient buildings. According to USGBC, efficient HVAC systems can reduce up to 60% of energy costs related to heating and cooling a building. USGBC's energy efficiency guidelines for HVAC systems include:

- Engineering for dynamic thermal zone sizing
- Engineering for individual control of thermal conditions

Buildings that install equipment and follow practices that support those two guidelines, earn credits that go toward achieving a specific LEED designation, i.e. Silver, Gold, or Platinum.

Micro-zoning supports both of these LEED guidelines[5]. Dynamic thermal zone sizing refers to an HVAC system with zones that can be adjusted for user or space changes. Micro-zones restrict a specific thermal condition to a personal airspace, allowing each user individual temperature control, without interfering with others, as well as the opportunity to limit airflow to unoccupied spaces or naturally better ventilated areas. By minimizing the interior area receiving airflow through smaller, more discrete zones, HVAC energy savings can be achieved.

R.J. Rose and J. Dozier studied various HVAC system controls for the Environmental Protection Agency, some of which allowed for control over individual rooms. The analyzed micro-zone systems reported energy savings of 43% compared to conventional HVAC systems[6] with larger zones.

Zonefirst™, a manufacturer of controls and dampers used for micro-zoning HVAC systems, conducted independent product tests for energy efficiency in multi-level structures and found that a 20% to 30% increase in energy efficiency could be achieved through micro-zoning such structures[7].

A report prepared for TIAX, a company that specializes in bringing new inventions and technologies to market, found potential energy savings of 0.07 quads (or $7*10^{13}$ BTU) across the entire U.S. office market with micro-zone HVAC technology[8]. This is enough energy to power the entire state of New York for a week[9]. Moreover, the system tested used additional fans to redirect airflow, adding equipment and operational costs. Without these costs, even more energy could be saved.

Fred Bauman, P.E., a researcher at the University of California, Berkeley who specializes in thermal environment studies led a team that conducted field test experiments showing that employees regularly spend up to 30% of business hours away from their workstations (this includes lunch breaks). This large proportion of time is an indicator of the amount of HVAC output that is routinely wasted and could be significantly reduced by feedback mechanisms in smaller HVAC zones that would have the ability to stop airflow during unoccupied hours [10].

Bauman, along with Drs. Arens and Brager from the Center for the Built Environment (CBE) at UC Berkeley, continued this study focusing on the feedback mechanisms available at the time – in this case, occupancy sensors. When micro-zone systems were properly coupled with occupancy sensors and the central air handler was set to react to wider temperature variances, the overall system reduced energy consumption by 18%. The experimental system demonstrated that control at the micro-zone level resulted in a greater conservation of heating and cooling output. The researchers predicted that this type of micro-zone system could yield savings equivalent to 21% of the energy used per square foot of an average commercial building[10].

The U.S. Department of Energy has sophisticated building simulation software for energy usage analysis. CBE researchers applied this building simulation software to over 120 new commercial building scenarios. The CBE researchers examined the impact of micro-zoning with the use of a Lateral Thermal Diffuser (LTD). They found an energy savings in new commercial buildings with these micro-zone systems of nearly 4 KWh per square foot when compared to the simulations of standard, large-zoned HVAC systems.

The simulation program was also performed focusing on the San Jose, CA commercial office market (due to potentially increased new office construction). a milder and relatively constant climate, including a similar micro-zone system (here known as a Personal Environment Module, or PEM). The PEM was very similar to the LTD as both had desk-mounted controls; however the PEM's diffusers released naturally ventilated flowing air above the desk to create an individual micro-zone. The simulation showed that, in comparison to the standard HVAC system, the PEM system in an office could save as much as 18% of the cooling energy, 18% of the distribution (fans and pumps) energy, 10% of the total electricity, and 9% of a building's total electricity cost annually[10].

UC Berkeley filed studies completed in 1994 also show the energy savings of another micro-zone system referred to as a Task Air Management (TAM) system. The TAM was able to level the usual early afternoon energy demand "spikes" as outdoor temperatures generally increased. The average of the maximum and minimum energy use was near 300 W with little variability, showing a very constant energy use leading to real savings during peak energy

use hours[10]. Demand during peak usage hours has a tremendous financial impact due to the higher rates charged by many utility companies. “Leveling off” that power demand by way of the TAM micro-zone system proved pivotal in reducing energy costs.

In another recent study conducted by CBE researchers, a Task-Ambient Conditioning (TAC) system was analyzed that allowed each user to control the temperature in a very small micro-zone, i.e the immediate environment of their individual workstation. Compared to conventional HVAC systems, the researchers observed 30% energy savings in TAC system-simulated Fresno, Oakland, and Minneapolis climates. Under extreme conditions (when the central HVAC system allowed temperatures to fall outside of the 68-82°F (20-28°C) range and more towards the outdoor temperature), the TAC systems improved energy savings by up to 40%. This data supports the positive association between use of a micro-zone system and overall energy savings[11].

HVAC studies at Oxford have concluded that giving personal control of the office environment to employees, as is the case in micro-zoning, has several potential benefits with regard to energy savings. Employees in these environments have an increased tolerance and forgiveness for temperatures outside of their stated preferences, and this saves money due to the lessened demand on HVAC systems for heating and cooling[12].

A study conducted by Bargmann Hendrie + Archetype shows the energy savings impact of three different HVAC systems: Variable air Volume and Temperature (VVT), Variable Air Volume (VAV), and a radiant ceiling system on a major building renovation. While the firm cites the radiant ceiling system as producing the greatest savings (70%), it also demonstrated that a VVT system would produce a 40% energy savings and have the lowest initial cost of the three. While the VVT system studied did not provide temperature control at the individual room level, it did operate using the same micro-zone principles on a slightly larger scale (zones were larger than individual workspaces, but did not cover whole floors of the building)[13].

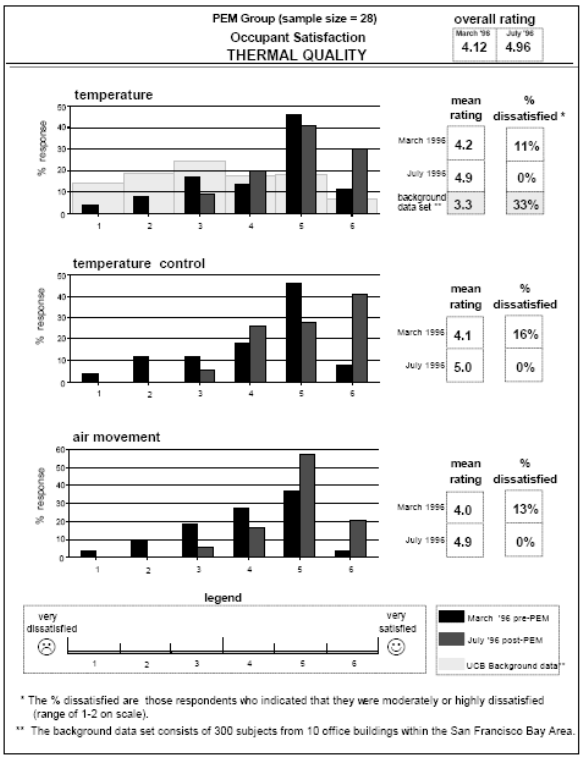
Recent research into Underfloor Air Distribution (UFAD) Systems demonstrates similar advantages to overhead micro-zone systems. With adjustable diffusers located on the floor, occupants can individually control the air entering each micro-zone. Simulation studies show an overall 48% energy savings compared to traditional overhead air distributions systems, and a 40% reduction during peak operating hours [14].

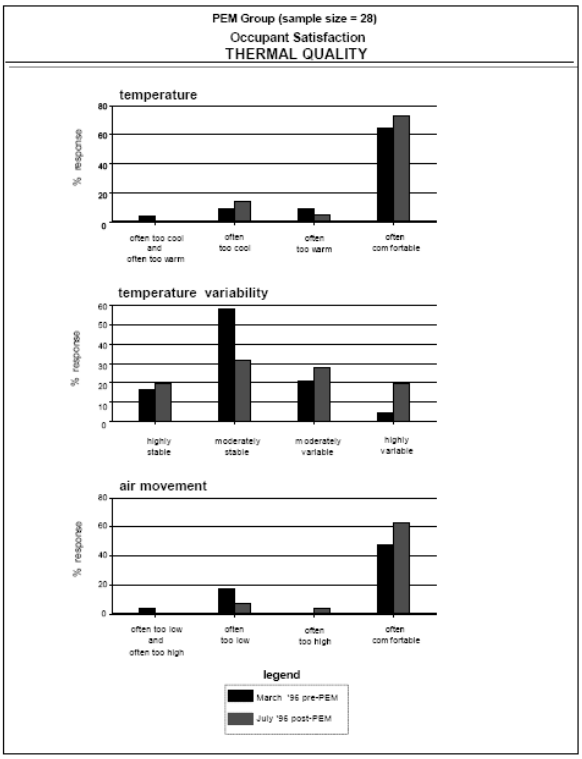
Increased Comfort

In addition to energy savings, micro-zone systems also provide the benefit of enhancing comfort. The ability to set one’s own temperature increases occupant comfort and leads to improved morale, thereby creating a more pleasant and productive work environment. A recent study at Cornell University’s Ergonomics Department found that as many as 74% of building occupants are dissatisfied with their thermal environment[15]. The following studies show correlations between individualized control over temperature, comfort, and overall satisfaction in office settings.

In the aforementioned 1994 UC Berkeley study, Bauman et al. surveyed 79 occupants before and after the installation of TAM modules, a form of micro-zone system, in an Arizona office and found overall increases in satisfaction with air movement and circulation (64%), thermal comfort (52%), and temperature (46%)[16].

In 1996, Bauman et al. surveyed office occupants in San Francisco before and after the installation of PEMs (Personal Environment Modules, which allow manual control of air flow direction and velocity by each individual user in addition to lighting and background noise). The following chart shows the results for one of the tested categories, “Thermal Quality”. The left graphs display the overall quantitative scale responses in each subcategory of temperature, temperature control, and air movement. The graphs on the right display the proporti respondents who gave each response to a given prompt concerning temperature, temperature variability, a movement. On all graphs, the darker bar represents the pre-installation results; the lighter bar represents installation of PEM results. It shows a large proportion of users responded as highly satisfied with thei environment. Perhaps even more impressive is the almost nonexistent proportion of users dissatisfied b implementation of the micro-zone system.





Hellwig, Brasche, and Bischof surveyed occupants in 16 office buildings, half of which were thermally regulated by standard large-zone HVAC systems, the other half regulated by operable windows and outside air. They found 27% higher satisfaction response amongst occupants with access to windows over those only serviced by the HVAC system, an increase they attributed to the occupant's individual control over the window. Occupants were also polled on whether they felt they had control over their office environment. This feeling was only half as prevalent amongst those in HVAC ventilated buildings when compared to the window-ventilated employees[18]. Although operable windows do not create a micro-zone of thermally controlled air, they do replicate the ability to control airflow similar to the control afforded by a micro-zone system and likewise, the same degree of satisfaction.

Field surveys show that with TAM micro-zones, employees feel an overall increased level of control and more importantly state that they are satisfied with this amount of control (67% of respondents). The surveyed responses to the question "How much control do you feel you have over the thermal conditions of [the] workplace?" are presented in the upper graph of the below chart while responses to the question "How satisfied are you with this level of control?" are presented in the lower graph:

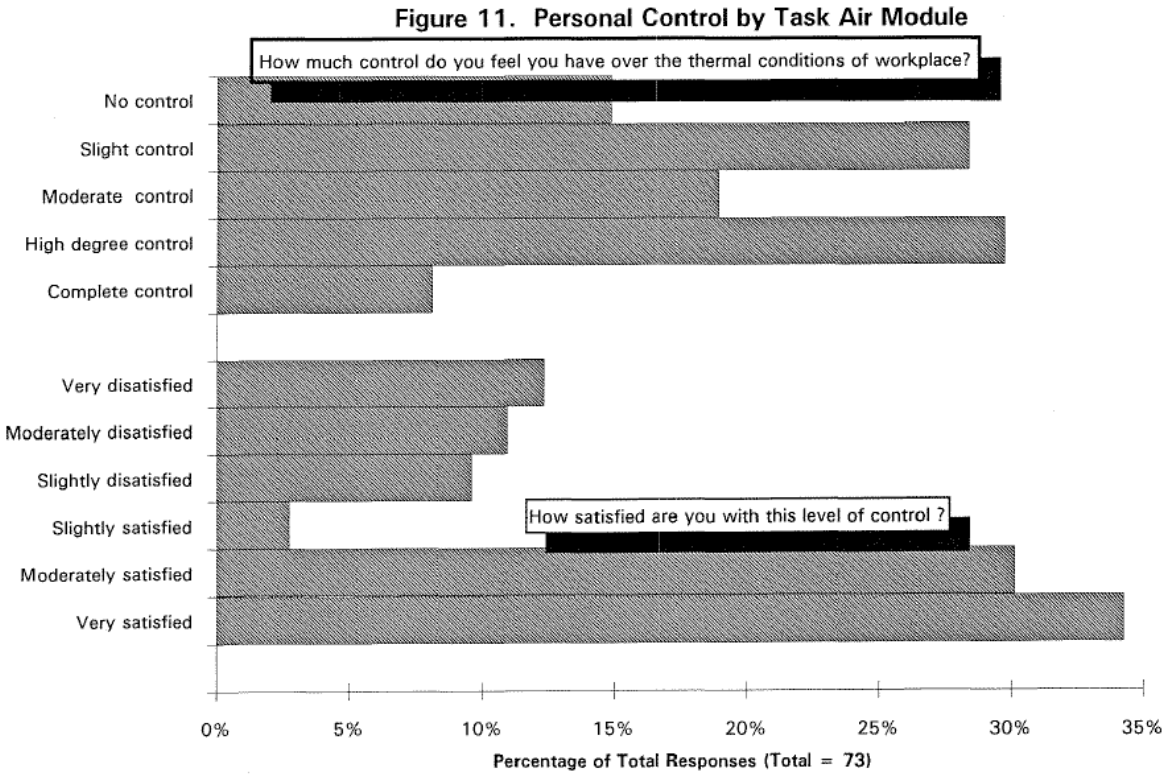


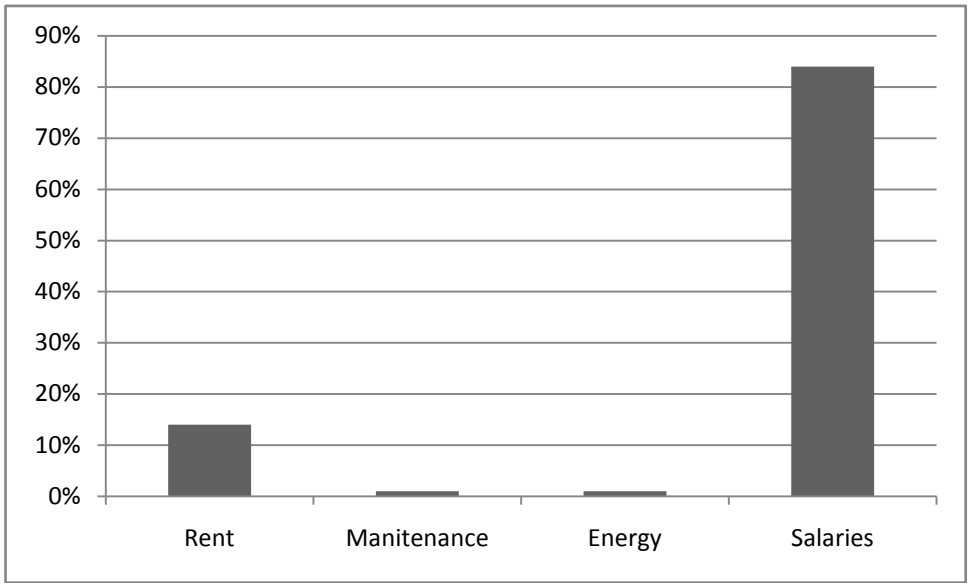
Figure 11. Personal Control by Task Air Module

Studies by environmental psychologists So Young Lee and Jay Brand have shown a strong correlation between self-efficacy, a feeling brought on by a sense of control at the individual level over factors such as temperature, and job satisfaction (0.25 r-value), comfort, satisfaction with the environment (0.52) and group cohesiveness (0.17). Lee and Brand used office surveys and interviews to determine their findings. All stated findings were significant to at least $p<0.05$ [20].

Productivity Enhancement

Lee and Brand also found another interesting correlation. Job satisfaction was strongly linked to individual performance with a 0.73 correlation coefficient[20]. In a comfortable environment, distractions are less likely to occur, workers feel confident about their abilities, and creativity goes unhindered. Enhanced individual worker productivity due to increased office comfort and employee self-efficacy can have large paybacks for employers in terms of productivity gains. The magnitude of these benefits is best understood by comparing total potential cost savings. Earlier, the energy savings potential of micro-zoning was shown to have significant payback – up to 30%+ of energy costs. However, this savings pales in comparison to the economic benefits of productivity increases brought about by micro-zoning. The difference can be seen by looking at a typical company's space related costs on a per square foot basis. Whole Building Design Guide breaks down various operating costs as shown in the following bar chart[21]:

Breakdown of Various Components of Total Space Occupancy Costs



Any gains in employee productivity can lead to enormous operating cost savings due to the large percentage of costs allocated to salaries. **As shown in the above chart, a 1% increase in productivity could nearly offset a company's entire annual energy cost!**

The following studies have shown large improvements in productivity due to micro-zone HVAC systems.

The West Bend Mutual Insurance company relocation in 1992 is one of the most compelling case studies available for micro-zone research. The company's move into its West Bend, Wisconsin office was studied by The Center for Architectural Research and the Center for Services Research and Education at the Rensselaer Polytechnic Institute (RPI). When West Bend Mutual built the then-new facility in the early 1990's, micro-zone HVAC equipment (an Environmentally Responsive Workstation or ERW) was installed in each office, providing individual control over the temperature, lighting, and ambient noise for each individual. The ERWs were also linked to occupancy sensors and shut down when the office was not in use to save energy. West Bend Mutual was able to carefully monitor worker productivity and shared this data with the investigating teams. Productivity data in the old building in the 26 weeks before the move and in the new building for 24 weeks after the move were analyzed. The study teams observed a 16% jump in productivity in the new building overall with an estimated 3-6% increase in productivity based on the ERW HVAC system alone alone[22].

In 1997, Bauman et al. found PEMs implemented in San Francisco's Bank of America buildings increased employee productivity by an estimated 2.8% using the same productivity measures as those used at the West Bend Mutual building by RPI. These findings positively correlated with increases in thermal satisfaction based on direct occupant survey responses[23].

The Carnegie Mellon Building Investment Decision Support (BIDS) team, a task force established to weigh cost benefits of office improvement technology, found annual returns on investment ranging from 23% to 205% for installed micro-zone systems when productivity increases were taken into account[24]. All systems show productivity increases varying from 0.2% to 3%.

Several researchers from the Center for Building Environmental Studies and Testing in Cairo, Egypt compiled studies linking indoor environmental air quality to productivity. One study of office building occupants in the Netherlands showed a 34% reduction in absences when employees were given control over thermal conditions in their workspace. The decrease in absent employee time leads to increases in individual employee productivity as well as group productivity. Employee self-examinations of productivity also show marked increases when presented

with controllable thermal conditions[25]. While the researchers conclude that no exact ratio exists between comfort improvement and productivity improvement, they do note that giving employees control over their environment strengthens the relationship between the employee and the company, and this leads to increased productivity, most likely arising from a sense of self-efficacy.

Self-assessed productivity and unsatisfactory indoor environment were the two variables most strongly correlated (-0.49 r-value with $p<0.01$) in a United Kingdom study on the impact of office environments on building occupants. The data compiled for the University of Reading, Department of Construction Management and Engineering indicates that a 10% productivity increase is attainable through office environment improvements alone. Among the negative factors hindering worker productivity, thermal discomfort was the most common complaint among those surveyed[26].

In their previously mentioned CBE research report, Zhang et al. show that there are significant improvements for rate and accuracy at which subjects can perform simple mathematical operations and solve logic puzzles while using a TAC system – a form of micro-zoning[27].

The Carnegie Mellon BIDS team also specifically analyzed cost savings of high performance building technology (such as improved HVAC systems) in terms of absenteeism reduction, churn costs, and employee value. Based on 2002 U.S. national average salaries, employers could save $4,500/employee annually for every 1% increase in overall employee productivity. This 1% increase could be achieved from reducing absenteeism, employee churn, and improving employee retention[28].

The effect of individual employee control in the office can be especially beneficial to the managerial staff. A report by Oxford Sustainable Development researchers Michael Humphreys and J. Fergus Nicol explores the idea that managers regularly dealing with temperature related complaints can relinquish these tasks and move on to more productive business in a micro-zone system[29]. An English building meta-survey of eight major office buildings known as the PROBE study also verifies this claim. The survey noted more self-sufficient employees, who are increasingly likely to solve problems on their own in other areas of work when given a fair degree of control over their environment. The survey noted that more autonomous employees allowed the managerial staff greater freedom to manage other aspects of the business[30].

Summary

The overall impact of micro-zone HVAC systems can be seen in reduced energy utilization, energy cost savings, increased office environment satisfaction and comfort, and improved productivity brought about by the enhanced environment. Studies cited herein demonstrate energy savings of up to 30% or more. Other studies document significant increases in employees' sense of comfort and general job satisfaction as a result of having control over their personal environments. Finally, several studies document the financial benefits of the increased productivity that results from enhanced employee comfort.

In summary, years of research and numerous studies by qualified independent researchers conclusively link micro-zone HVAC systems to significant cost, comfort and conservation benefits. The economic payback on these systems is compelling and the resulting intangible benefits are arguably even more resounding.

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