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LOCALIZED THERMAL DISTRIBUTION FOR OFFICE BUILDINGS

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LOCALIZED THERMAL DISTRIBUTION FOR OFFICE BUILDINGS

Final Report - Phase III

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Executive Summary

ABSTRACT

This final report presents the results of research completed during Phase III of the project, "Localized Thermal Distribution (LTD) for Office Buildings," sponsored by the California Institute for Energy Efficiency. The project team consisted of researchers from the University of California at Berkeley, Lawrence Berkeley Laboratory, and Humboldt State University. Work was performed in three task areas: (1) Whole-Building Energy Simulations, (2) Field Studies, and (3) LTD Engineering and Applications Guide Outline. Following this *Executive Summary*, the final report is presented in four separate parts, each addressing one of the above task areas with two describing work on the two separate field studies.

INTRODUCTION

During recent years an increasing amount of attention has been paid to air distribution systems that individually condition the immediate environments of office workers within their workstations. As with task lighting systems, the controls for these systems are partially or entirely decentralized and under the control of the occupants. Typically, the occupant has control over the speed and direction, and in some cases the temperature, of the incoming air supply. The systems have been variously called "task/ambient conditioning," "localized thermal distribution," and "personalized air conditioning" systems. These task/ambient conditioning systems provide supply air and (in some cases) radiant heating directly into the workstation, either through a raised access floor system, or in conjunction with the workstation furniture and partitions.

The goal of this project is to quantify and improve the effectiveness and energy efficiency of localized thermal distribution (LTD) systems for office buildings. LTD systems have the potential to improve the energy efficiency of the building's air distribution system by enabling only the local workstation environments to be tightly controlled while relaxing the energy and comfort requirements in the less critical surrounding spaces. In addition, LTD systems have demonstrated significant improvements in thermal comfort, ventilation performance, and environmental satisfaction among office workers, and as a result, increased levels of worker productivity are also likely to emerge as more LTD systems are introduced.

During the past four years, this project has examined LTD systems in order to quantify their performance in energy terms, compared with comparable conventional systems. The systems' performance in conditioning local workspaces has been quantified, in order to provide the data needed for modeling them in building energy simulation programs, and to identify key areas where their energy efficiency might be improved. Available results from field studies of operational LTD systems have also been collected to provide practical information on current operation and energy performance of LTD systems. A survey was completed to assess the building industry's current perspective on LTD technology and to identify the major barriers to greater acceptance and development of LTD technology by the industry. Applicable energy and indoor environment codes and standards have also been reviewed to identify areas where changes may be required to encourage energy efficiency in the installation and operation of such systems. A full description of work completed during previous phases of this project is presented by Bauman et al. (1991) and Bauman et al. (1992).

The results from this project are also intended to serve the utilities by projecting the energy use implications of LTD technology. The energy savings potential for LTD technology in new construction office buildings is estimated to be approximately 4 KWh/ft^2-yr based on DOE-2 energy simulations (described in this report). Similarly, the peak demand savings potential is estimated to be approximately 1 W/ft^2. These savings represent the difference between an inefficient LTD system (i.e., current practice) and an energy efficient (well-designed) LTD system. The total predicted energy savings are equal to 21% of the energy use density of an office building containing a well-designed conventional air distribution system (variable-air-volume system with economizer). Installation of a well-designed conventional system would yield approximately half the estimated savings relative to the current practice for LTD systems.

SUMMARY

During Phase III, work was carried out in three task areas. Task 1, Whole-Building Energy Simulations, was carried out primarily by Humboldt State University (HSU) with assistance from UC Berkeley (UCB). UCB had lead responsibility with some assistance from Lawrence Berkeley Laboratory (LBL) on Task 2, Field Studies, and Task 3, LTD Engineering and Applications Guide Outline. The three task areas are listed below with a brief action summary.

Task 1: Whole-Building Energy Simulations (Milestone 1.2)

Action summary: More than 120 annual simulations were completed using the DOE-2.1E computer program to investigate the energy performance and operating costs of a prototypical new California office building using a variety of LTD system configurations and control strategies in comparison to the same building with a conventional ceiling-based air distribution system. Two basic LTD systems were investigated: (1) a floor-based system modeled after Tate's Task Air Modules (TAMs) that are installed as part of a raised access floor system (see Figure 1), and (2) a desktop-based system modeled after Johnson Control's Personal Environmental Modules (PEMs) that deliver the air through supply nozzles at desk height and are controlled by an occupancy sensor (see Figure 2).

The operational control strategies investigated in this study are:

- allowing a limited degree of temperature stratification to occur in regions which do not affect occupant comfort;
- exploring the workstation floor plan and the effects of additional areas, such as aisleways and approaches, which are held to less stringent comfort levels;
- permitting localized occupied areas to vary somewhat more in air temperature over the course of the day because the occupant has greater individual control over the local thermal conditions;
- placing a percentage of the workstation lighting and equipment under the control of an occupancy sensor, which in the occupant's absence, reduces electrical demand; and

- precooling of the building thermal mass by nighttime venting, to reduce daytime chiller demands.

Simulations were performed for two California climates: Fresno and San Jose. The development of simulation models for the two LTD systems are described and the simulation results are presented and discussed in **Section 1** of this final report.

Task 2: Field Studies (Milestones 1.4 and 1.5)

Action summary: The purpose of this task was to perform two field studies in buildings having operational LTD systems. The primary focus of each field study was to measure energy use patterns of the LTD units in order to characterize system design and operating parameters affecting energy performance. In addition, the experimental plan called for us to (1) measure thermal conditions in the building, (2) obtain occupant survey data describing comfort, satisfaction, and LTD system use patterns, (3) monitor or obtain data describing the thermal conditions in the supply and return lines of the building's air distribution system, and (4) collect additional relevant information from the building manager regarding mechanical system design, operating strategies, and other factors influencing building energy consumption. The data gathered from the field studies is intended to help put the results of the laboratory experiments and building energy simulations into perspective by improving our understanding of the system-based issues associated with the energy efficient operation and performance of LTD systems.

Of the two field study sites, one uses underfloor air distribution with Task Air Modules (TAMs), manufactured by Tate Access Floors, Jessup, MD, and the other uses desk-mounted Personal Environmental Modules (PEMs), manufactured by Johnson Controls, Milwaukee, WI. Both systems have been tested in the Controlled Environment Chamber at UC Berkeley during Phases I and II of the project. The first field study was performed in an engineering office building near Phoenix, Arizona. The results of this study, completed in December 1993, are presented and discussed in **Section 2** of this report. The second field study is currently ongoing at PG&E's Advanced Office Systems Testbed (AOST) facility in San Ramon. The status of this study is briefly described in **Section 3** of this report. A final field study report will be submitted upon completion of the field tests in the AOST facility.

Task 3: LTD Engineering and Applications Guide Outline (Milestone 1.6)

Action Summary: The ultimate goal of work in this area is to develop an engineering and applications guide summarizing recommended methods for specifying, installing, and operating energy efficient LTD systems. The guide will be based on all major findings of the project, including: (1) laboratory experiments, (2) field studies, (3) energy simulations, (4) industry survey, and (5) applicable building standards and codes. We will also incorporate other relevant results and information available from the literature and industry. An outline for the guide, entitled "Task/Ambient Conditioning Systems: Engineering and Applications Guidelines," is presented in **Section 4** of this report.

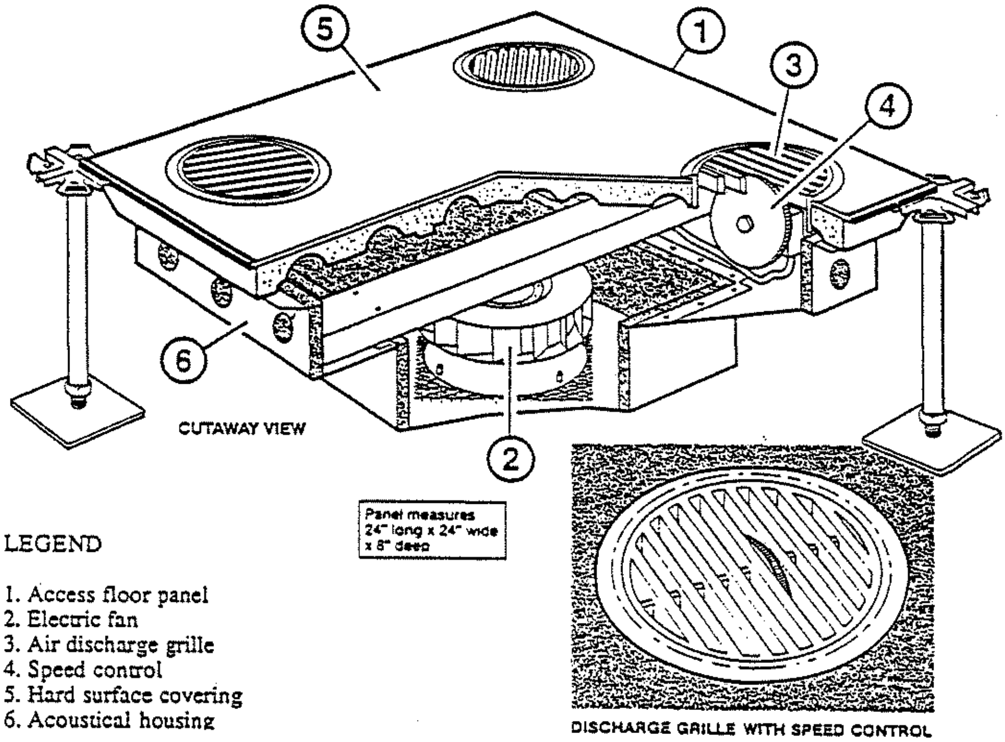

Figure 1. Floor Supply Module

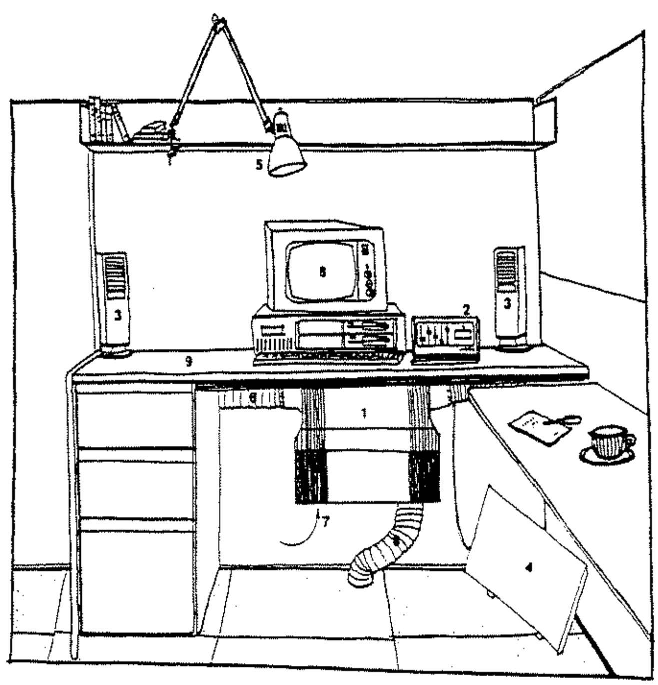

Figure 2. Desk-Mounted Supply System

TECHNOLOGY TRANSFER

Several technical papers and presentations describing results from this project were completed and presented, as listed below.

1. Bauman, F.S., E.A. Arens, S. Tanabe, H. Zhang, and A. Baharlo. In press. "Testing and Optimizing the Performance of a Floor-Based Task Conditioning System." To be published in *Energy and Buildings*.

2. Faulkner, D., W.J. Fisk, and D.P. Sullivan. In press. "Indoor Airflow and Pollutant Removal in a Room with Floor-Based Task Ventilation: Results of Additional Experiments." Submitted to *Building and Environment*.

3. Bauman, F. "Improving the Environmental Quality and Energy Performance of Office Buildings." Seminar presented at the PG&E Energy Center, San Francisco, CA, 17 February 1994.

4. Tanabe, S., E. Arens, F. Bauman, H. Zhang, and T. Madsen. 1994. "Evaluating Thermal Environments By Using a Thermal Manikin with Controlled Skin Surface Temperature." Presented at the ASHRAE Winter Meeting, January 1994, New Orleans, LA, and published in *ASHRAE Transactions*, Vol. 100, Pt. 1, 10 pp.

5. Arens, E.A., and F.S. Bauman. 1994. "Improving the Performance of Task Conditioning Systems." Presented and published in *Proceedings*, International Symposium: Issues on Task-Ambient Conditioning. Nagoya University, Nagoya, Japan, 11 January, pp. 77-94.

6. Bauman, F., and M. McClintock. 1993. "A Study of Occupant Comfort and Workstation Performance in PG&E's Advanced Office Systems Testbed." Final Report to PG&E Research and Development. Center for Environmental Design Research, University of California, Berkeley, May, 135 pp.

7. Bauman, F., H. Zhang, E. Arens, and C. Benton. 1993. "Localized Comfort Control with a Desktop Task Conditioning System: Laboratory and Field Measurements." Presented at the ASHRAE Annual Meeting, June 1993, Denver, CO, and published in *ASHRAE Transactions*, Vol. 99, Pt. 2, pp. 733-749.

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Bauman, F., K. Heinemeier, H. Zhang, A. Sharag-Eldin, E. Arens, W. Fisk, D. Faulkner, D. Pih, P. McNeel, and D. Sullivan. 1991. "Localized Thermal Distribution for Office Buildings: Final Report - Phase I." Center for Environmental Design Research, University of California, June, 81 pp.

SECTION 1

Whole-Building Energy Simulations

by

Tom Borgers and Fred Bauman

WHOLE-BUILDING ENERGY SIMULATIONS

Introduction

The purpose of this task was to use the DOE-2.1E computer program to examine the energy performance of a prototypical new California office building using a variety of LTD system configurations and control strategies in comparison to the same building with a conventional ceiling supply-and-return air distribution system. Two basic LTD systems have been investigated, both of which have been studied through laboratory and field measurements in this project. Both systems feature local fan units that allow the nearby occupant to control their immediate thermal environment by changing the direction and amount of supply air. The two LTD systems are: (1) a floor-based system modeled after Tate's Task Air Modules (TAMs) that are installed as part of a raised access floor system, and (2) a desktop-based system modeled after Johnson Control's Personal Environmental Modules (PEMs) that deliver the air through supply nozzles at desk height and are controlled by an occupancy sensor.

There are a variety of approaches which have been explored in practice, and are worthy of attempting some degree of comparison as to their effectiveness. The techniques which are given the most attention in this study are:

- allowing a limited degree of temperature stratification to occur in regions which do not affect occupant comfort;
- exploring the workstation floor plan and the effects of additional areas, such as aisleways and approaches, which are held to less stringent comfort levels;
- permitting localized occupied areas to vary somewhat more in air temperature over the course of the day because the occupant has greater individual control over the local thermal conditions;
- placing a percentage of the workstation lighting and equipment under the control of an occupancy sensor, which in the occupant's absence, reduces electrical demand; and
- precooling of the building thermal mass by nighttime venting, to reduce daytime chiller demands.

Simulations were planned for three California climates, representing areas of potentially rapid growth in new office construction: Fresno, San Jose, and San Bernardino. After several preliminary simulations were performed for San Bernardino and compared with those of Fresno, it was decided that to a large degree, the conclusions as to preferred strategies would be the same for both. Therefore, San Bernardino was not included. Fresno was chosen as the climate in which the most extensive model formulation work was done because of the greater temperature variability. Seventy archived year-long simulations were performed for the Fresno analysis and a set of fifty simulations were performed for the San Jose area to explore the differences in performance between an inland and coastal climate.

The background and development of simulation models for the two LTD systems are described in greater detail below. Representative results of simulation efforts are then presented, and assessments made regarding the effectiveness of the technique or combination of techniques investigated.

In the recent decade there has been a trend toward more intense use of space in the typical commercial building, one example of which is the adoption of the "open" floor plan. Heating, cooling and ventilation practices have had to adapt to this configuration in a manner that maintains proper comfort to all occupants. One such application frequently used in South Africa is described by Spoormaker (1990) and is based upon cooling systems that had been previously used almost exclusively for conditioning the older mainframe computer installations. The system incorporates the open underfloor plenum as the supply route for conditioned air which is admitted to the occupied space above through manually operable and relocatable terminal fan/diffuser units (TAMs) positioned close to an occupant's workspace. Such installations routinely circulate nearly 12 air changes per hour, depending upon occupant density. Approximately 16 to 20 percent is primary air containing 50 percent outside air and 50 percent recirculated air. The remaining 80 to 84 percent is drawn back into the floor plenum from near ceiling level, mixed with the primary air and readmitted as supply air through the floor diffusers. The typical range of room air temperature variation found in such installations is about 4°C (7°F) over the course of the day. The occupant has control of an effective range of about 2°C (3.6°F) by manipulating local air speed and direction of air flow [Spoormaker 1990].

The primary energy advantages over conventional ducted air distribution design are dependent upon the reduced pressures required for air delivery through the open plenum supply configuration, the ability to precool the building structure within the plenum using nighttime ventilation, and the fact that depending upon occupant density, localized regions of the typical office space may be allowed to fluctuate beyond the more common tightly controlled temperature range. On the other hand, the major energy disadvantages of this floor-based LTD system are the operation of many small individual supply fans throughout the building, and the fact that for California climates, where air-side economizer operation is advantageous, the limited primary fan capacity may restrict real-time cooling opportunities.

Modeling of Air Distribution System

It is necessary to briefly describe the air delivery system used in the model of the floor-based system. Some of the details are difficult to incorporate directly into the model using DOE-2 input instructions. There is no mention of return fan power requirements, but there are three levels of supply fans in this system, and their purposes are described below.

The primary fan, the first level, is responsible for supplying the necessary fresh air and filtering of recirculated air, as well as providing humidification, dehumidification, and part of the cooling and heating. The volume of primary supply air is constant, and is equivalent to 20 cfm per person plus an additional 20 cfm of recirculated air. Additionally, it supplies the same volume at night for slab cooling, when needed, turning off when low limit space temperature set points are reached.

The second level is local (zonal) fan coil units served by variable flow piped chilled water, which can supply additional cooling especially as might occur in perimeter areas. These units are located in the floor plenum, operate when needed, cooling the low pressure, largely recirculated, supply air in the floor plenum.

The third level of fan-driven circulation is the occupant-controlled Task Air Modules (TAMs), which are located at floor level within reach of occupants at their desks. Air discharged from these units may be directed toward or away from the occupant, or the fan motor may be turned off. These units handle all the supply air to the space.

All return or recirculated air leaves at near ceiling levels, a portion of which returns directly to the main supply fan, and the remainder is recirculated to the floor plenum, where it mixes with the incoming primary supply air for reentry to the occupied space. In the system configuration described by Spoormaker (1990), the typical air handling unit serves on the order of 10,000 to 15,000 ft^2, and can be scheduled to accommodate flexible tenant occupancy, such as weekend operation.

One of the most important modeling parameters in the floor-based system is the total air circulation rate. This value is referenced to be 8.5 $L/s\text{-}m^2$ or 1.7 cfm/ft^2 or 11.9 ACH [Spoormaker 1984]. The gross floor area per occupant is approximately 160 ft^2, and using the ventilation values described with recirculated air from the primary fan, this rate of energy use is 0.54 W/cfm, and is 16% of the total supply air. The remaining 84% of 11.9 ACH circulation is driven by the TAMs and fan coil units, and has a rate of energy use of 0.22 W/cfm. Thus, the total energy use rate of the chosen air supply volume is 0.31 W/cfm. [(1.4 primary cfm/8.5 total cfm)*0.5396 W/cfm + (8.5 cfm/8.5 cfm)*0.222 W/cfm = 0.31 W/cfm, since all the supply must pass through the TAM units]. Using this result, one may calculate a reasonable supply fan static pressure assuming above average motor/drive/wheel efficiencies to be slightly less than 2 in. H_2O.

DOE-2 does not simulate any system that has more than two layers of supply fans, nor does it simulate the two stages of cooling, one at the primary fan, and a second stage in the floor plenum, each with different specific fan power requirements. These aspects presented problems for the simulation and were approximated in the following ways.

Because all cooling was to be simulated by the DOE-2 primary system, the cost to move the primary system volume of air was determined by the occupancy of each zone served. The total required volume to meet cooling needs was first determined by simulation, and an energy use rate was then calculated for delivery of that air. This rate and the air temperature rise across the fan was determined for each simulation for each of the five simulated systems serving the office spaces in the building. There is one air handling unit for each of the four perimeter office areas, one for the office environment of the core, and an additional system to serve the hallways, restrooms, and elevator shafts. TAMs were simulated by zonal series fan-powered induction units. Series boxes were chosen because their operation is synchronous with the primary system and handle all supply air to the zone. The simulation allowed all cooling loads to be satisfied at the primary coil, but assessed delivery costs associated with the combined performance of the primary fan and the local fan coil units. The TAMs were sized to deliver 11.9 air changes per hour to each zone, but were set to higher values whenever perimeter zones indicated a greater volume was required for cooling.

Since the office areas were to be optionally modeled with stratification, an allocation scheme had to be devised to divide the supply air between the occupied zone and the upper stratified zone of each real zone. The fictitious zones, representing the upper stratified layer, have no occupants, therefore no fresh air requirements, but do generate cooling loads due to lighting, and are thermally coupled with the real zones (floor to 5.6 foot height) below and the suspended ceilings above. Just enough supply air was assigned to these zones to satisfy the cooling required to stay within the throttling range consistent with the measurements of Bauman, et al. (1991). This quantity was set for each of the 18 such zones (six zones per floor) after every trial simulation. The self sizing routine in DOE-2 did not always perform reliably, and more accurate assignments were attained manually. One of the manifestations of not quite correct sizing is the appearance of zone temperatures which are outside of the acceptable range. The supply rate determined for each stratified zone was subtracted from the 11.9 air changes per hour required for the true zone, and the remainder was the maximum air flow rate delivered to the lower zone (floor to 5.6 foot height). Because of the higher temperatures allowed above the 5.6 foot height in the office, lower overall primary volumes were required to keep these upper zones within the desired temperature range. Trial simulations were repeated and parameters were adjusted until there were no zones indicating temperatures outside respective throttling ranges for a period greater than 1% of total annual hours of operation.

Nighttime Ventilation

Nighttime venting using the floor-based system requires special attention because all venting is to be accomplished using only primary fan capacity. Recall that this capacity is limited to twice the minimum outside air requirements for full occupancy. The daytime simulation, however, required that the primary fan provide not only the central coil cooling, but also the additional cooling generated by the zone fan coil units, which brought simulated primary capacity considerably over the actual value. To properly estimate nighttime cooling of the structure, the primary fans were de-rated to correct values, requiring manual re-setting of capacities, power requirements, and temperature rises across the fans, after the correct day-time performance was established. This was necessary for each simulated variation in which nighttime venting was allowed. Fortunately, keywords are present in DOE-2 for these adjustments. Variations were also simulated in which primary plus local fan coil capacities were used at night to precool the structure, as would be the case in the conventional building where all cooling actually occurs at the primary coil.

Additional simulations were explored in which nighttime cooling is possible using oversized primary capacity fans that could be dedicated exclusively for that purpose. Each assumption required a readjustment of fan power and temperature rises. As discussed further below, nighttime cooling emerged as a challenge to optimal simulated building operation, as quite frequently, overall energy use increased when it was employed.

Thermal Coupling Between Stratified Zones

The extent of thermal coupling between the surfaces comprising the lower occupied space of a typical office enclosure (floor to 5.6 foot height) and the surfaces in the upper zone (5.6 foot to ceiling height) was approximated as though radiative exchange is the dominant means. The fact that a definite, apparently stable, stratification layer develops experimentally, indicates that at least a significant portion of thermal exchange is radiative. Verification of this assumption should be tested experimentally in the future since surface characteristics vary from building to building, and asymmetry effects exist, especially in zones which have outside walls or windows.

DOE-2 algorithms do not evaluate radiative exchanges in the calculation of heat transfer, but rely, instead, on an effective heat transfer coefficient. A separate calculation was made to estimate the magnitude of this coefficient by considering an office geometry consisting of a typical 14 ft x 14 ft floor area in the core zone of the building with a 9 ft ceiling. The measured air temperature difference between the lower and upper zones [Bauman et al. 1991] was also assumed to apply to the surfaces of each zone. This temperature difference is assumed to develop during the morning hours, then stabilizes at 2.5°C (4.5°F) for the rest of the day. The simulations assume the maximum temperature difference is reached only after four hours of occupancy, which may, in fact, be too long.

The use of view factor algebra confirmed that the exchange may be treated as a two surface enclosure, but this calculation was not extended to perimeter zones where the complications of surface temperature asymmetry arise. All surfaces were considered gray, resulting in an effective heat transfer coefficient which varied little from 4.0 W/m^2-K (0.71 Btu/ft^2-°F), over the range of experimentally measured temperature differences. Several sets of simulations were run at extended temperature differences of 10 and 15°F to note magnitude of the increase in radiative exchange, for which the approximate effective heat transfer coefficient increased to 4.1 and 4.2 W/m^2-K (0.72 and 0.74 Btu/ft^2-°F), respectively. These higher transfer rates would serve to dampen further temperature stratification.

Desktop-Based System

A variation of the LTD system described by Spoormaker is a desktop-based system (PEM) that is incorporated into the desk of a typical workstation. While it is possible to duct the primary air to the PEM unit from an overhead air distribution system (e.g., down through architectural columns), for purposes of this simulation study we used much the same approach as the floor-based TAM system described above. Supply air is again provided through an open underfloor plenum, and then is drawn through flexible ducts from the underfloor plenum to the local fan unit under the desk and delivered to the space through desktop nozzles. Due to the individual controllability of this system, it may also allow greater variations from tightly controlled space temperatures immediately adjacent to the occupant, and in addition, benefits from the energy-saving features of an occupancy sensor that turns off the unit (including fans, task lighting, and radiant heating panel) whenever the workstation is unoccupied. A more detailed description of this system is found in Bauman et al. (1993a).

The desktop-based system is modeled by assuming that each workstation contains a dedicated PEM. Workstations are grouped into clusters of four and placed in the core zones of the building. Each cluster occupies 466 gross square feet of floor space, including the approach areas immediately surrounding the workstations. There are 50 such clusters in the core zone on each of the three floors of the building. The net area attributable to the four workstations is 280 ft^2, or 14,000 ft^2 per floor. The approach areas total 9,300 ft^2 per floor and are not conditioned as carefully as the workstation area itself. These less rigidly conditioned areas can lower the overall cooling demands of the building, but are rather closely coupled to the workstation environment. Measurements [Bauman, et al. 1993a] show that it is uncommon to find these approach areas differing by more than about 1°C (2°F) from those of the workstation. As found in the floor-based system, a vertical temperature gradient does develop at almost the same floor height, but is smaller in magnitude. The simulations presented here assume the same temperature gradient as was used with the floor-based system. For purposes of comparison, the air circulation parameters of the desktop-based system simulations are also the same as those used in the floor-based system model.

Occupancy Sensor Control
A logical extension of the desktop-based system configuration is the placement of a portion of the lighting and workstation equipment under the control of occupancy sensors. Monitored office occupancy data [Bauman and McClintock 1993] revealed that, including lunch breaks, occupants in this field study spent approximately 30% of the normal business hours away from the workstation. This percentage could easily be higher in other situations. During these times, occupancy sensors can turn off task lighting, and power down or turn off various interruptable office equipment used by the occupant, and in the case of the PEMs, the small supply fan itself. This is similar in effect to the growing availability of "sleep mode" desktop computers with their monitors and hard drives.

A group of simulations was completed in which approximately 125 watts per occupant was placed under the control of an occupancy sensor to schedule the above uses in parallel with workstation occupancy. This value could very well be higher under current practice, but is admittedly a moving target as office equipment suppliers and lighting manufacturers are rapidly moving in the direction of automated power management (APM) which increasingly will have much the same effect as the simulations attempt to show [EPRI 1992].

DOE-2 does not permit scheduling of the local fan powered induction units (PEMs), thus to mimic the occupancy-sensor-controlled intermittent local fan operation, the workstation fan power is re-allocated to sensor-controlled equipment. An equivalent un-interruptable power of equipment, which typically runs constantly during occupied hours, is put in its place. All heat gain from the workstation-based fans and office equipment used in this exchange is sensible, thus does not disturb the energy balance, and allows an accounting of workstation power reductions whenever the occupant is away. Automatic reporting of such exchanges does not appear in the simulation results. The fan energy is overstated whenever occupancy sensor control for it is simulated, and it is necessary to manually calculate the reduction and enter a corrected value for reporting purposes. These adjusted values are used in all results shown in this report.

DOE-2.1E Simulation Approach

The DOE-2.1E simulation results presented below have investigated the effects of localized temperature control, increased stratification, less well-controlled space temperatures that may develop in close proximity to the occupant during the typical work day, and the novel underfloor air distribution techniques described above. The prototypical new California office building selected for study has been used previously and is described by Bauman et al. (1993b). Much of the description of the building shell, scheduling, and internal energy use is based on the work of Huang et al. (1991), who investigated the characteristics of commercial office buildings in California.

In the current study, a comparative approach is taken in which a well designed conventional variable-air-volume (VAV) system is the base case for both Fresno and San Jose simulations. The supply air temperature in all cases is 9.4°C (49°F) and is consistent with the floor plenum and workstation models described above. The base case simulations allow the use of a full air-side economizer whenever the ambient temperature is less than 21°C (70°F). The supply fan operates at 3.5 in. H_2O and the return at 1.5 in. H_2O. Several groups of simulations were completed and are described below.

Group 1: The base case building was modeled using the conventional VAV system under a variety of strategies, including (1) nighttime precooling of the building by fan-driven ventilation, (2) operating with and without an air-side economizer, and (3) using larger duct sizes requiring much lower fan pressures. Even though some of these techniques would be problematic to implement in an existing building, they are included here for comparison with the more elaborate distribution schemes that follow. At the design stage of a new building, these options could be considered in view of their potential energy savings.

Group 2: A second group of simulations used the underfloor air supply system parameters of Spoormaker, including floor-level supply grills. Various operational control options were studied, including (1) increased throttling range for space temperature control, (2) increased stratification in the space produced by the floor-to-ceiling room air distribution, (3) nighttime precooling of the building by fan-driven ventilation, and (4) operating with and without an air-side economizer. For California climates, where air-side economizer operation is advantageous, the limited primary fan capacity of the Spoormaker system may restrict real-time cooling opportunities, and therefore additional simulations for this configuration allowed a comparison of the building performance of the conventional larger primary air fan capacities versus that of the smaller primary volumes.

Group 3: A third group of simulations examined the use of the desktop air supply system in workstations in the core regions of the building. It is less common that perimeter zones have the open floor high density occupant levels, and thus, perimeter zones were assumed to have more conventional control. The operation and control strategies investigated included (1) increased throttling range for space temperature control, (2) increased stratification in the space, and (3) nighttime precooling of the building by fan-driven ventilation.

Group 4: The fourth group of simulations retained the desktop-based configuration in the core as in Group 3, but added occupancy sensor control of the personal air supply fans, task lighting, and some workstation equipment. The variables examined included (1) increased throttling range for space temperature control, (2) increased stratification in the space, (3) nighttime precooling of the building by fan-driven ventilation, (4) localized temperature variation, and (5) operating with and without an air-side economizer. In view of the energy reductions indicated by core zones under the control of occupancy sensors, additional simulations were added for the Fresno climate only to include occupancy sensor control of the perimeter zones that remain as executive suites.

Additional simulations were completed to more extensively explore the advantages of nighttime cooling if larger conventional fan capacity was in place and could be used to more rapidly cool the building during the coolest hours of diurnal temperature swings. These results are placed in the four groupings for both Fresno and San Jose.

Seventy archived year-long simulations were performed for the Fresno analysis and a set of fifty simulations were performed for the San Jose area to explore the impact of a typical inland and marine climate on the above described strategies. The simulation results are presented and discussed below.

Fresno Results

For the base case building in Fresno (standard VAV system with air-side economizer), the site energy use is 42.4 KBtu/ft^2-yr. Of the 2,113 MWh of total electricity use, 14.7% is used by the chillers, cooling tower and condenser water pumps, 6.7% is used by ventilation fans and hot and cold water circulation pumps, 0.1% is used in the mechanical room for boiler fans, 46.3% is used by lighting, 7.3% is used for elevators, and 25% is used by office equipment. Therefore, less than 22% of the total electricity is used for conditioning the building. The total gas consumption for domestic hot water and space heat is 429 MBtu. The categories of electricity use associated with lighting and office equipment are held constant in all simulations, with lighting equal to 978 MWh (3,340 MBtu) and equipment equal to 529 MWh (1,805 MBtu).

Table 1 lists annual DOE-2.1E predictions and percent change from the base case for cooling, distribution, and peak electricity use, annual total building electricity use, and annual total operating cost from the Group 1 simulations. Note that distribution energy use includes ventilation fans and chilled and hot water pumps, of which fan energy use is by far the larger quantity. Figure 1 compares annual cooling and distribution electricity use for the four simulations listed in Table 1. The results indicate that implementation of a variety of strategies on a standard VAV building can be effective in reducing energy use.

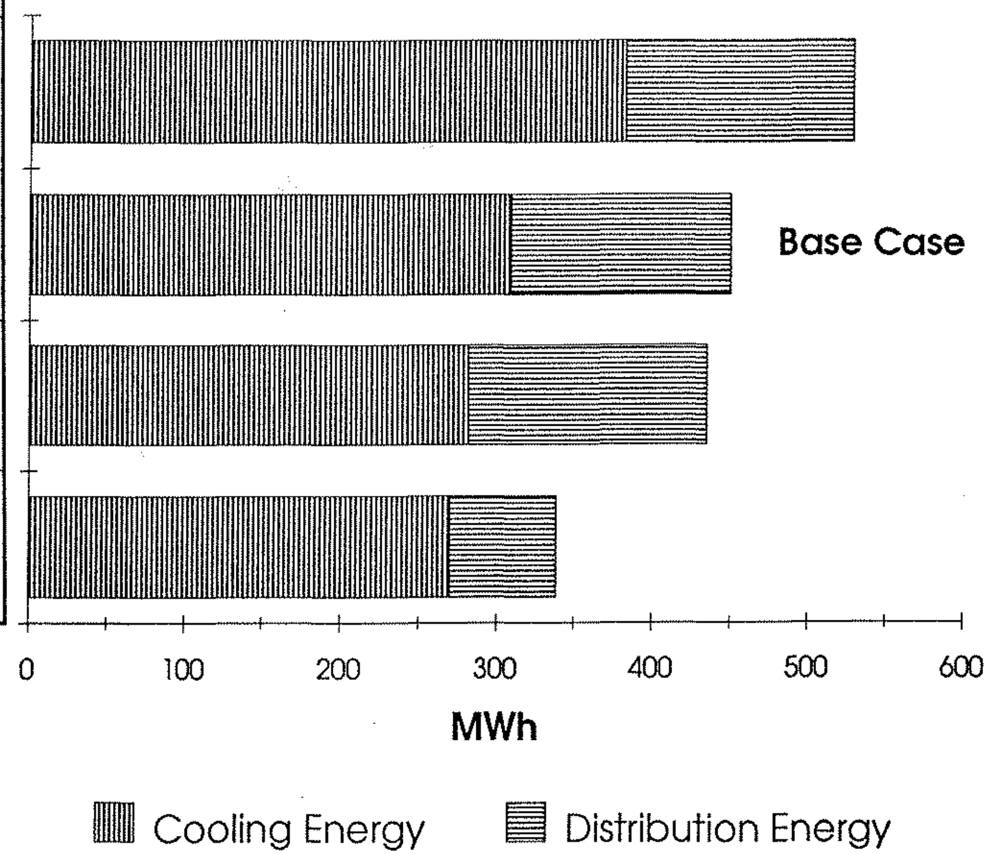
In Table 1, the first simulation, representing the base case, uses a typical VAV design duct pressure of 3.5 in. H_2O, air-side economizer (Econ), and a typical conditioned space temperature

Table 1. Standard VAV Building Annual Simulation Results (Fresno)

	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
System ID	MWh	%	MWh	%	KW	%	MWh	%	K$	%
1. Econ (Base Case)	310	0	141	0	876	0	2,113	0	234	0
2. No Econ	383	23.7	147	4.2	876	0	2,192	3.7	238	1.7
3. EcVt	282	-8.8	153	8.5	870	-0.7	2,099	-0.7	231	-1.3
4. EcVtLP	270	-12.7	69	-51.2	798	-8.9	2,002	-5.3	217	-7.3

FIGURE 1
Annual Cooling & Fan Electricity
Standard VAV System, Fresno

Econ	Vent	LoPr
X		
X	X	
X	X	X



throttling range of approximately 2.5°C (4.5°F). The second simulation does not employ the economizer (No Econ), and the third uses both economizer and nighttime ventilation for structural pre-cooling (EcVt). The fourth simulation assumes a low pressure delivery system (LP) advocated by Spoormaker (1990) in which the design pressure is approximately 2 in. H_2O. It should be mentioned that the larger daytime temperature swings allowed by Spoormaker and the localized temperature differences associated with the workstation configuration were not assumed variations of this series of base case building simulations.

The first two simulations of Table 1 demonstrate the importance of economizer operation for the Fresno climate. With no economizer option, the energy for cooling exceeds 380 MWh with a peak demand of 876 KW and 2.19 GWh of total electricity use. In comparison to the base case, cooling energy increases by 24%, distribution energy increases by 4.2%, and total building electricity by 3.7%. As indicated, when nighttime ventilation is added (EcVt), the fan energy use increases by 8.5% due to added hours of fan operation, but overall costs are reduced by 1.3% in part because of the lower cost of off-peak power when the fans are in use. If a low pressure supply air delivery system is added, more substantial savings can be realized. For this case (EcVtLP), the cooling energy is reduced by 13%, distribution energy by more than 50%, peak demand by 9%, total electricity use by 5.3%, and electricity costs by 7.3% below the base case.

Floor-Based System

The relative impacts of various conservation measures when applied to the low-pressure floor-based LTD system forms the second group of simulations. As described earlier, this system employs a central fan capacity that may be significantly less than the typical primary fan capacity. This may reduce the advantages of economizer operation which for much of California is shown to be highly beneficial. The floor-based system primary fan supplies only the minimum outside air per occupant plus an additional equal amount of recirculated air. Thus, the ability to introduce large quantities of outside air for economical cooling is limited. All air circulation within the occupied area is accomplished by the TAMs. As discussed below, simulations show encouraging features of the floor-based system, and exploration of possible refinements certainly appears to be warranted.

Table 2 lists the results of simulations for Group 2, and includes the base case results for comparison. The percentages listed in the table represent the change for that quantity in relation to the base case. Figure 2 presents annual cooling and distribution electricity use for the first five new simulations listed in Table 2, along with the base case. The low-pressure underfloor air distribution system of Spoormaker employs a central fan capacity which may be significantly less than the typical VAV capacity, thereby reducing the advantages of economizer operation. The Spoormaker central fan system supplies only the minimum outside air per occupant plus an additional equal amount of recirculated air. The majority of air movement within the occupied area is accomplished by the floor-based terminal fan units (TAMs). Thus, the ability to introduce large quantities of outside air for economical cooling is lacking. The results explore the effects of some of the same variations used for the base case building above.

FIGURE 2
Annual Cooling & Fan Electricity
Floor System, Fresno

LTD	Econ	7°F	Vent	Strat
	X			
X	X			
X		X		
X		X	X	
X				X
X	X	X		X

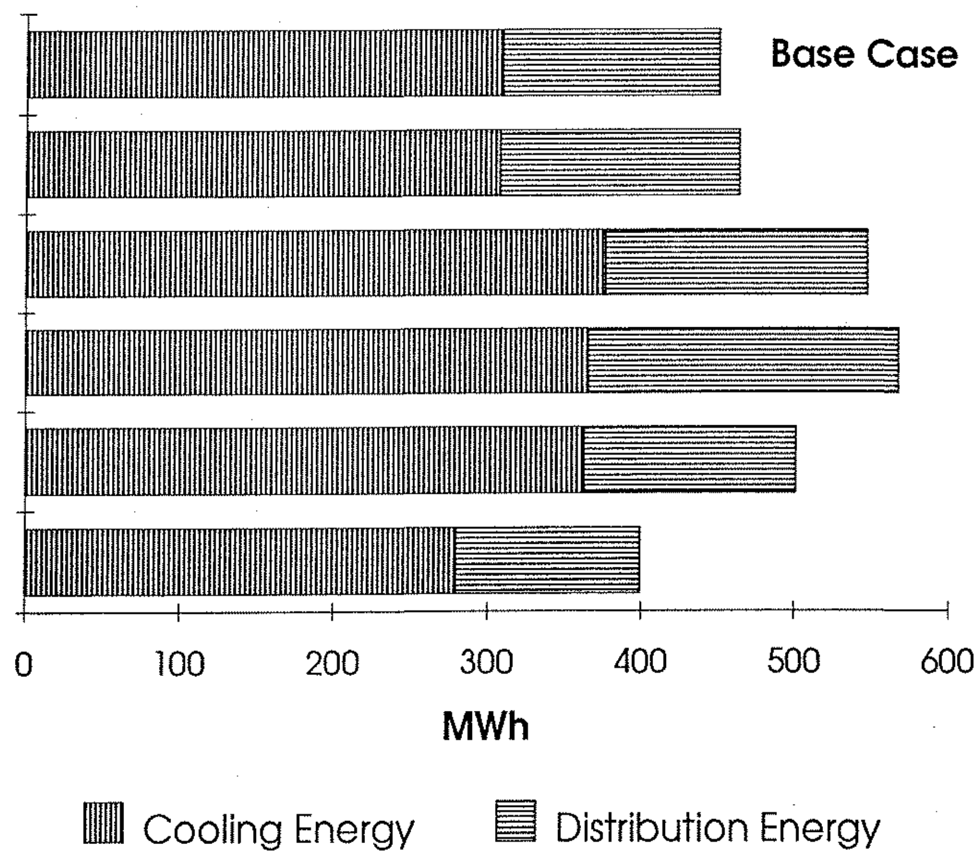


Table 2. Floor-Based LTD System Annual Simulation Results (Fresno)

System ID	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
	MWh	%	MWh	%	KW	%	MWh	%	K$	%
Base Case	310	0	141	0	876	0	2,113	0	234	0
1. Econ	308	-0.6	156	10.6	837	-4.5	2,126	0.6	232	-1.0
2. NEc7F	377	21.6	171	21.3	827	-5.6	2,209	4.5	235	0.6
3. NEc7°FVt	365	17.7	203	44.0	823	-6.1	2,230	5.5	236	0.7
4. NEcSt	363	17.1	138	-2.1	812	-7.3	2,163	2.4	231	-1.5
5. Ec7°FSt	280	-9.7	120	-14.9	794	-9.4	2,061	-2.5	222	-5.1
6. NEcVtStLF	297	-4.2	169	19.9	781	-10.8	2,129	0.8	224	-4.4
7. EcVtStSF	281	-9.4	146	3.5	796	-9.1	2,089	-1.1	224	-4.4
8. NEc7FVtStSF	340	9.7	146	3.5	796	-9.1	2,149	1.7	227	-3.0

In Table 2, the first new simulation of this group uses an economizer (Econ). The second simulation does not use an economizer and shows the influence of the larger permitted temperature 4°C (7°F) throttling range (NEc7°F). It can be compared to the second entry of Table 1 which assumed the tighter temperature throttling range of 2.5°C (4.5°F). Nighttime venting can result in significant fan usage as indicated by results of the third simulation (NEc7°FVt), yet because of the lower off-peak utility charges, there is little cost penalty compared to the results of the second entry. Results of the fourth entry (NEcSt) indicate that permitting stratification to develop to the extent (up to 2.5°C [4.5°F]) measured by Bauman et al. (1991) may be more effective in reducing electricity use than non-optimized nighttime cooling efforts. The night venting technique seems to require careful control in its application. If the addition of a larger tolerated range of temperatures together with some stratification is permitted and the economizer is used, the results of the fifth entry (Ec7°FSt) indicate meaningful energy reductions are possible (both total and peak). Spoormaker does not indicate the use of economizer in his designs, however, all simulations used in this study, where indicated, assumed its use.

It has already been mentioned that full advantage of economizing is limited by the reduced primary fan capacity used in this design. The last three simulations listed in Table 2 investigate different system configurations using night ventilation. Figure 3a presents the annual cooling and distribution electricity use, and Figure 3b presents peak electricity and total electricity cost for these three cases. The base case simulation is also included in the figures for comparison. It is seen from the sixth and seventh entries of Table 2 that operating costs vary negligibly if large capacity primary fans (LF), comparable to what would be present in a standard VAV system, could be used for night venting without the benefit of economizer (NEcVtStLF), as opposed to

FIGURE 3a
Annual Cooling and Fan Electricity
Floor System with Night Ventilation
Fresno

LTD	Econ	7°F	Vent	Strat	Lrg Fan	Sm Fan
	X					
X			X	X	X	
X	X		X	X		X
X		X	X	X		X

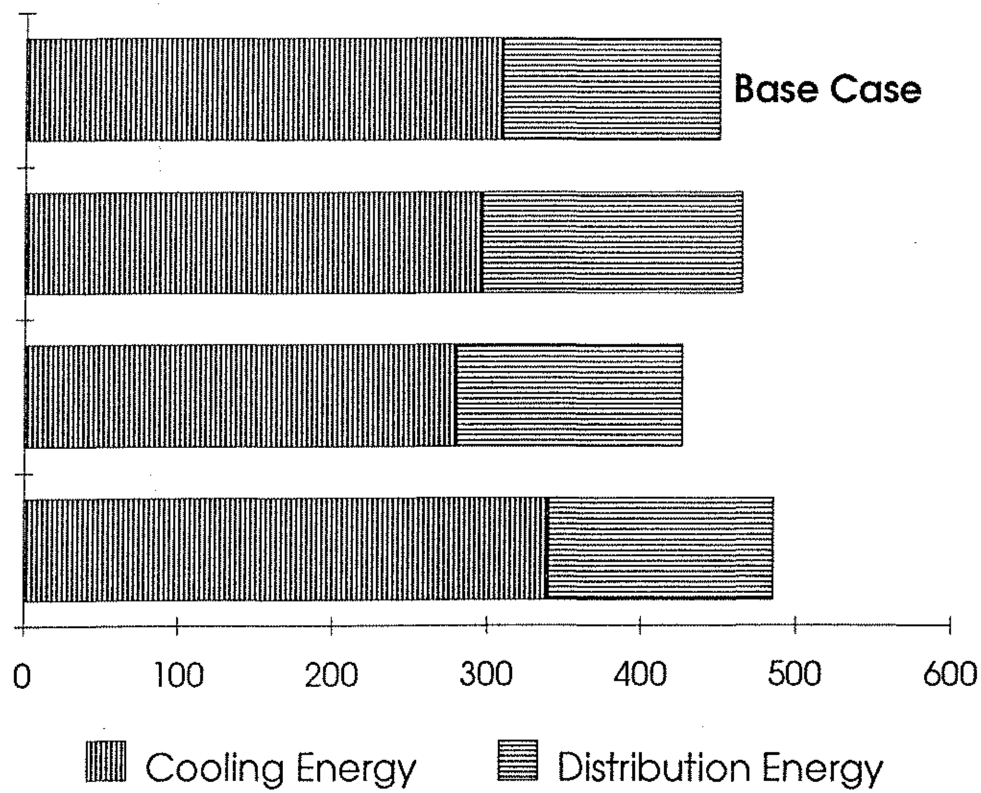
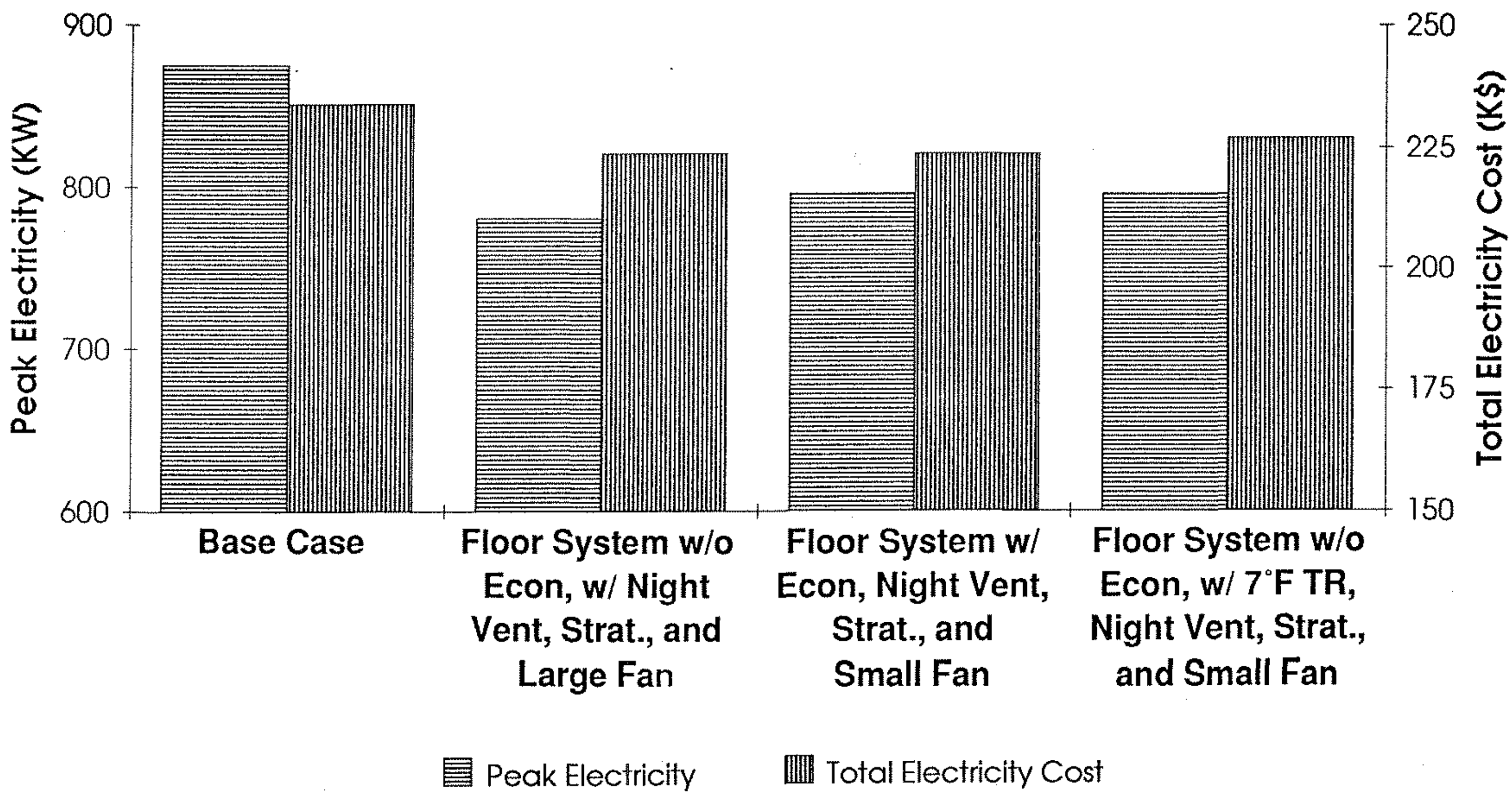


FIGURE 3b
Peak Electricity Demand & Annual Electricity Cost
Floor System with Night Ventilation
Fresno



the limited capacity of the smaller primary fans (SF) with economizer which also serve in night venting (EcVtStSF). In comparison to the sixth simulation, the last entry of Table 2 (NEc7°FVtStSF) indicates that it may be more advantageous for night venting to use larger fan capacities which run fewer hours than longer running smaller fans. Even the advantage of the wider 4°C (7°F) temperature throttling range in the occupied spaces used in case 8, does not give the overall energy performance of example 6, which uses the larger fans. In terms of shifting electricity demand from peak periods to off-peak nighttime hours, all three system configurations using night ventilation show peak demand reductions in the range of 9-11% in comparison to the base case.

The simulation results from Group 2 show that if the underfloor air distribution system is examined without economizer option, it is seen that the high circulation rate of approximately 12 air changes per hour adds to fan energy use in spite of the low pressure primary air system and the very low pressure generated by these local terminal fan units. Nonetheless, there is a reduction in operating cost from the comparable VAV base case without economizer, due in large part to the larger temperature swings allowed under the Spoormaker regime made possible by occupant control of the effective draft temperature. The floor supply system also allows a warm stratification layer above approximately 5 1/2 feet to develop, and when allowances for this are included in the simulation, an energy benefit is realized. The encouraging results from these simulations suggest that possible refinements to the floor-based system model appear to be warranted. For example, the possibility of including larger primary fan capacity in the design should be explored so that full advantage can be taken of the frequent availability of economizer use in suitable California climates. It may also be possible to reduce the high air exchange rate without compromising health and comfort.

Desktop-Based System

The third group of results simulates the desktop-based air supply module (PEM). For consistency in the simulation approach, most of the system operating characteristics are modeled in the same manner as the floor-based system. The major differences in the desktop model are (1) fan power characteristics of the PEM units, (2) local workstation-based temperature control provided by the PEM, and (3) use of occupancy sensors to turn off equipment in unoccupied workstations. Table 3 lists the results for the Group 3 simulations investigating various operation and control strategies, with the exception of occupancy sensor control, for the desktop-based system. The table includes the base case results for comparison, and the percentages listed represent the change for that quantity in relation to the base case.

In Table 3, the first simulation (NEc) does not use an economizer and all zones are held to the more usual 2.5°C (4.5°F) temperature throttling range, the second (NEc7°F) allows the larger permitted temperature throttling range 4°C (7°F) throughout the day to occur for all occupied areas of the building, the third (NEc7°FSt) adds increased stratification to develop in the space, the fourth (NEc7°FStVt) adds nighttime ventilation which successfully lowers the expenditure of cooling energy, but inflates fan energy, and the fifth (NEc7°FVt) combines no economizer with the larger throttling range and nighttime ventilation.

Table 3. Desktop-Based LTD System Annual Simulation Results (Fresno)

System ID	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
	MWh	%	MWh	%	KW	%	MWh	%	K$	%
Base Case	310	0	141	0	876	0	2,113	0	234	0
1. NEc	384	23.9	139	-1.4	833	-4.9	2,184	3.4	234	0
2. NEc7°F	374	20.6	139	-1.4	823	-6.1	2,175	2.9	232	-0.6
3. NEc7°FSt	350	12.9	103	-30.0	794	-9.4	2,114	0	224	-3.9
4. NEc7°FStVt	338	9.0	165	17.0	800	-8.7	2,165	2.5	228	-2.4
5. NEc7°FVt	360	16.1	166	17.7	816	-6.8	2,188	3.5	232	-0.8
6. NEc7°FStVtZ1	340	9.7	166	17.7	798	-8.9	2,167	2.6	229	-2.1
7. NEc7°FZ2	381	22.9	137	-2.8	832	-5.0	2,179	3.1	233	-0.4
8. NEc7°FZ3	375	21.0	138	-2.1	822	-6.2	2,174	2.9	232	-0.9

The last three simulations in Table 3 investigate various zoning control strategies for the desktop system. The sixth simulation (NEc7°FStVtZ1) permits no temperature variation between the workstation itself and the immediate access areas surrounding them, but does allow hallways and the upper zone in the space (5.6-ft height to ceiling) to stratify. The sixth simulation also includes night ventilation. The seventh example (NEc7°FZ2) permits the larger temperature throttling range for the halls and the 5.6-ft height to ceiling space, but requires all other areas including the immediate access areas to the workstation to be kept within the smaller more standard throttling range of 2.5°C (4.5°F), with no stratification. The last entry (NEc7°FZ3) permits all zones including occupied areas to have the larger temperature throttling range over the course of a day, but does not permit stratification to develop. The economizer option was not investigated with the set of runs in Table 3 as the energy savings are expected to be of similar magnitude to the other cases.

The desktop system simulations of Group 3 show that reductions in fan energy, peak electricity demand, and total electricity cost are possible if less well-controlled spaces are tolerated in the occupied portion of the building. This control strategy is more feasible than the usual more-uniformly-controlled space because of the local control provided to each occupant. The slight discomfort experienced a few steps away from the workstation itself can be temporarily ignored. Although no reductions in cooling or total electricity are observed for this set of simulations, the third option investigated (NEc7°FSt) shows the best overall performance for the combination of the larger temperature throttling range and increased stratification. For this simulation, in comparison to the base case, total electricity use is the same, and reductions are obtained of 30% for distribution energy, 9% for peak demand, and 4% for total electricity cost. Simulations involving nighttime venting of the building, however, did not always produce convincing evidence of energy reductions. Indeed, the cooling energy for these cases decreased in comparison to simulations not using night venting, but often the expenditure of fan energy exceeded the benefits of reduced chiller and cooling tower energy use. The success of this strategy is dependent upon a variety of parameters which need further investigation, including building mass, fan scheduling, fan sizes, specific building zone requirements, the current temperature difference between the space and ambient, and the target temperature desired.

The fourth group of simulations uses the desktop-based system (PEMs) as above, but also allows a portion of the building energy use to be placed under the control of occupancy sensors. Table 4 lists the results for some of the simulations from Group 4, and Figure 4 compares annual cooling and distribution electricity use for the six simulations listed in Table 4. As mentioned earlier, the scheduling of localized fans is not a feature of DOE-2, however, manual corrections to the "Distribution Electricity" column are contained in Table 4 accounting for the reductions in fan electricity use. The "Total Electricity" column shows the simulated total use which includes the impact of sensor management.

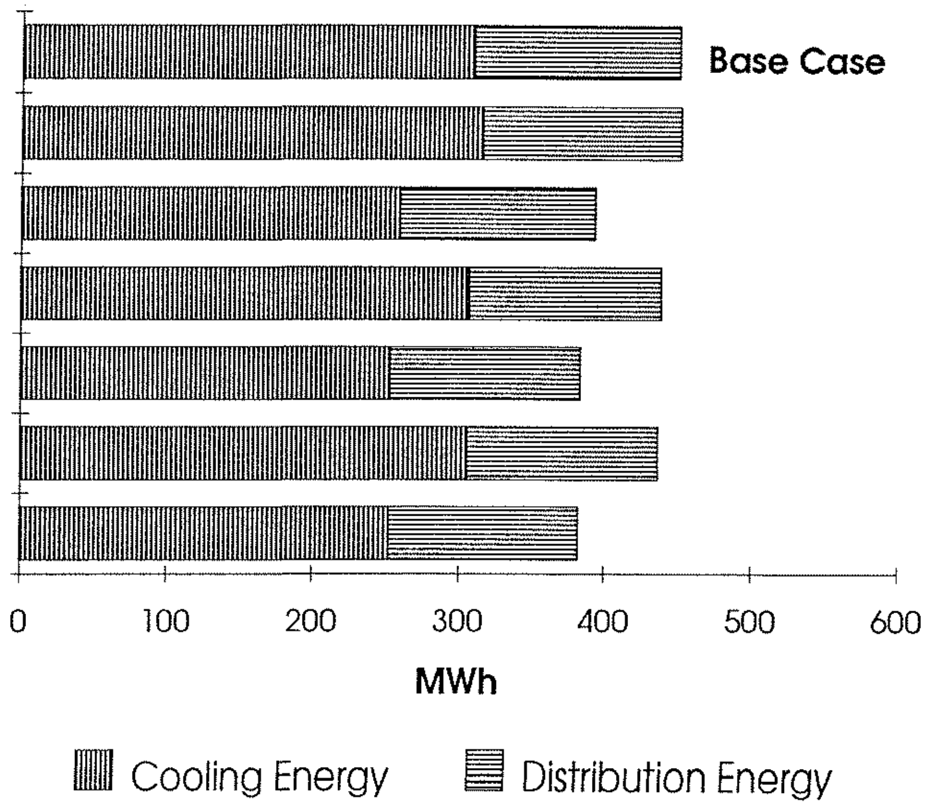
Table 4. Desktop-Based LTD System With Occupancy Sensor Control (Fresno)

	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
System ID	MWh	%	MWh	%	KW	%	MWh	%	K$	%
Base Case	310	0	141	0	876	0	2,113	0	234	0
1. NEc7°FVtStOc	316	1.9	136	-3.5	792	-9.6	2,038	-3.5	218	-6.7
2. Ec7°FVtStOc	259	-16.5	135	-4.3	792	-9.6	1,980	-6.3	215	-8.2
3. NEc7°FVtStOa	307	-1.0	132	-6.4	790	-9.8	1,977	-6.4	213	-8.9
4. Ec7°FVtStOa	253	-18.4	131	-7.1	790	-9.8	1,922	-9.0	209	-10.7
5. NEc7VSOa150	306	-1.3	132	-6.4	780	-11	1,976	-6.5	212	-9.4
6. Ec7VSOa150	252	-18.7	130	-7.8	780	-11	1,921	-9.1	209	-10.9

In Table 4, all variations shown allow the larger temperature throttling range (4°C [7°F]) used by Spoormaker, nighttime ventilation, and the presence of stratification. The first two simulations place equipment in the core offices only under occupancy sensor control (Oc), with the first simulation not using an economizer (NEc7°FVtStOc), and the second using the economizer option (Ec7°FVtStOc). The remaining four simulations place all perimeter and core office areas under occupancy sensor control (Oa). The last two simulations in Table 4 investigate the dampening effect on cooling loads and peak demand for a building with increased thermal mass. For these two simulations, the floor construction is assumed to be 150 pounds per square foot compared to 100 pounds per square foot of floor construction for the standard building model used in this study without (NEc7VSOa150) and with economizer (Ec7VSOa150).

FIGURE 4
Annual Cooling & Fan Electricity
Desktop System, Fresno

LTD	Econ	7°F	Vent	Strat	Occ Core	Occ All	150 lb/ft²
	X						
X		X	X	X	X		
X	X	X	X	X	X		
X		X	X	X		X	
X	X	X	X	X		X	
X		X	X	X		X	X
X	X	X	X	X		X	X



Examples of occupancy sensor controlled equipment simulations, Group 4, clearly indicate advantage should be taken of this technology. The application extends well beyond the typical office building. The assignment of a modest 125 watts per person to occupancy sensor control, comprised of task lighting, individual workstation equipment and the personal ventilation fan, could easily be increased. Together with the desirable trend toward more efficient office equipment such as copiers, facsimile machines and printers, the great differences between peak and baseload demand presently experienced by utilities could be reduced. The impact of 1 watt demand reduction by the occupant translates to roughly 1.2 to 1.3 watts demand at the building boundary depending upon system cooling efficiency. This is clearly demonstrated by the simulations, an example of which is provided by a comparison of case 4 of Table 3 and case 3 of Table 4. The annual reduction of lighting, terminal fan and equipment use, realized from occupancy sensor control, though not shown in the tables, is 124.8 MWh; the reduction in energy used for cooling from the tables is 31.4 MWh. The total energy reduction is 156.1 MWh giving a ratio of 1.25 KWh total savings/KWh realized directly from occupancy sensor control.

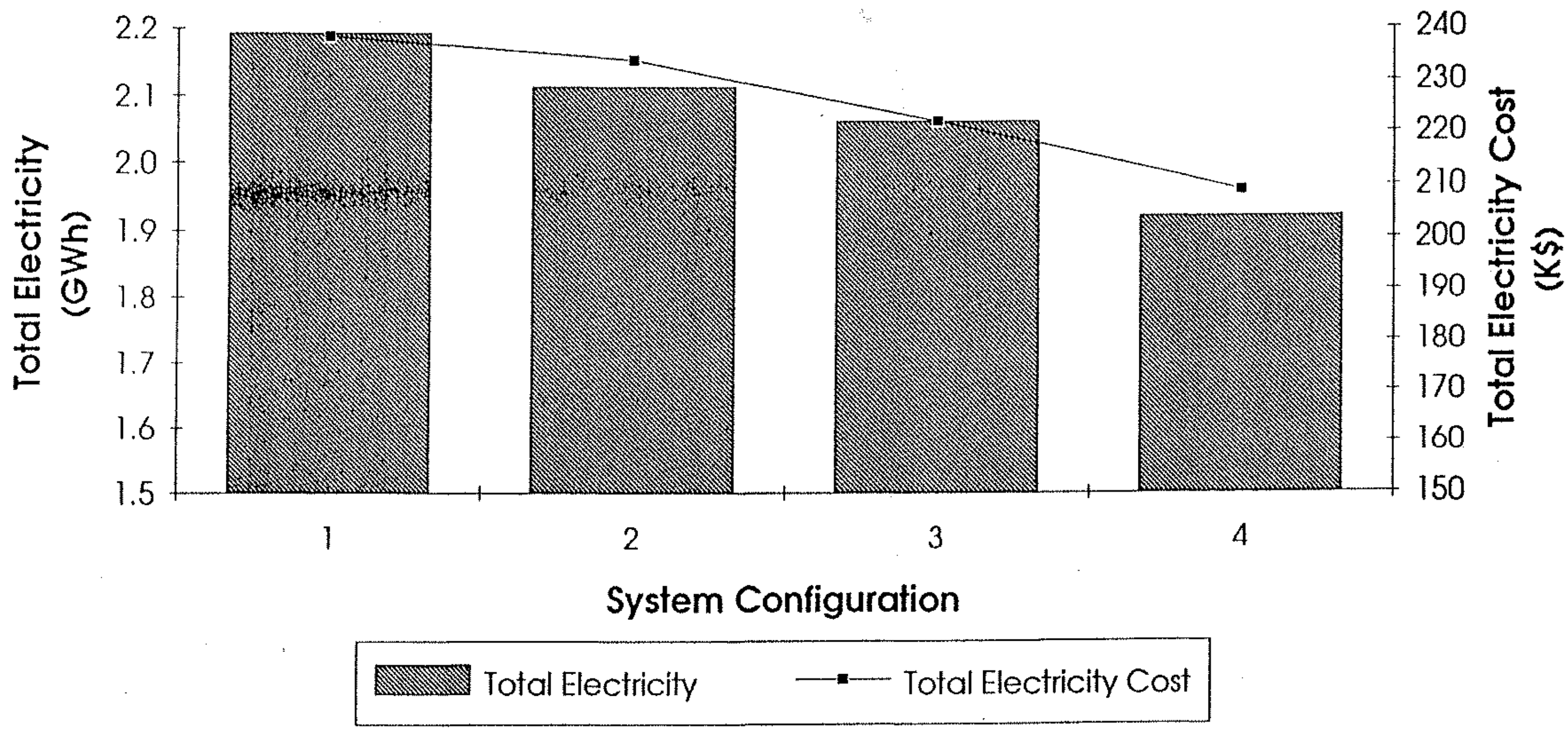
The additional benefits of heavier building construction may not be cost effective, but simulations show that peak demand may be reduced by over 1% if floor mass is increased from 100 to 150 pounds per square foot.

Summary of Fresno Results

In summary, a large amount of simulation results have been produced and analyzed to indicate the range of potential energy savings associated with the various LTD system configurations and control strategies. Table 5 lists the results for four selected simulations to allow a comparison over the full range of systems investigated for the Fresno climate. The four examples shown are (1) standard VAV system with economizer (base case); (2) standard VAV system without economizer; (3) floor-based LTD system with economizer that allows a wider 4°C (7°F) temperature throttling range (compared to the normal 2.5°C [4.5°F]) and increased stratification in the space (up to 2.5°C [4.5°F]) above heights of 5 1/2 feet; and (4) desktop-based LTD system with economizer that allows the wider throttling range and increased stratification, uses nighttime ventilation to precool the building mass, and uses occupancy sensors to turn off workstation-based fans, lights, and equipment (total of 125 W) in unoccupied workstations throughout the building assuming a 30% time of absence. Figure 5 presents the annual total electricity use and total electricity cost for these same four system configurations.

The results of Table 5 and Figure 5 show that, as expected, adding an economizer to a conventional overhead VAV system is an effective energy saving strategy in California climates. Beyond the use of an economizer, the two LTD system configurations demonstrate additional energy and cost savings in all categories shown. In comparison to the standard VAV system with economizer, the floor-based LTD system produces the following reductions: 9.7% in cooling energy, 15% in fan energy, 9.4% in peak demand, 2.5% in total electricity, and 5.1% in total electricity cost. In comparison to the standard VAV system with economizer, the desktop LTD system produces the following reductions: 18% in cooling energy, 7.1% in fan energy, 9.8% in peak demand, 9.0% in total electricity, and 10.7% in total electricity cost, indicating the significant advantage of using occupancy sensors. The fourth system configuration of these

Figure 5. Annual Total Electricity Use and Cost, Fresno



1. Standard Overhead VAV System without Economizer
2. Standard Overhead VAV System with Economizer
3. Floor-based LTD System with Economizer, 7˚F Throttling Range, Increased Stratification
4. Desktop-based LTD System with Economizer, 7˚F Throttling Range, Increased Stratification, Nighttime Ventilation, Occupancy Sensor Control

Table 5. Comparison of Standard and LTD System Energy Performance (Fresno)

System ID	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
	MWh	%	MWh	%	KW	%	MWh	%	K$	%
1. Std. VAV w/ Econ (Base Case)	310	0	141	0	876	0	2,113	0	234	0
2. Std. VAV w/o Econ	383	23.7	147	4.2	876	0	2,192	3.7	238	1.7
3. Floor LTD w/ Econ., 7°F TR, Strat.	280	-9.7	120	-14.9	794	-9.4	2,061	-2.5	222	-5.1
4. Desk LTD w/ Econ., 7°F TR, Strat., Night Vent, Occ.	253	-18.4	131	-7.1	790	-9.8	1,922	-9.0	209	-10.7

simulations helps to show how the use of occupancy sensors can be well matched to the application of workstation-based LTD systems to minimize excessive energy consumption, while allowing building occupants the comfort and ventilation advantages of having individual control of their local environment.

San Jose Results

For the base case building in San Jose (standard VAV system with air-side economizer), the site energy use is 40.5 KBtu/ft^2-yr, with 2,034 MWh of total electricity use and Gas 340 MBtu of gas consumption. The gas used for space heating is 59 MBtu, with the remainder for domestic hot water. The electricity use is roughly divided as follows: space cooling (chiller, condenser fan and pump) 12.5%, distribution (ventilation fans, chilled and hot water pumps) 5.9%, lighting 48.1%, office equipment 26.0%, and the remainder is miscellaneous, including elevator and boiler fan use 7.5%. The fraction of building electricity use for space conditioning is 18.4%. Without reductions in the other major use categories, the possible overall reductions brought about by systems upgrades are limited.

Table 6 lists the annual DOE-2.1E predictions and percent change from the base case for some of the system variations examined with the standard VAV building for the San Jose climate. Figure 6 compares annual cooling and distribution electricity use for the first four simulations listed in Table 6.

FIGURE 6
Annual Cooling & Fan Electricity
Standard VAV System, San Jose

Econ	Vent	LoPr
X		
X	X	
X	X	X

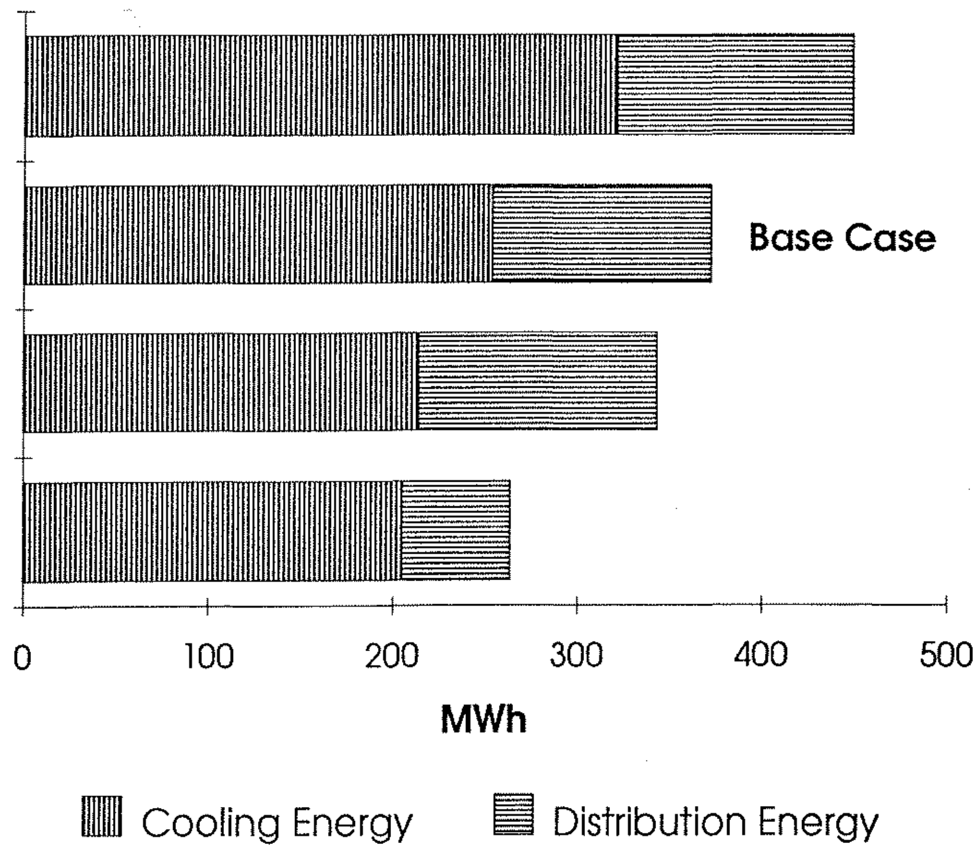


Table 6. Standard VAV Building Annual Simulation Results (San Jose)

System ID	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
	MWh	%	MWh	%	KW	%	MWh	%	K$	%
1. Econ (Base Case)	254	0	119	0	797	0	2,034	0	220	0
2. EcVt	214	-16	130	9	767	-4	2,005	-1	215	-2
3. EcVtLP	205	-19	59	-50	716	-10	1,925	-5	204	-7
4. NEc7°F	322	27	128	7	796	0	2,111	4	224	2
5. NEcVt7°FSF	305	20	147	23	764	-4	2,113	4	221	0
6. NEcVt7°FLF	256	1	164	38	753	-6	2,082	2	217	-1
7. EcVt7°FLF	205	-19	160	34	752	-6	2,026	0	214	-3

In Table 6, the first simulation (Econ) is the base case building (standard VAV system with economizer). The second example (EcVt) uses night ventilation to pre-cool the structure and shows that the scheduling, and setpoints are in need of further study to optimize performance. The electricity used for cooling is reduced about 16%, but that for fans is increased by nearly 9%, and the fuel for space heating (not shown) increases by 70%. Due to the cooler structure, peak building demand is lowered by nearly 4%. Annual electricity costs decrease about 2%, (-$5K), but gas costs (not shown) rise about 13%, which is only $0.3K. In California climates requiring very little space heating, small absolute changes in gas use appear as huge percentages. The situation would be much different in more severe heating climates.

The third case (EcVtLP) simulates the use of oversized ducting, which lowers the delivery system pressures to those implied by the underfloor air distribution system, approximately 2 in. H_2O, but which does not require the high overall circulation rate of approximately 11.9 ACH. The savings in both fan power and cooling energy are noteworthy. The cooling energy decreases below that of the night venting case (EcVt) in part because of less heat dissipated by fans and the lower pressures required. In comparison to the base case, the following reductions are observed: cooling energy by 19%, fan energy by 50%, peak electricity demand by 10%, total electricity use by 5%, and its annual cost by 7%.

The fourth simulation (NEc7°F) demonstrates the importance of economizer operation for the San Jose climate and is shown as the top bar in Figure 6. This simulation does not use the economizer option, and despite the fact that a wider 4°C (7°F) temperature throttling range is allowed (similar to the LTD systems), cooling electricity increases by 27%, total electricity increases by 4%, and total electricity costs increase by 2% in comparison to the base case (with economizer).

Cases 5-7 are demonstrations of attempts to correctly modify a variety of parameters affecting nighttime ventilation performance. The parameters investigated included fan scheduling, fan capacities, low temperature set points, and inside/outside air temperature differences. All three simulations allow the increased temperature throttling range. In each of these cases using night venting, fan energy use exceeds that of the base case by 23 to 38%, while energy used for space cooling may decrease by as much as 19% when the economizer is also used in case 7 (EcVt7°FLF), or increase by 20% in case 5 (NEcVt7°FSF), where no economizer option is used and small fan (SF) capacities are simulated. A comparison of cases 5 and 6 (both without economizer) shows that the use of a larger capacity fan in case 6 (NEcVt7°FLF) produces reductions in all categories except fan energy use. Both cases 6 and 7 use large night fan capacities (LF), and case 7, which uses an economizer, achieves reductions in all categories compared to case 6.

Floor-Based System

The simulations using this system parallel closely those for the Fresno climate. As was discussed earlier, the large total circulation rate used by this system, and the restricted use of the economizer due to smaller primary fan capacities present some limitations on the amount fan energy may be reduced below that of a well-designed base case which can closely follow load requirements. There are certain features of this system, however, that are very appealing, such as the local occupant control of the TAM units, and the ease by which advantage may be taken of stratification benefits during cooling. Table 7 contains results of some simulations indicating how such a system would perform in the San Jose climate. Figure 7 compares annual cooling and distribution electricity use for the simulations listed in Table 7.

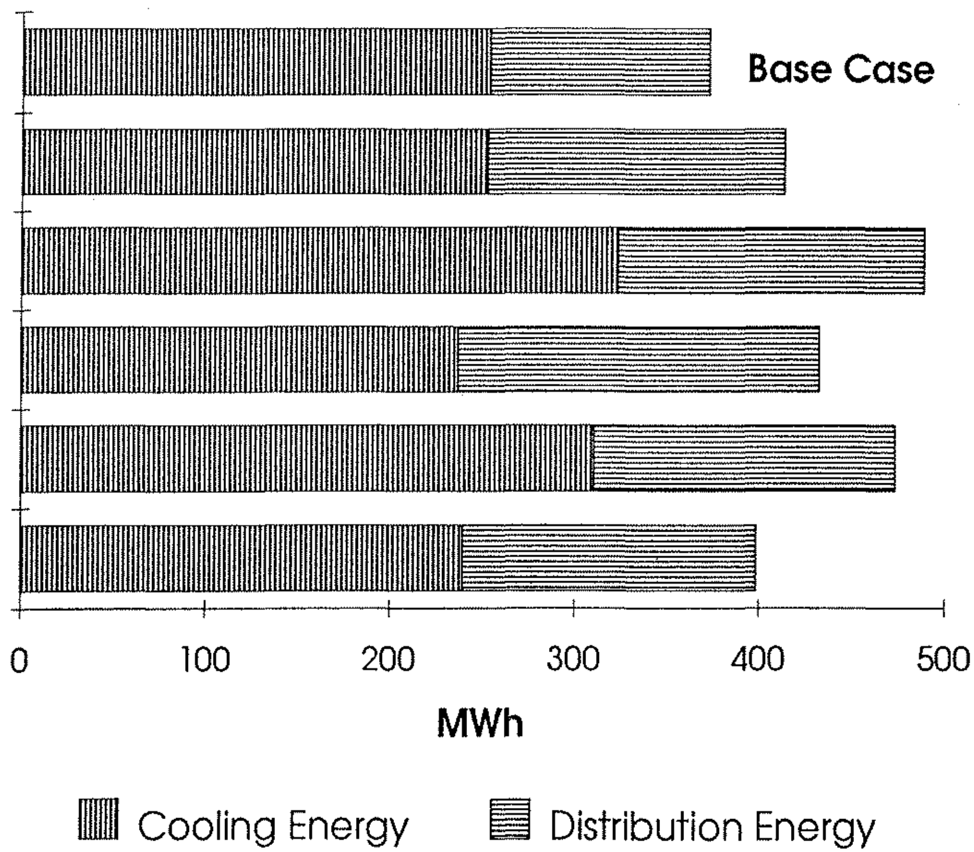
All simulations in Table 7 assume the higher 11.9 ACH circulation rate and the wider temperature throttling range (4°C [7°F]) of Spoormaker's design, yet in many instances appear competitive in energy use with a good base system. The primary reason for this is the low cost of air

Table 7. Floor-Based LTD System Annual Simulation Results (San Jose)

	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
System ID	MWh	%	MWh	%	KW	%	MWh	%	K$	%
Base Case	254	0	119	0	797	0	2,034	0	220	0
1. Ec7°F	253	0	161	35	777	-3	2,075	2	222	1
2. NEc7°F	324	28	166	39	763	-4	2,150	6	225	2
3. Ec7°FStVt	237	-7	196	65	775	-3	2,094	3	221	0
4. NEc7°FSt	311	22	163	37	761	-5	2,134	5	224	2
5. Ec7°FSt	240	-6	159	34	779	-2	2,060	1	220	0

FIGURE 7
Annual Cooling & Fan Electricity
Floor System, San Jose

LTD	Econ	7˚F	Strat	Vent
	X			
X	X	X		
X		X		
X	X	X	X	X
X		X	X	
X	X	X	X	



delivery/cfm. If this system were to be designed to use lower total circulation rates, the operational costs could be noticeably lowered.

The first simulation (Ec7°F) uses the economizer and, in comparison to the second simulation (NEc7°F), without an economizer, shows the impacts of using economizers in the San Jose climate. The third simulation (Ec7°FStVt) shows that adding night venting, economizer and stratification can reduce the cooling load, but the fan use may increase sufficiently to nearly offset the benefits of the latter two options. Due to reductions in peak demand, overall costs remain about the same as the base case.

The fourth and fifth simulations indicate that allowing increased stratification with the floor-based LTD system can be effective in lowering categories of cooling load, fan energy, and total electricity. These advantages can be seen by comparing case 4 (NEc7°FSt) with case 2, both without the economizer option, and case 5 (Ec7°FSt) with case 1, both with the economizer option. Although the heating gas consumption is not shown in the table, the simulation results indicate that the higher structure temperatures due to stratification seem to reduce the need for heating, but may increase the peak demand for the infrequent hottest days of the year to hold temperature setpoints.

Desktop-Based System

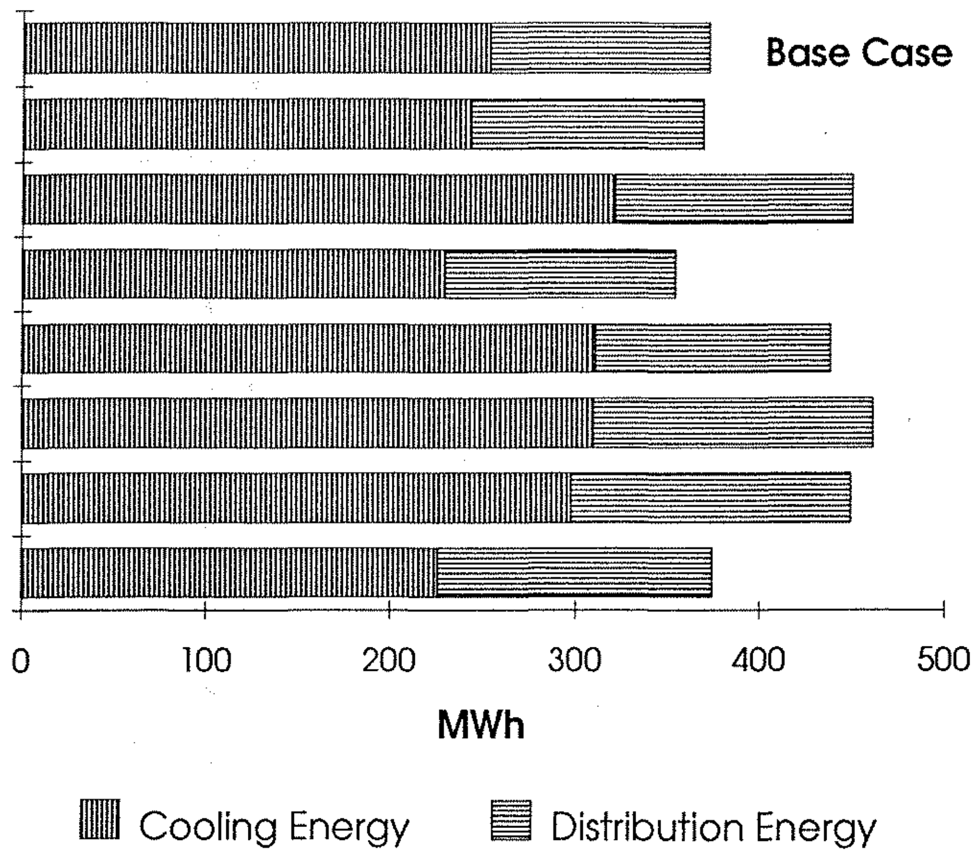
Table 8 shows annual DOE-2.1E predictions for the desktop-based system using a variety of techniques already discussed. Figure 8 compares annual cooling and distribution electricity use for the simulations listed in Table 8. Again, all simulations assume the larger temperature throttling range allowed by the individually-controlled desktop units (PEMs) and, for consistency with the floor-based system simulations, use the large 11.9 ACH circulation rate and the reduced total pressure of the supply air (2 in. H_2O). One PEM is assigned to each workstation with the

Table 8. Desktop-Based LTD System Annual Simulation Results (San Jose)

	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
System ID	MWh	%	MWh	%	KW	%	MWh	%	K$	%
Base Case	254	0	119	0	797	0	2,034	0	220	0
1. Ec7°F	244	-4	126	6	762	-4	2,031	0	217	-1
2. NEc7°F	322	27	129	8	763	-4	2,112	4	222	1
3. Ec7°FSt	230	-9	125	5	760	-5	2,016	-1	215	-2
4. NEc7°FSt	311	22	128	8	760	-5	2,100	3	220	0
5. NEc7°FVt	310	22	152	28	754	-5	2,123	4	221	0
6. NEc7°FStVt	298	17	152	28	751	-6	2,110	4	220	0
7. Ec7°FStVt	226	-11	149	25	751	-6	2,036	0	215	-2

FIGURE 8
Annual Cooling & Fan Electricity
Desktop System, San Jose

LTD	Econ	7°F	Strat	Vent
	X			
X	X	X		
X		X		
X	X	X	X	
X		X	X	
X		X		X
X		X	X	X
X	X	X	X	X



workstations arranged in clusters of four. There is a less rigorously controlled area immediately surrounding each workstation which is allowed to float above the temperature of the workstation by approximately 1°C (2°F).

Again, the importance of the economizer is seen in cases 2, and 4-6, which do not use the economizer, but use different combinations of increased throttling range, stratification, and night ventilation. For these simulations, cooling electricity exceeds the base case by 17-27%, fan energy by 8% when no night venting is used, and by 28% when night venting is used. Overall electricity costs are quite similar, however, and any sacrificed rentable space taken by economizer equipment could result in a net revenue reduction. Case 3 (Ec7°FSt), which permits stratification and uses the economizer, produces savings in all categories and has the lowest total electricity use and total electricity cost in this group of simulations. It is of interest to note that the level of stratification allowed by the model should not affect comfort and, yet, if designed into the system controls, should be accomplished without increasing capital costs. When night venting is added, as in case 7 (Ec7°FStVt), additional reductions are achieved in cooling energy and peak demand, and total costs remain the same, even though fan energy use increases noticeably and total electricity use increases slightly.

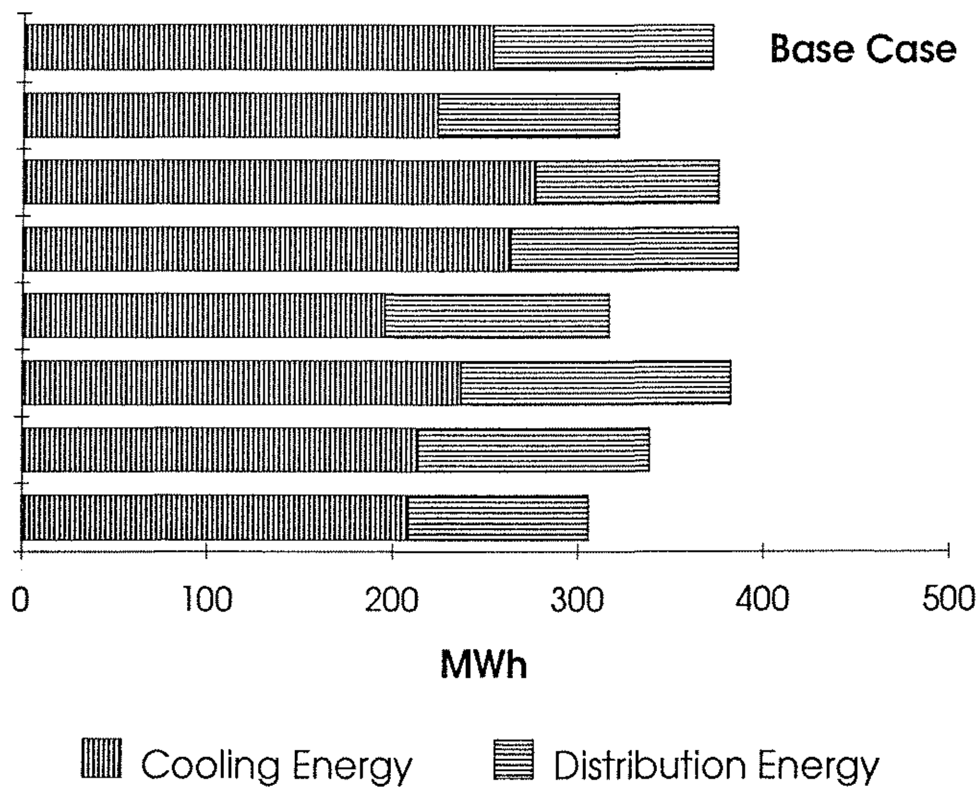
Table 9 lists the annual DOE-2.1E simulation results for the desktop-based system with limited occupancy sensor control of lighting and equipment. Figure 9 compares annual cooling and distribution electricity use for the simulations listed in Table 9. In this group, all simulations assume the higher temperature throttling range, and workstations in both core and perimeter office areas are placed under occupancy sensor control. Occupancy-sensor-controlled workspaces show the most promise in terms of energy use reduction efforts and, if used in conjunction with some of the techniques investigated above, can result in significantly improved use of energy. The degree of sensor control is modest in these simulations because of the lack of

Table 9. Desktop-Based LTD System With Occupancy Sensor Control (San Jose)

	Cooling Electricity		Distribution Electricity		Peak Electricity		Total Electricity		Total Electricity Cost	
System ID	MWh	%	MWh	%	KW	%	MWh	%	K$	%
Base Case	254	0	119	0	797	0	2,034	0	220	0
1. Ec7°FOa	224	-12	98	-18	744	-7	1,857	-9	202	-8
2. NEc7°FStOa	277	9	99	-17	745	-7	1,911	-6	205	-7
3. NEc7°FVtStOa	264	4	123	3	736	-8	1,922	-6	204	-7
4. Ec7°FVtStOa	196	-23	121	2	736	-8	1,861	-9	200	-9
5. NEc7°FVtLFOa	237	-7	146	23	730	-8	1,919	-6	204	-7
6. Ec7°FVtOa	214	-16	125	5	741	-7	1,875	-8	203	-8
7. Ec7°FStOa	209	-18	97	-18	745	-7	1,840	-10	201	-9

FIGURE 9
Annual Cooling & Fan Electricity Desktop System with Occupancy Control, San Jose

LTD	Econ	7°F	Vent	Strat	Occ	Lrg Fan
	X					
X	X	X			X	
X		X		X	X	
X		X	X	X	X	
X	X	X	X	X	X	
X		X	X		X	X
X	X	X	X		X	
X	X	X		X	X	



extensive data and uncertainty in occupant behavior, and the recent move by office equipment manufacturers to include energy saving features in their products. This group of simulations is intended to show a first approximation to the impacts brought about by the improved equipment designs and the habits of occupants. The potential benefits are greater than indicated because even though the occupant may be present, the full use of equipment or lighting may not be routinely needed, and "sleep mode" equipment will automatically reduce power after a short period of inactivity.

The first simulation (Ec7°FOa), with an economizer, wider temperature throttling range, and occupancy sensor control, shows significant reductions in all categories in comparison to the base case. Further reductions in total electricity use are not achieved until case 7 (Ec7°FStOa), which allows increased stratification to occur. In comparison to the base case, this last simulation shows the following reductions: 18% in both cooling energy and distribution energy, 7% in peak demand, 10% in total electricity use, and 9% in total electricity cost. Case 4 (Ec7°FVtStOa), using night ventilation with both stratification and economizer, lowers electricity use by cooling equipment 23%, raises fan energy 2%, and still obtains the lowest electricity costs because of the favorable pricing structure associated with shifting demand from daytime to nighttime hours.

The closest any non-economizer simulation comes to one with economizer in terms of overall electricity use is case 2 (NEc7°FStOa) which allows stratification. As previous results have shown, it appears that nighttime ventilation with larger capacity fans using shorter run times may be more beneficial than the use of smaller capacity fans. In this group of simulations, case 5 (NEc7°FVtLFOa) produces noticeable reductions in all categories except fan energy, which increases by 23%. Although not shown in the table, the negative side of this simulation is the large increase of gas use for heating, raising the annual gas bill by $1,200 due to overcooling.

Comparing simulations 2 and 3 (NEc7°FVtStOa), net electricity costs are lower for the night venting case even though it uses the greater amount of total electricity. Peak power is reduced by precooling the structure, thus lowering the demand charges and taking advantage of the lower night unit charges. Comparing simulations 6 (Ec7°FVtOa) and 7 results shows that both approaches lower the cooling energy, but the passive nature of stratification used in case 6 is superior to the use of night ventilation in terms of both overall electricity and fuel use (not shown), as well as the total costs for both.

Summary of San Jose Results
Although an extensive analysis might be warranted, the approximations inherent in the simulations dictate a more qualitative comparison. In this section the techniques which have been shown to have the greatest impact within the four simulation groups are compared across those groups. These techniques are (1) use of an air-side economizer, (2) increased throttling range (up to 4°C [7°F]) for space temperature control allowed by the individual controllability of the LTD systems, (3) increased stratification (up to 2.5°C [4.5°F]) in the space produced by the floor-to-ceiling air distribution of the LTD systems, and (4) nighttime precooling of the building thermal mass in the underfloor plenum by fan-driven ventilation. While economizer use is an assumed control strategy for all simulations compared below, including the standard overhead VAV system (base case), the other three techniques are assumed to be only available with the LTD system

configurations. Table 10 shows a comparison of the energy use, operating costs, and percent change from base case between the four simulation groups for two different combinations of the above techniques. The four simulation groups include Group 1 (the base case), Group 2 (floor-based LTD system), Group 3 (desktop-based LTD system), and Group 4 (desktop-based LTD system with occupancy control). Table 10a presents results for when the LTD systems include increased throttling range and stratification, and Table 10b presents results for when the LTD systems include increased throttling range and stratification, and nighttime ventilation.

At first glance, it may appear that the floor-based LTD system (Group 2), offers little advantage to the base case building. This configuration was modeled using a constant 11.9 ACH which may not be necessary. The encouraging characteristics of its performance are improved local comfort control, and, in spite of the large constant circulation rate, it is comparable in terms of peak demand and total electricity use and cost with the base case, representing a reasonably efficient variable air volume system that follows the cooling demand. This provides evidence that low pressure delivery of supply air can reduce costs, and with refinements, should prove to be a competitive system. The base case building used in this study was reasonably efficient, with its metered energy use approximately equal to 42 $KBtu/ft^2$ annually in Fresno, and 40 $KBtu/ft^2$ in San Jose. In comparison, the study performed by Huang et al. (1991) found that the mean energy use density was in the range of 70-75 $KBtu/ft^2$ for buildings in the Los Angeles basin, which is a cooling climate roughly between San Jose and Fresno.

Table 10a. Comparison of Annual Simulation Results for LTD Systems with Increased Throttling Range and Stratification (San Jose)

	Group 1 Std. Overhead System with Economizer (Base Case)		Group 2 Floor-Based LTD System with Econ.		Group 3 Desktop-Based LTD System with Econ.		Group 4 Desktop-Based LTD System with Econ. and Occ. Control	
Category Description	Value	%	Value	%	Value	%	Value	%
Space Cooling (MWh)	254	0	240	-6	230	-9	209	-18
Distribution (MWh)	119	0	159	34	125	5	97	-18
Total Electricity (MWh)	2,034	0	2,060	1	2,016	-1	1,840	-10
Peak Electricity (KW)	797	0	779	-2	760	-5	745	-7
Total Electricity Cost (K$)	220	0	220	0	215	-2	201	-9
Total Fuel Cost (K$)	2.3	0	2.0	-13	2.0	-13	2.3	0

Table 10b. Comparison of Annual Simulation Results for LTD Systems with Increased Throttling Range, Stratification, and Nighttime Ventilation (San Jose)

	Group 1 Std. Overhead System with Economizer (Base Case)		Group 2 Floor-Based LTD System with Econ.		Group 3 Desktop-Based LTD System with Econ.		Group 4 Desktop-Based LTD System with Econ. and Occ. Control	
Category Description	Value	%	Value	%	Value	%	Value	%
Space Cooling (MWh)	254	0	237	-7	226	-11	196	-23
Distribution (MWh)	119	0	196	65	149	25	121	2
Total Electricity (MWh)	2,034	0	2,094	3	2,036	0	1,861	-9
Peak Electricity (KW)	797	0	775	-3	751	-6	736	-8
Total Electricity Cost (K$)	220	0	221	0	215	-2	200	-9
Total Fuel Cost (K$)	2.3	0	2.2	-4	2.2	-4	2.4	4

Group 3, the workstation model, is essentially a refinement of Group 2 and shows that localization of comfort regions does reduce the cooling energy needed, and is accompanied by lower fan use compared to Group 2. Finally, Group 4 is a further refinement of Group 3 in which occupancy sensors control a fraction of typical lighting and workstation equipment, (in both core and perimeter zones). As a result of these additional refinements, it becomes a superior system in almost every category, with occupancy sensor control having a significant beneficial impact on energy use. Group 4 contains the most efficient LTD system simulated for the San Jose climate. Listed in Table 10a, it is a desktop-based system with economizer, increased throttling range and stratification, and occupancy sensor control. In comparison to the base case, it shows reductions of 18% in both cooling and distribution energy, 10% in total electricity, 7% in peak demand, and 9% in total electricity cost. When nighttime ventilation is added to this system, as listed in Table 10b, distribution energy is significantly increased due to the nighttime operation of the fans. Although total electricity use is slightly increased, total electricity costs remain about the same because of the further reduction in peak demand provided by the nighttime ventilation strategy.

In the future, additional laboratory and full scale studies should be performed to determine if the high circulation rates (assumed to be 11.9 ACH based on the Spoormaker (1990) model) are essential to good air quality and thermal comfort. The owners of some of the older building stock may be interested in exploring possible adoption of energy saving retrofit measures such as those investigated in this study. Those measures are using fan driven nighttime cooling of the building structure, and permitting limited stratification to develop within areas which do not degrade comfort of the occupied workspace. More extensive retrofit measures would include the installation of a floor-based or desktop-based LTD system, enlargement of ducting systems, or the incorporation of a low pressure air supply plenum. Without question, these energy reducing measures would be most effective if integrated into the design phase of a new building.

Figures

Tables

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SECTION 2

Field Study #1 in Engineering Office Building Near Phoenix, Arizona

by

Fred Bauman, David Faulkner, Marc Fountain, Charlie Huizenga,
Katsuhiro Miura, and Tengfang Xu

FIELD STUDY #1 in ENGINEERING OFFICE BUILDING, near PHOENIX, ARIZONA

This field study was performed over a 45-day period during the Fall of 1993. On October 27 and 28, Marc Fountain and David Faulkner traveled to the test building to install a number of portable dataloggers to monitor energy use and characteristic temperatures in the air distribution system and conditioned space. The monitoring equipment was left in place until David Faulkner returned on December 14 to retrieve it. During these two visits, a written survey of occupant comfort response was distributed to office workers in the building. Responses were received from 79 occupants.

METHOD

Site Description

The building where the field work was performed is located near Phoenix, Arizona. A two story structure, the building was completed in 1987 and is divided into two sections by function. The south wing of the building is devoted to manufacturing semi-conductors, electronic components, and other devices. The north wing of the building provides office space for the product design engineers and their associated managerial groups. This north wing of the building contains approximately 280 Task Air Modules (TAMs) installed over 3,000 m^2 (32,000 ft^2) of raised access floor area. Field measurements were performed in the first floor of this north wing (see Figure 1), having a floor area of approximately 1,000 m^2 (11,000 ft^2) served by about 100 TAM units. In this office, the depth of the underfloor plenum is 0.3 m (1 ft), that of the ceiling plenum is 0.6 m (2 ft), and the floor-to-ceiling height is 2.7 m (9 ft). The majority of the office space is taken up by partitioned workstations (≈9.3 m^2 [100 ft^2] each) defined by 1.5-m (5-ft) high partitions. Each worker occupies a single workstation although in some cases workstations were shared by two people. Each workstation is equipped with a TAM, and in some cases, two or three TAMs. Some workstations did not have human occupants but provided space for concentrations of computer and photocopying equipment. In these workstations, additional TAM units handled the excess cooling load generated. Three of the perimeter walls are dedicated to private offices that are also equipped with TAMs. The fourth wall along the northern side is glazed and is separated from the workstations by a corridor with four TAMs regularly spaced along its length. An identical second floor is located just above the first.

The air-handling-unit (AHU) serving the underfloor plenum is located in the equipment room at the southwest corner of the open-plan office area. In addition to supplying air to the open-plan office area and enclosed perimeter offices via the underfloor plenum, the AHU also serves several conference rooms and other enclosed spaces on the first floor using conventional ceiling-based diffusers. Supply volume control is achieved through varying the fan speed to maintain a 370 Pa (1.5 in. H_2O) pressure drop across a variable-air-volume (VAV) terminal box immediately downstream of the fan. We were told by the building engineers that this method of control was chosen after efforts were unsuccessful to control the flow based on the pressure difference between the underfloor plenum and the room. This pressure difference is typically very low (we measured in the range of +2 to +3 Pa [+0.008 to +0.012 in. H_2O] with a high quality digital manometer) and is difficult to measure accurately with standard instrumentation. With the above described control strategy, the building engineers estimated that the AHU provides a constant volume of approximately 4,700 L/s (10,000 cfm) to the underfloor plenum. After passing through the VAV box, the cool primary air is ducted through two lines contained in the concrete sub-floor and released into the underfloor plenum at six evenly distributed locations through vertically-oriented outlets. Each outlet has a hood (horizontal plate) above it that directs the air flow out in all directions under the floor. TAMs in each workstation then draw the cool air from the slightly pressurized underfloor plenum according to the fan setting adjusted by the occupant. Air exits the space through a number of ceiling grilles into an open return plenum.

The temperature of the air being supplied to the underfloor plenum is modulated in response to the signals from three wall thermostats 1.6 m (5.25 ft) above the floor and located as indicated in Figure 1. The control strategy maintains the temperature of the highest thermostat reading to be at the setpoint (23°C-24°C [74°F-75°F]). For heating requirements, ceiling radiant heating panels are also located in some of the perimeter office areas.

Laboratory Measurements

Prior to the field study, we performed detailed power measurements on five TAM units that we have in our laboratory. The following instrumentation was used: (1) an AEMC Nuwatt rms digital power meter to measure true rms power; (2) a Fluke Model 33 true-rms clamp meter to measure true rms current; (3) a Fluke Model 80 true rms multimeter to measure true rms voltage; and (4) an ACR clamp-on amprobe with SmartReader 3 Logger (described below) . The purpose of these measurements was to characterize the power consumption of the TAMs as a function of TAM fan speed setting, and for different combinations of settings among the five TAM units tested. Also, by taking simultaneous readings from these sensors, data were also obtained describing the TAM power factor (real power [W] divided by apparent power [V_{RMS}*A_{RMS}]) as a function of current measured by the ACR amprobe (a non-true-rms current transducer). This empirical relationship allowed the conversion of subsequent measurements taken during the 45-day field study into estimates of real power consumption.

Sensor Installation for Long-Term Measurements

It was decided to use several miniature, battery-powered, portable dataloggers to collect data over the 45-day monitoring period. These small units with their connected sensors are very easy to install, as they are completely stand-alone. Because they are easily hidden from view, the installation is quite unobtrusive to the building occupants, an important consideration to the building owner. The portable dataloggers store data in non-volatile memory, and at the end of the monitoring period, the data are down-loaded via RS-232 interface to a laptop computer. Two types of sensors were installed to perform long-term measurements, as described below. Table 1 presents an itemized list of the installed sensors. The identification numbers in the table are used to indicate the sensor locations on Figure 1.

Table 1. Installed Sensor Description and Key to Figure 1

ID No.	Sensor Type	Description
1	Amprobe	Circuit #1 in Panel P16
2	Amprobe	Circuit #3 in Panel P16
3	Amprobe	Circuit #5 in Panel P16
4	Amprobe	Circuit #7 in Panel P16
5	Amprobe	Upstream of TAM in workstation #61
6	Amprobe	Downstream of TAM in workstation #61
7	Amprobe	Upstream of TAM in workstation #63
8	Amprobe	Downstream of TAM in workstation #63
9	Amprobe	Upstream of TAM in workstation #58
10	Amprobe	Downstream of TAM in workstation #58
11	Thermistor	Primary supply outlet under workstation #54
12	Thermistor	Primary supply outlet under workstation #10
13	Thermistor	TAM in workstation #61
14	Thermistor	TAM in corridor outside workstation #2
15	Thermistor	Outside workstation #75 at 1.1 m height
16	Thermistor	Outside workstation #2 at 1.1 m height
17	Thermistor	Ceiling return grille above workstation #49
18	Thermistor	Ceiling return grille above workstation #14

Multi-range clamp-on current probes connected to ACR SmartReader 3 Loggers were used to record power consumption trends of the TAM units in two location: (1) at the main electrical breaker box to measure total TAM power, and (2) at selected points in the underfloor plenum to assess the draw of individual TAM units. The current transducers resolve the AC current flowing through a wire into a DC signal that is proportional to the current. Each SmartReader 3 can accommodate three clamp-on probes. The ACR loggers were programmed to store data into non-volatile memory at a 30-minute sampling interval. Each 30-minute reading represents the average of 225 individual readings taken at an 8-second scan rate. The accuracy specified by the manufacturer is ±4% of full scale + 0.4 amps.

Electrical circuits for powering the TAM units are routed through a circuit breaker cabinet (Panel P16) located in a room directly to the south of the equipment room. All of the TAMs in the monitored area of the first floor are served by four discrete circuits We attached clamp-on current transducers to one leg of each of the four circuits at the breaker box.

Several current-monitoring dataloggers were also installed in the underfloor plenum to track the energy use of individual TAMs. As power is provided to individual TAM units in a daisy-chain arrangement, to isolate the current flow to a single TAM in this circuit design, it was necessary to make measurements "upstream" and "downstream" and compute the difference. To facilitate these measurements we modified six TAM power cables in our laboratory prior to the field experiments. The 10-ft prefabricated power cables are encased in flexible metal conduit and come complete with male and female connectors. The cables allow easy hook-up to TAM units and other cables, and are UL tested and suitable for use in air distribution plenums. We modified the power cables by removing the outer flexible conduit, exposing the individual wires. When a clamp-on amprobe was installed onto one of the individual wires in the field, the wire was looped several times as needed through the clamp-on probe to magnify the signal from the sensor to an acceptable level (each loop multiplies the original signal by one additional power). Since the amprobes had a measurement range of 0-5 amps, the signal was magnified to produce an output in the 4-5 amp range, improving the accuracy of the measurement. Accordingly, by inserting one of the modified power cables at the desired measurement location, clamp-on current probes were installed upstream and downstream of three selected TAM units, allowing the calculation of current flow to each TAM individually.

A thermistor connected to Onset Computer's HOBO-TEMP-XT Logger was used for making four types of air temperature measurements: (1) primary supply air in the underfloor plenum, (2) TAM supply air, (3) room air, and (4) return air at ceiling level. These small, self-contained dataloggers can store up to 1800 total measurements in non-volatile memory, each reading representing a single scan of the connected thermistor. The HOBO loggers were programmed to record data at a 36-minute sampling interval, allowing the desired 45-day deployment. The accuracy specified by the manufacturer is ±0.2°C (±0.4°F).

The primary air supply temperature at two of the six main outlets under the floor was measured by placing a HOBO logger on top of the diffusing hood and allowing the sensor to hang over the side into the air flow. As shown in Figure 1, one measurement was made at the outlet closest to the AHU (sensor 11), and the other at the outlet farthest away from the AHU (sensor 12), to determine the range of temperature variation across the underfloor plenum. The supply air temperature of two TAMs was monitored by pulling up one of the removable grilles on the TAM, placing the datalogger inside the unit, and replacing the grille. Again, TAMs were chosen at the nearest (sensor 13) and farthest (sensor 14) points from the AHU. Room air temperature in two workstations was collected by dataloggers attached to support columns at sitting head height (1.1 m [43 in.]). Return air temperature was monitored at two locations by placing a HOBO logger just above selected ceiling return grills.

Refer to Table 1 and Figure 1 for a complete list of sensor definitions and locations.

Short-Term Measurements

During the first visit to the test building, short-term measurements were made of the TAM power consumption characteristics for a range of operating conditions. These measurements were taken on one of the four circuits at the main circuit breaker panel using the same instrumentation described above under *Laboratory Measurements*. The data obtained were used in conjunction with the laboratory results to convert subsequent current measurements into estimates of real power consumption.

The short-term measurement procedure was as follows. While one researcher walked through the space and adjusted each TAM's fan to "fully-on", the incremental aggregate power consumption, voltage, and current of the TAMs on that circuit was recorded by another researcher at the breaker box. Each TAM on the circuit was adjusted to "fully on" in turn until all TAMs were "fully on". Then each TAM was adjusted to "fully off" until all TAMs were "fully off". Finally, all TAMs were reset to their original occupant-adjusted positions. This procedure provided a strong record of the incremental full power of a single TAM unit as well as the minimum and maximum draw of the circuit.

At the same time that the above measurements were taken, field personnel also measured the static pressure difference between the underfloor plenum and the room using a precision digital manometer. The underfloor pressure was measured by connecting to a pressure line installed by the building engineering staff. Over the same range of TAM operating condition, the underfloor plenum was slightly pressurized with a minimum of 2 Pa (0.008 in. H_2O) at the highest combined TAM fan speed setting, and a maximum of 3 Pa (0.012 in. H_2O) at the lowest combined TAM fan speed setting. This change in pressure difference corresponded to turning nine TAM units on or off.

As a spot check of TAM air supply conditions, hand-held measurements were made for a selected number of TAM units. Inlet velocity and temperature were measured one inch above the center of the floor supply grilles with a digital anemometer. Supply volume from the TAMs was measured with a flowhood placed over all four grilles on a single TAM.

Occupant Survey

A survey of occupant comfort response was distributed during the first field visit to as many occupants as possible who had access to a TAM unit near their desk and were located on either the first or second floors of the building. A few additional surveys were distributed during the follow-up field visit. Of the approximately 160 surveys that were handed out, 79 completed surveys were received, nearly a 50% response rate. The original version of the survey was revised onsite based on requirements from the building engineering staff to remove questions about age, gender, and health attributes. The identities of all respondents to the survey have remained completely anonymous because no name, gender, age, or location information was recorded.

The survey included questions to establish some limited demographics about the sample population, including questions about how long the subject had been working in the building and using the TAM unit. Further questions investigated the TAM operation effectiveness, how the performance of the TAM unit compared to the performance of other ventilation systems, how the subject perceived his/her level of personal control in the workstation, and how satisfied the subject was with the environment in the workstation. A few additional questions asked whether HVAC and comfort problems were experienced at particular times of the day or year, and asked the subject to list specific advantages and disadvantages of the Task Air System. The format of the survey consisted primarily of rating scales, multiple choice questions, and a few fill-in-the-blank statements. The final page of the survey contained questions requiring short answers and provided space for general comments. A copy of the Individual Worker Survey appears in Appendix A.

RESULTS

Laboratory Measurements

Figure 2a shows the measured power factor as a function of fan speed setting for the five individual TAMs tested in our laboratory. The fan speed setting varies in equal increments from setting 1, representing the minimum air flow rate (≈43 L/s [90 cfm] with zero-pressure plenum) without turning the fan off, up to setting 10, representing the maximum air flow rate (≈90 L/s [190 cfm] with zero-pressure plenum). The power factor for the TAM is seen to increase quite linearly with fan speed setting from a minimum of 0.41 to a maximum of 0.66, with very little variation between the five units tested. The maximum difference in measured power factor for different TAM units was 4% at the minimum setting. Figure 2b presents the same power factor results in terms of average data from the five TAMs, and includes a regression line representing the best least squares fit to the data ($R^2 = 0.98$). Figure 2c shows the real power and apparent power data (both true-rms values) used to obtain the power factor results. Real power for a TAM unit is seen to increase from 20 W (68 Btu/hr) at the minimum fan setting up to 43 W (147 Btu/hr) at the maximum setting.

A second series of tests measured the power factor for all five TAMs operating simultaneously as a function of electric current recorded by the ACR clamp-on amprobe (a non-true-rms current transducer) that will be used for the field measurements. Six different combinations of fan speed settings were tested, ranging from all five TAMs set at maximum air flow to all five TAMs set at minimum air flow (not OFF). Figure 3 presents the results of these measurements which follow a trend similar to the data from individual TAMs shown in Figure 2. The results also indicate that, as measured by the ACR sensor, each TAM uses about 0.25 amps at minimum setting and 0.45 amps at maximum setting.

Building Walk-Through

Upon first arrival at the test building, researchers performed a building walk-through, during which the following initial observations were made.

1. A surprisingly small percentage of the TAMs were actually being used by the occupants. At the time of the walk-through, a preliminary survey found less than 25% of the fans in the TAM units to be turned on.
2. Informal interviews with building occupants found that the general perception was that the overall space temperature met their thermal comfort requirements without the need for additional local cooling provided by the TAM air supply. However, comments received from several people indicated that there existed a strong opinion among some dissatisfied occupants of feeling too cold ("too cold," "cold feet," "air temperature was stratified").
3. A significant number (>50%) of the occupants in this office space had implemented measures to restrict the TAM air flow due to feeling "too cold" or feeling an uncomfortable draft. The air flow from these TAM units was restricted by covering the floor grilles or blocking the openings below the grilles with foreign objects, including duct tape, plastic, paper, and books. We discovered later that this action was needed because, even when the fan was turned off,

some amount of air flow was always being delivered through the TAMs to the space due to the positive pressure maintained in the underfloor plenum (see below under *Short-Term Measurements*).

4. TAMs in workstations with high concentrations of computer equipment were being used effectively to remove these locally-generated loads.

Short-Term Measurements

Power measurements taken on one of the four TAM circuits at the main circuit breaker panel found the following readings for the TAM fan speed settings in use at that time: real power = 255 W, V_{RMS} = 119 VAC, A_{ACR} = 3.2 amps (where A_{ACR} is the current measured by the ACR amprobe). These data produced a characteristic power factor of PF_{ACR} = 0.66, where PF_{ACR} is the empirical power factor based on current measured by the ACR sensor. Based on our earlier laboratory measurements, the true power factor for this circuit would be closer to 0.57. It was determined that this circuit had eight operating TAMs on it, so that for each TAM, the average real power consumption was 32 W and the average current, as measured by the ACR amprobe was 0.4 amps. This corresponded to an average fan speed setting of 7 on a scale of 1 to 10 (see Figure 2).

As presented and discussed below under *Long-Term Measurements*, the general trend of TAM fan energy use was relatively constant over the entire field study period. It was therefore decided to assume that the overall power factor was constant in all subsequent data analysis of the current measurements recorded by the ACR sensors. Accordingly, all current measurement data was converted into estimates of real power consumption by the following formula:

$$\text{Real Power} = A_{ACR} * V_{RMS} * PF_{ACR} = A_{ACR} * (119) * (0.66)$$

For the selected TAM units tested, measured supply volumes ranged from 19 L/s (40 cfm) with the fan turned off, to 140 L/s (290 cfm) with the fan full on. Over this same range of operating conditions, inlet velocities ranged from approximately 0.5 to 3 m/s (100 to 600 fpm). Supply air temperatures were in the range of 18.3°C to 20.6°C (65°F to 69°F). The above data suggest that the underfloor plenum is being unnecessarily pressurized by the central air handling unit. Occupants desiring to turn off the air supply from their nearby TAM are unable to do so without physically obstructing the floor grilles, as discussed above under *Building Walk-Through*. Similarly, the supply volume at maximum fan setting is significantly higher that the nominal volume of 90 L/s (190 cfm) specified by the manufacturer, and measured in our laboratory, for conditions representing a zero-pressure or very low pressure plenum.

Occupant Survey

This section presents and discusses the major findings from the analysis of the survey results. The survey, as distributed to the building occupants, is presented in Appendix A. A complete listing of all survey results, including detailed frequency tables and comments, is presented in Appendix B. The same question numbers assigned in the original survey (Appendix A) are also used to identify the results (Appendix B). Note that some numbers are missing from the 67 total questions due to the required removal of certain questions, as described earlier.

Demographic Characteristics

The demographic characteristics (questions 3 through 6) of the 79 respondents to the survey are presented in Table 2. Mean, maximum, and minimum values are shown. On average, each respondent works 42 hours per week, sits at their desk for 6.6 hours per day, has worked in the building for 3.8 years, and has used a Task Air Module for 3.1 years.

Table 2. Survey Results: Demographic Characteristics (Questions 3-6)

	3. working hours per week (hr)	4. sitting hours per day (hr)	5. years working in building (yr)	6. years using TAM (yr)
mean	41.9	6.6	3.8	3.1
maximum	53.0	9.5	10.0	8.0
minimum	5.0	1.0	0.3	0.0

Task Air Module Operation Effectiveness

Questions 7a and 8a asked how often the respondents adjusted the direction or velocity of air delivery from their TAM. Figure 4 presents a histogram showing the percentage of respondents who answered in each category. The trend that is immediately obvious is that the TAMs are adjusted very infrequently by a large majority of the respondents. About half of the respondents (56% for air direction, 48% for air velocity) admitted that they essentially do not adjust their TAM at all (they either never adjusted their TAM, or had only adjusted it when they first moved into their workstation). A total of about 80% of the respondents adjusted their TAMs less often than once per week. Only 3-4% of the respondents stated that they adjusted their TAM at least once per day, and no one used it several times per day.

The significant lack of adjustment of the TAMs reinforces the initial observations made during the building walk-through that many TAMs were either turned off or blocked. Since air flow from the TAMs is used for local occupant cooling, these results suggest that the building's interior temperature is too cool. To take advantage of the improved thermal comfort that is possible by individual control of the TAMs, a more intelligent control strategy would raise the average room air temperature that is maintained in the space (by increasing the supply air temperature and/or by decreasing the supply air volume), thereby encouraging greater use of the TAM units. These operational changes would also serve to reduce cooling and central fan energy use.

Figure 5 presents the frequency histogram for responses to questions 9 and 10, concerning uncomfortably cool and warm conditions produced by the TAMs. Uncomfortably warm conditions are experienced only rarely, as 45% of the respondents report never having this experience and 82% experience it less often than once per week. However, in comparison, uncomfortably cool conditions are experienced by a noticeably larger percentage of respondents as 31% report feeling uncomfortably cool at least 2-4 times each week or more frequently, and 10% say it happens several times per day. Despite the fact that a majority of respondents (53%) report uncomfortably cool conditions less often than once per week, these survey findings indicate that thermal conditions within the monitored office area are considered to be too cool by a larger number of occupants than would be considered acceptable according to ASHRAE Standard 55-92 (ASHRAE 1992). This standard specifies conditions to maintain acceptable comfort for at least 80% of the building occupants.

Figure 6 presents the frequency histogram for responses to questions 11 through 13, concerning air movement produced by the TAMs. The results indicate that too little air movement is experienced relatively infrequently with 83% of the respondents reporting such conditions less often than once per week. Reports of too much air movement show a similar trend with 69% reporting such conditions less often than once per week. However, a small but noticeably higher percentage of respondents reported experiencing too much air movement compared to too little air movement at greater frequency (17% reported too much air movement at least 2-4 times each week, and only 8% reported too little air movement at least 2-4 times each week). The sensation of an uncomfortably cool draft coincides with the trends described above in Figure 5. The trend for reported experiences of comfortable air movement is the opposite of the trend for too little or too much air movement, suggesting that the majority of respondents are satisfied with the air movement produced by the TAMs. However, the results still identify a small but strongly dissatisfied group of respondents (14%) who claim that they never experience comfortable air movement.

Comparative Performance of Task Air Module

Figure 7 presents the frequency histogram for responses to questions 16 through 19, concerning the performance of the TAM compared to the performance of conventional ventilation systems in other buildings that did not have TAMs. For each of these four performance issues, a significantly larger percentage of respondents rated the TAMs as being much or somewhat better compared to the percentage who rated the TAMs as being much or somewhat worse. The percentage splits for better/worse ratings are as follows: air movement and circulation 64%/12%, thermal comfort 52%/27%, temperature 46%/29%, air quality 42%/5%. In this group, air movement and circulation is the highest rated comparative performance attribute. Results for both thermal comfort and temperature, again indicate that a noticeable percentage of the respondents are dissatisfied with the thermal comfort and temperature performance of the TAM. Air quality produced by the TAMs is rated as being better than conventional ventilation systems, although over half (53%) consider both types of systems to be roughly equivalent.

Figure 8 presents the frequency histogram for responses to questions 21 through 23, concerning the comparative performance of the TAM in terms of personal control and the avoidance of overheating and draft problems. The comparative performance of the TAM was rated as being better by at least half of the respondents for all three issues. The percentage splits for better/worse ratings are as follows: avoid overheating 70%/5%, personal control of environment 61%/10%, avoid draft 50%/29%. The results again suggest that overcooled and drafty conditions are creating a negative impression on a nontrivial number (29%) of the respondents. On the other hand, very few people (5%) report overheating problems to be worse with the TAM. As expected, the ability of the TAM to provide personal control is rated very highly in comparison to conventional ventilation systems.

To further analyze the relationship between the respondents' satisfaction with the TAM and their frequency of use, we divided the results into two groups based on the data shown in Figure 4: (1) those who adjust either the velocity or direction of air from the TAM at least once each week or more frequently, and (2) those who adjust the TAM less frequently than once each week. Figure 9 presents the frequency histogram for responses for these two groups to question 16, concerning the comparative performance of the TAM in terms of thermal comfort. There is an obvious trend that those who use their TAM more frequently have a much more positive perception of its thermal comfort performance in comparison to convention ventilation systems. Among the more frequent users, 50% rate the TAM performance as much better and 81% rate its performance as at least somewhat better. Among those who rarely use their TAM, the distribution is less one-sided with 45% rating the TAM as being somewhat or much better and 31% rating the TAM as being somewhat or much worse.

Figure 10 presents the frequency histogram for responses for the above two groups to question 20, concerning the comparative performance of the TAM in terms of productivity. Again, those who adjust their TAM more frequently have a more positive perception of its performance in terms of their productivity. Over half (56%) of the more frequent users rate the TAM performance as somewhat or much better. Among those who rarely use their TAM, a large majority (70%) feel that their productivity is roughly equivalent using either the TAM or a convention ventilation system, and 26% rate the TAM performance as somewhat or much better. Only a few respondents in both groups rated the TAM performance as being somewhat or much worse in terms of productivity.

Personal Control

Figure 11 presents the frequency histogram for responses to question 26, concerning personal control provided by the TAMs. Responses to the first question -- "How much control do you feel you have over the thermal conditions of your workplace?" -- indicate that a large majority (85%) feel that they have at least slight control, and over half (57%) have at least moderate control over their local thermal conditions. Responses to the second part of the question -- "How satisfied are you with this level of control?" -- show that about two-thirds of the respondents (64%) feel moderately or very satisfied with their level of personal control. However, as the survey results discussed above have also indicated, there exists a significant minority group of respondents (33%) who are at least slightly dissatisfied with their level of personal control. By making adjustments to the operating and control strategies of the building's air distribution system, it should be possible to achieve a higher degree of satisfaction among the building occupants.

Comments

The last page of the survey asked respondents to provide comments and short answers to five questions about the TAMs. Refer to Appendix B for a complete listing of all responses. Only selected examples are discussed briefly below.

Questions 63 and 64 asked whether particular problems were noticed at specific times of the day or year. Answers were divided into groups having similar themes. For those respondents reporting that they did have problems, the most common topic was feeling too cold. One-third of the respondents (35%) related their cold feelings to the seasons (Question 64). Several of these comments described how the building was too cold, especially during the hot summer months.

- "The building is overcooled in summer on a regular basis."
- "The relative feeling of being cold is probably worse in the summer. In the summer you roast if you dress for the cold (inside) and go out into above 100°F heat."
- Yes, it is way too cold in the building during the hot summer months. Sometimes I even turn on a heater to counter the cold AC (air-conditioning). What a waste of energy and dollars!"

When asked in question 65 about the major advantages of the Task Air System in the test building compared to other conventional air distribution systems, by far the most common response (60%) identified the capability of the TAMs to provide individual control.

- "Individual control of air flow."
- "Able to control temperature and air flow. Not available on personal level at other sites."
- "It's nice that people who get warm easily can use their Task Air Module to keep them cool. It does a good job of circulating the air. I just wish there were a way for me to warm up my cubicle, because I'm usually cold."

When asked in question 66 about the major disadvantages of the Task Air System in the test building compared to other conventional air distribution systems, the two most common types of responses dealt with the position of the TAMs (41%), and their operation and performance (39%).

- "Act like speed bumps for chairs."
- "A woman caught her shoe heel in a module, fell, and missed a few days work."
- "Office has to be arranged so feet or legs are not over the floor mounted air vents."
- "Air coming from the system is too cold, consequently fan is turned off and direction is rotated away from me unless I just came in from the outside and I am hot (and need to cool down)."
- "Still get some airflow even if turned off. Draft around feet and ankles. Difficult to set such that all desk working areas are draft free."
- "My office mate doesn't like air blowing as much as I do."

The final question of the survey asked for additional comments about the comfort of the office work area or the Task Air Module. A full spectrum of responses was received, ranging from very positive to very negative in nature. Of particular interest are comments from those who realize the advantages of the TAM, and make suggestions for improving the performance of the TAMs in the test building.

- "Sometimes the central thermostat seems to be set too low so that it feels very cold in the work area. I have to wear a sweatshirt when that happens. More individual control or better monitoring of the work area temperature is desired."
- "It would be a better device if I could shut the draft off completely or if the air under the floor was a source of warm air I could use to locally warm my office."

- "Make it a few degrees warmer in the building so I can make use of my Task Air Module."

Long-Term Measurements

Temperature Results

Temperature data collected by the eight HOBO portable dataloggers were analyzed over the 44-day period, 00:00 on October 28 through 24:00 on December 10, 1993. The original 45-day data set, which began in the afternoon on October 27, was truncated to provide 44 complete days of data (00:00 to 24:00). Seven of the eight dataloggers recorded the full 1800 data points allowed by their memory capacity. One temperature datalogger located at the 1.1 m height outside workstation #2, however, stopped collecting data on Nov. 10, for unknown reasons. For this sensor, we analyzed only the available 546 data points. Table 3 summarizes the statistical results for each of these sensors during typical working hours (8:00 am - 6:00 pm, Monday through Friday, excluding November 25 and 26). Table 4 summarizes the results for all days and times.

Table 3. Test Building Temperature Measurements: 28 Oct. - 10 Dec. 1993, 8:00 am - 6:00 pm, Monday - Friday, excluding 25, 26 Nov.

Location	25th °C (°F)	Median °C (°F)	75th °C (°F)
first underfloor outlet:			
primary supply under WS #54	15.7 (60.3)	16.4 (61.5)	16.8 (62.2)
TAM supply in WS #61	17.2 (63.0)	17.5 (63.5)	17.8 (64.0)
outside WS #75 at 1.1 m height	23.4 (74.1)	23.4 (74.1)	23.8 (74.8)
ceiling return above WS #49	23.8 (74.8)	23.8 (74.8)	24.2 (75.6)
last underfloor outlet:			
primary supply under WS #10	16.8 (62.2)	17.2 (63.0)	17.2 (63.0)
TAM supply outside WS #2	17.2 (63.0)	17.5 (63.5)	17.8 (64.0)
outside WS #2 at 1.1 m height	22.7 (72.9)	23.1 (73.6)	23.4 (74.1)
ceiling return above WS #14	24.2 (75.6)	24.5 (76.1)	24.9 (76.8)

Table 4. Test Building Temperature Measurements: 28 Oct. - 10 Dec. 1993, all data

Location	25th °C (°F)	Median °C (°F)	75th °C (°F)
first underfloor outlet:			
primary supply under WS #54	16.4 (61.5)	17.2 (63.0)	17.8 (64.0)
TAM supply in WS #61	17.5 (63.5)	17.8 (64.0)	18.2 (64.8)
outside WS #75 at 1.1 m height	22.7 (72.9)	23.1 (73.6)	23.4 (74.1)
ceiling return above WS #49	23.1 (73.6)	23.4 (74.1)	23.8 (74.8)
last underfloor outlet:			
primary supply under WS #10	17.2 (63.0)	17.5 (63.5)	17.8 (64.0)
TAM supply outside WS #2	17.5 (63.5)	18.2 (64.8)	18.2 (64.8)
outside WS #2 at 1.1 m height	21.7 (71.1)	22.0 (71.6)	22.7 (72.9)
ceiling return above WS #14	23.4 (74.1)	24.2 (75.6)	24.2 (75.6)

The sensors are divided into two groups: (1) primary supply, TAM supply, room air, and return air in the vicinity of the first underfloor outlet (sensor nos. 11, 13, 15, and 17 in Table 1); and (2) these same four measurements in the vicinity of the last underfloor outlet (sensor nos. 12, 14, 16, and 18 in Table 1). Results are shown for the 25th percentile (25% of readings below, 75% above), median (50% below, 50% above), and 75th percentile (75% below, 25% above). Note that the average values over these same time periods are very close to the median values.

Figures 12 and 13 present the data contained in Tables 3 and 4, respectively. In addition, temperature results are also shown in the figures for maximum and minimum values, and the 5th and 95th percentile.

The temperature results indicate that the median TAM supply air temperature at both locations is 17.5°C (63.5°F) during working hours, a value that is only slightly below the recommended supply temperature for underfloor systems, (18.3°C [65°F]). However, considering the significant number of occupant complaints of feeling too cold from the survey, it seems quite desirable to raise the supply air temperature. Due to the rapid mixing of the turbulent supply air jet from the TAM with the room air, the average room air temperature at floor level will be several degrees warmer than the supply temperatures measured inside the TAM units. Based on previous laboratory measurements of TAM performance [Bauman et al. in press], the average temperature at the 0.1-m (4-in.) level in a workstation will be about 21°C to 21.5°C (70°F to 71°F). Under normal conditions, this temperature is near the lower boundary of the acceptable comfort zone for people in typical winter clothing, and is below the lower boundary of the comfort zone for people in typical summer clothing [ASHRAE 1992]. Considering the moderate Phoenix climate, even during the months of November and December people probably dress in lighter weight clothing that could contribute to a cooler thermal sensation. Furthermore, the occupants will be exposed to even cooler temperatures if the TAM supply air jets are directed toward them.

Results from the two sensors located at 1.1 m (43 in.) height in the office indicate that the median temperatures at these locations were quite similar (23.1°C - 23.4°C [73.6°F - 74.1°F]). This suggests that on average there existed approximately a 2°C (3.5°F) temperature difference between ankle and head heights for a seated office worker. While this magnitude of stratification is within acceptable bounds, it does point out a potential problem with the thermostatic control of the supply air temperature to the space. Since all three thermostats (see Figure 1) are positioned at 1.6 m (5.25 ft) height (above head level for a seated office worker), overall temperatures experienced by occupants may be cooler than desired when the thermostats are maintained at a typical setpoint temperature (23°C-24°C [74°F-75°F]) in the middle of the comfort zone. As a result, it may be advisable to compensate for the expected stratification by raising the setpoint temperature.

The floor-to-ceiling temperature stratification is slightly higher near the north window, as would be expected. The median temperature difference between the floor-level TAM supply and ceiling return is 6.3°C - 7.0°C (11.3°F - 12.6°F). Previously published guidelines for underfloor air distribution systems [Sodec and Craig 1991] recommend that, depending on heat load level, the maximum temperature difference between floor supply and ceiling return should be 8°C - 10°C

(15°F - 18°F). Based on this observation, it may be possible to reduce the air supply volume to the underfloor plenum, allowing for reductions in central fan energy use.

In comparing the two groups of sensors in Table 3, it is seen that during working hours, the temperature at the underfloor air supply outlet closest to the equipment room is about 1°C (1.5°F) cooler than the temperature at the last underfloor outlet. There appears to be relatively good mixing in the underfloor plenum as the measured TAM supply air temperatures are nearly identical, about 1°C (2°F) warmer than the coolest underfloor primary supply air temperature.

The weekly trends of temperature data were quite similar over the measurement period. As an example, Figure 14 presents the temperature trends for all eight sensors during the week of Sunday, Nov. 7, through Saturday, Nov. 13. In the legend , the temperatures identified as 1 refer to the group of sensors near the first underfloor outlet. Those identified as 2 are near the last underfloor outlet. Note that on the morning of Nov. 10, one of the room air sensors stopped collecting data. The results clearly indicate the daily peak cooling periods that occur in the afternoons, Monday through Friday. The strategy to thermostatically control the supply air temperature appears to be working properly as the minimum daily supply temperature always coincides with the maximum room air temperature. During the weekend, this peak daily cooling load is largely absent, and as a result, the temperatures are much more constant. Many of the same temperature trends described above are also observed in Figure 14. For example, both TAM supply temperatures are very similar throughout the entire week. In addition, room temperature 2 (near the north window) is seen to cool off considerably during the evening and early morning hours compared to the room temperature 1 (at an interior location).

Energy Use Results

Current measurement data collected by the ACR portable dataloggers were analyzed over the 46-day period, October 28 through December 12, 1993. Figure 15 presents the time trend of total power used by the TAM fans over the field study period, as monitored on the four TAM circuits at the main circuit breaker panel. Table 5 summarizes the statistical results for these same data.

Table 5. Test Building Total TAM Fan Power Measurements: 28 Oct. - 12 Dec. 1993

Statistic	Power (W)
mean	881
minimum	749
25th percentile	822
median	894
75th percentile	942
maximum	1,054

The results indicate that there is relatively little variation in the magnitude of total power used by the TAM units. Using our earlier estimate of 32 W per TAM, the difference between the minimum and maximum power consumption (305 W) represents the equivalent of turning less than ten TAMs on or off. Similarly, the mean power consumption of 881 W indicates that, on average, less than one-third [881/(32 * 100)] of the approximately 100 TAMs on the four monitored circuits were in operation during the field study period. The overall trend shown in Figure 15 suggests a general decrease in usage of the TAMs over the measurement period, perhaps associated with cooler weather.

The characteristic occupant use pattern of the TAMs can be observed more clearly by looking at a typical week of TAM power data, as shown in Figure 16. During this week, November 7 - November 13, noticeable changes in power level (i.e., on the order of 32 W or more, representing turning one or more TAM units on or off) occur at five times (three reductions, two increases), as indicated. The three reductions, always occur in the morning (Monday, Wednesday, and Thursday at 8 am), and the two increases always occur near noon or early afternoon (Tuesday at noon, Friday at 1 pm). Presumably, some office workers who are feeling too cool, are turning their TAMs off when they first arrive in the morning. Around lunchtime or shortly thereafter, when conditions in the building have warmed up, some office workers are deciding to turn on (or increase the fan speed of) their TAM to provide additional cooling.

During the largely unoccupied weekend, there is no adjustment in TAM fan power as whatever TAMs are left on at the end of the day on Friday remain on throughout the weekend. This use pattern results in excessive TAM fan energy use during weekends, holidays, and other low-occupancy, low-load periods. Figure 17 shows an example of this type of unnecessary energy use over the Thanksgiving holiday. On the Wednesday afternoon before Thanksgiving around 1:00 pm, approximately three additional TAMs (≈100 W) were turned on by office workers and remained on during the 4-day holiday. Although this does not represent a significant amount of energy, it does demonstrate how the use of occupancy sensors to control local fans could provide valuable energy savings during unoccupied periods. During times when the test building is only occupied at a low level (nights, weekends, and holidays), it should be possible to turn off a substantial number of TAM units, and still satisfy the reduced building cooling load. The number of hours that fall into this category of low-occupancy periods is quite substantial. During the 46-day monitoring period, there were 30 working days. Assuming the TAMs are used 12 hours per work day, the fraction of hours representing low-occupancy conditions was (46*24 - 30*12) / (46*24) = 67%. Since occupancy sensors are currently not available to control the TAMs, a recommended energy-saving strategy would be to turn off (manually) a selected number of TAM units at the end of the day on week days, or at least every Friday and day prior to a long holiday.

Data collected from current-monitoring dataloggers located in the underfloor plenum were analyzed to observe examples of energy-use patterns from individual TAMs. Figure 18a and 18b present the trends of power use over the field study period for the TAMs in workstation # 61 and #58, respectively. Both TAMs are seen to be turned on or off in only a few instances. The TAM in WS #61 is already on when the monitoring begins on October 28, remains on at the same fan speed until it is turned off in the morning of November 1, is turned back on in the afternoon of November 5, is turned off in the morning of November 8, and remains off for the duration of the monitoring period. The TAM in WS #58 is turned off and on during the morning of October 28 (perhaps during a short-term test by our researchers in the field), remains on at the same level until the morning of November 22, when it is turned off and remains off for the duration of the monitoring period. The average power consumption when the TAMs are turned on is 29.0 W for WS #61, and 24.8 W for WS #58.

As described previously in *Site Description*, it is estimated that the central fan serving the underfloor plenum delivers a fairly constant volume of approximately 4,700 L/s (10,000 cfm). For the 1,000 m^2 (11,000 ft^2) office area this represents a supply volume of nearly 5 L/s·m^2 (1 cfm/ft^2). Although no direct energy measurements were taken on the central fan, a reasonable estimate is 2.1 W/L/s (1 W/cfm), translating into a constant central fan power usage of approximately 10 kW for air delivered to the underfloor plenum. Note that this is more than ten times the average power consumption of all TAMs together.

Based on the findings from the field study concerning the pressurized underfloor plenum and the lower than recommended peak temperature difference between floor supply and ceiling return, it should be possible to reduce the volume of air supplied by the central AHU. Even a conservative reduction of 25% would save 2.5 kW for this wing of office space during peak periods without raising the floor-to-ceiling temperature difference above the recommended level of 8°C - 10°C (15°F - 18°F). Larger reductions in central fan energy use could be achieved during off-peak periods. If the floor-level supply air temperature is raised in combination with a lower primary supply volume, the average office temperature would be increased, and presumably the use of the TAMs for local occupant cooling would also increase. This would be a desirable trend as a larger percentage of office workers should be able to control the thermal conditions in their workstation to their personal comfort preferences. Even if the TAM usage doubled in comparison to the current use, the additional power consumption would only be about 0.9 kW, considerably less than the above described central fan energy savings. If all 100 TAM units were in operation at the average rate of 32 W, the additional TAM power consumption over the current level would be about 2.3 kW, roughly equivalent to the central fan energy savings associated with a 25% reduction.

SUMMARY AND RECOMMENDATIONS

A field study was performed in an engineering office building near Phoenix, Arizona, over the period October 27 to December 14, 1994. Measurements were taken in a 1,000 m^2 (11,000 ft^2) office area served by an underfloor air distribution system with about 100 Task Air Modules (TAMs). Miniature portable dataloggers were used to monitor the pattern of energy use by the TAMs and selected temperatures within the air distribution system and office space. A written survey on occupant comfort response was given to 160 office workers; 79 completed surveys were returned. The major findings from the survey and measurements are summarized below.

1. Most office workers appear to like the TAM system or to at least realize its advantages over conventional air distribution systems if operated correctly. Survey results indicated that a significantly larger percentage of respondents rate the performance of the TAMs as being much or somewhat better than the performance of conventional ventilation systems in other buildings that do not have TAMs compared to the percentage who rate the TAMs as being much or somewhat worse.
2. On average, a surprisingly small percentage of the TAM units (less than one-third) were in use (turned on). Most office workers either had their TAM turned off, or had implemented measures to restrict or block the TAM air flow due to feeling an uncomfortable draft. The

survey indicated that the TAM controls (direction or velocity of air delivery) are adjusted very infrequently by a large majority of the respondents. A total of about 80% adjust their TAMs less often than once per week.

3. The uncomfortably cool conditions that restricted the use of the TAMs are caused by an excessive air supply volume provided to the underfloor plenum by the central air handling unit in combination with a supply air temperature that is lower than necessary. Also contributing to the possibility of temperatures in the occupied zone of the office that are cooler than desired is the placement of the room thermostats at 1.6 m (5.25 ft) height (above head level for a seated office worker). The temperature stratification that naturally occurs in a floor-to-ceiling air distribution system will produce cooler temperatures near the floor level even when the thermostats are maintained in the middle of the comfort zone.
4. Each TAM unit that was turned on used an average of 32 W. The average power factor for the TAMs in use was 0.57. The average total power used by all TAM units over the field study period was about 0.9 kW with relatively small variations (±150 W between maximum and minimum). In comparison, it is estimated that the average power used by the central fan for air delivery to the underfloor plenum is approximately 10 kW.
5. Since the central AHU operates on a constant volume basis and there is no automatic provision to reduce TAM fan settings, either through the use of occupancy sensors or regularly scheduled manual setbacks, fan energy use during low-load, low-occupancy periods (nights, weekends, holidays) is higher than necessary.

Based on the results of this field study and our research work on task conditioning systems during the past six years, the following recommendations can be made to improve the performance of the underfloor air distribution system using Task Air Modules in the test building.

1. The greatest potential energy savings are associated with reducing the volume of air supplied by the central AHU to the underfloor plenum. In combination with other operational and control changes, it should be possible to not only save energy, but also provide thermal environmental conditions that are acceptable to a larger number of building occupants, as discussed further below.
2. By reducing the volume of air supplied by the central AHU, the average office temperature should increase, thereby encouraging greater use of the TAMs. This would be a desirable control change because there was a noticeable percentage of survey respondents (≈30%) who noted overcooled and drafty conditions, while very few (5%) complained of overheating problems. While TAM fan energy use would increase, this should be more than offset by savings in central fan energy use. This strategy would increase the percentage of occupants who could control their workstations to maintain comfort while at the same time realizing some amount of overall fan energy savings.
3. Raising the supply air temperature slightly may also be desirable and this should be accomplished by improving the control of the underfloor plenum pressure. As was measured and observed in the test building, the underfloor plenum is currently being operated at a positive pressure in relation to the office space. The Task Air system, however, is designed to operate, nominally, with a very small negative pressure (5 Pa [0.02 in. H_2O]) in relation to the space. This means that the air exchange rate should be greater from the underfloor plenum to the occupied space, than from the primary supply duct to the underfloor plenum.

The extra amount of make-up air can be provided by connecting an induction shaft from the return air at ceiling level to the underfloor plenum, or by simply installing floor grilles (no TAM unit) that allow air to pass in either direction between the conditioned space and underfloor plenum. When operated properly, the larger air flow rate through the TAM units will induce higher temperature room air (or return air) into the underfloor plenum, thereby blending with the cooler primary supply air and raising its temperature before delivery to the space.

4. Since it is not practical to measure and control based on the very low pressure differentials that exist between the space and underfloor plenum, an ingenious primary air volume control strategy proposed by Shute (1992) uses a temperature sensor as an indicator of plenum pressure differential. The sensor should be located in the vertical induction shaft connecting return air to the underfloor plenum, or, if this option is not available, perhaps in a shorter shaft placed on top of a floor grill and open to room air on its top near the ceiling. Under normal operating conditions, the floor supply units will be delivering more air to the space than is provided by the central system. In this case, the temperature sensor will measure normal return air (or room air) temperatures as the air is drawn down the induction shaft to mix with incoming primary air. If, however, the temperature in the induction shaft decreases rapidly, it indicates that the demand for air supply through the floor supply modules has been reduced (i.e., fan units have been turned down or off), resulting in the overpressurization of the underfloor plenum. The central air handler can then be throttled down until the reversal in flow direction through the induction shaft is eliminated.
5. By operating the underfloor plenum at a slight negative pressure in relation to the space, the TAM performance will also be improved and greater acceptance and satisfaction among building occupants should result. An office worker would be able to turn off the TAM completely when desired, without having unwanted air supply produced by the pressurized plenum. This should eliminate the rather widespread practice of blocking the air flow through the TAM units that was observed in the test building.
6. In its current configuration, the wall thermostats are used to modulate the primary supply air temperature. As discussed earlier, the naturally occurring stratification in the space results in temperatures below the thermostat setpoint at locations near the floor where seated occupants are working. To improve the performance of the thermostat control, it is recommended that either the setpoint be raised slightly to compensate for the stratification, or that the thermostats be relocated at a lower height on the wall.
7. As draft complaints can often mean improperly positioned TAMs or placement too close to the work area, it is recommended that TAMs be positioned at least 1.2 m (4 ft) away from the occupants normal work location. TAM positions should be checked and maintained as furniture and partitions are rearranged in the future. If one or two of the four grills on a TAM unit are covered by a piece of furniture, make sure that the grill containing the fan speed control knob is still accessible to the office worker.
8. Building occupants who have access to TAM units should be properly trained to allow the operation and control of the air distribution system to be optimized.

ACKNOWLEDGMENTS

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FIGURES

TABLES

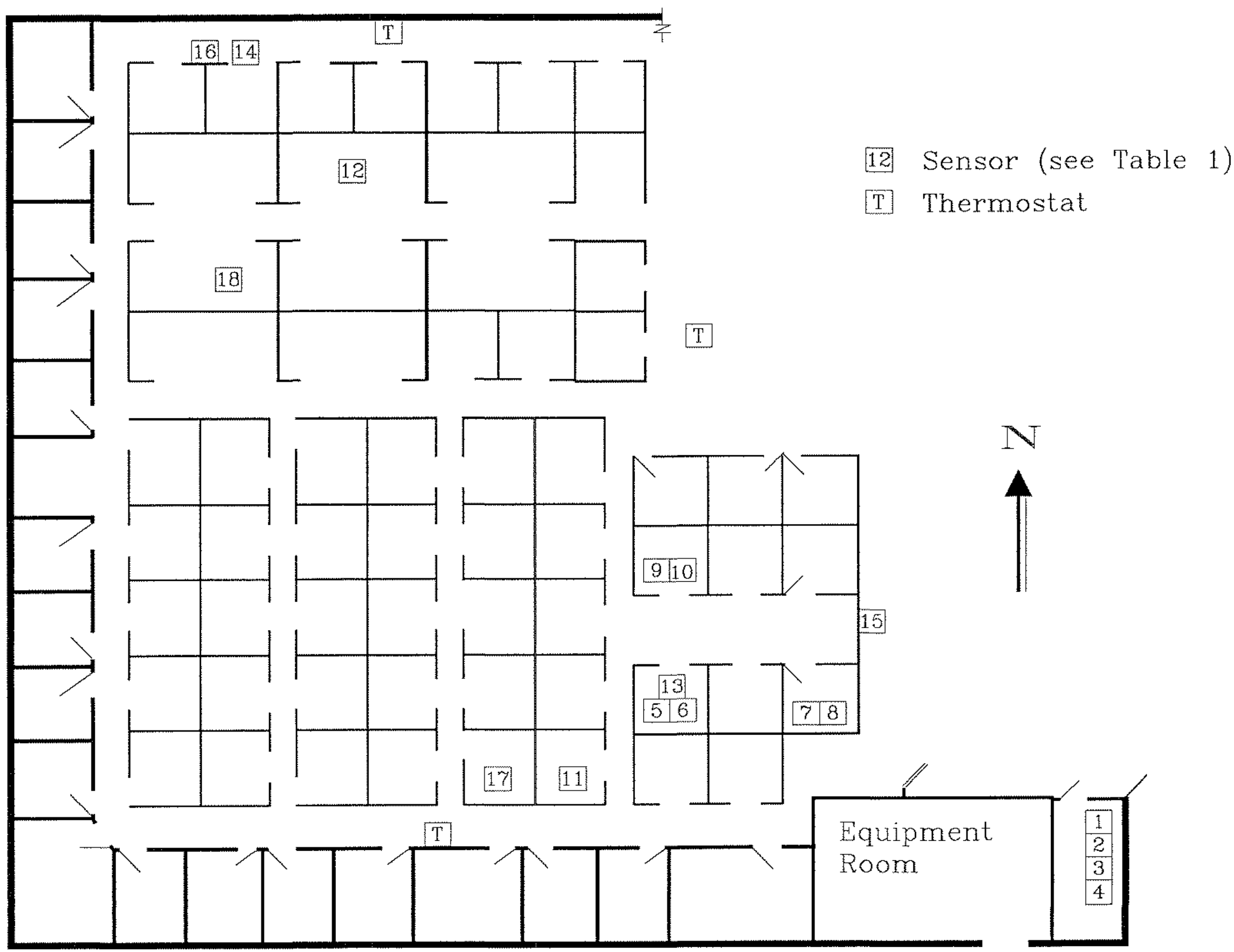


Figure 1. First Floor Plan, North Wing

Figure 2a. TAM Power Factor vs Fan Speed Setting

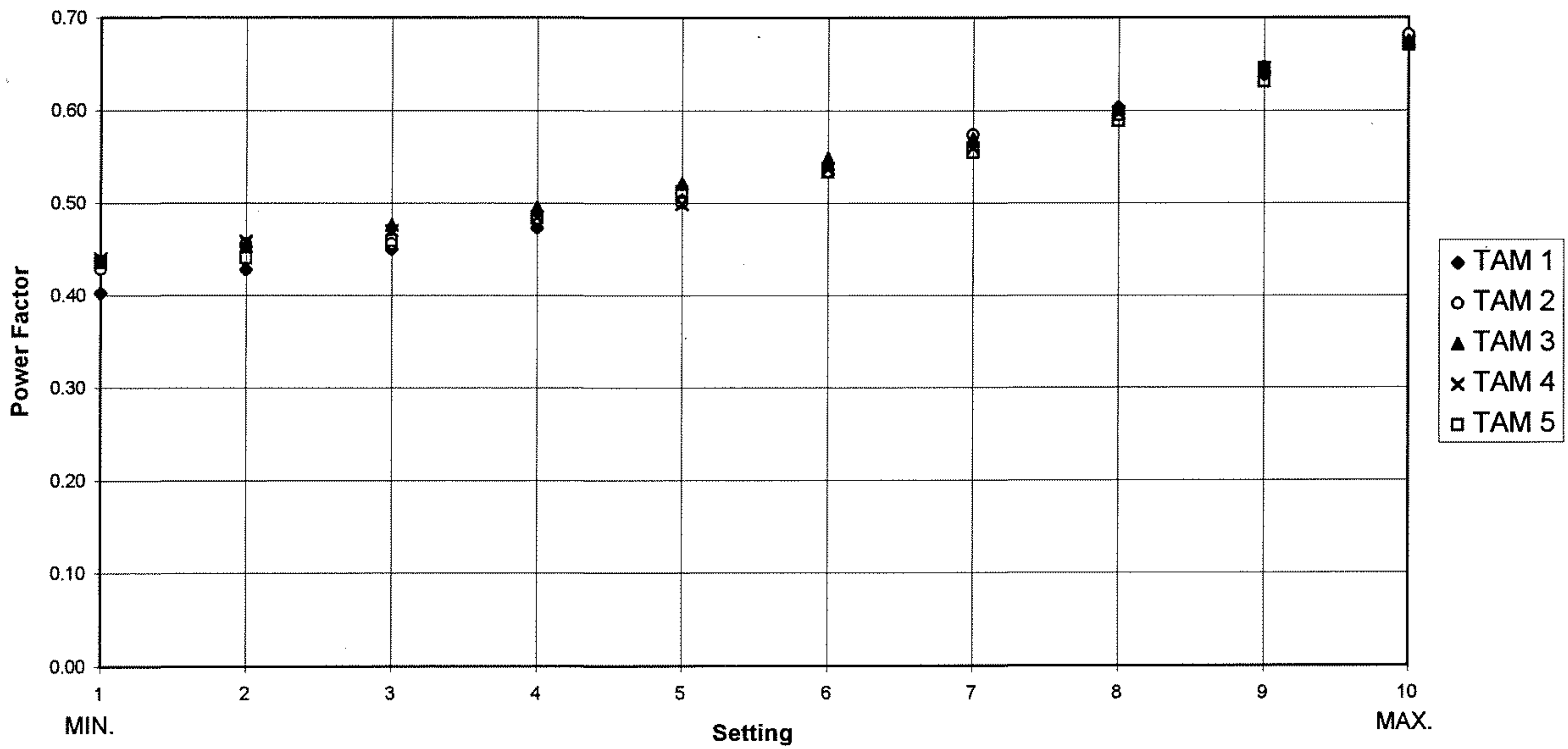


Figure 2b. Tam Power Factor vs Fan Speed Setting: Average Data

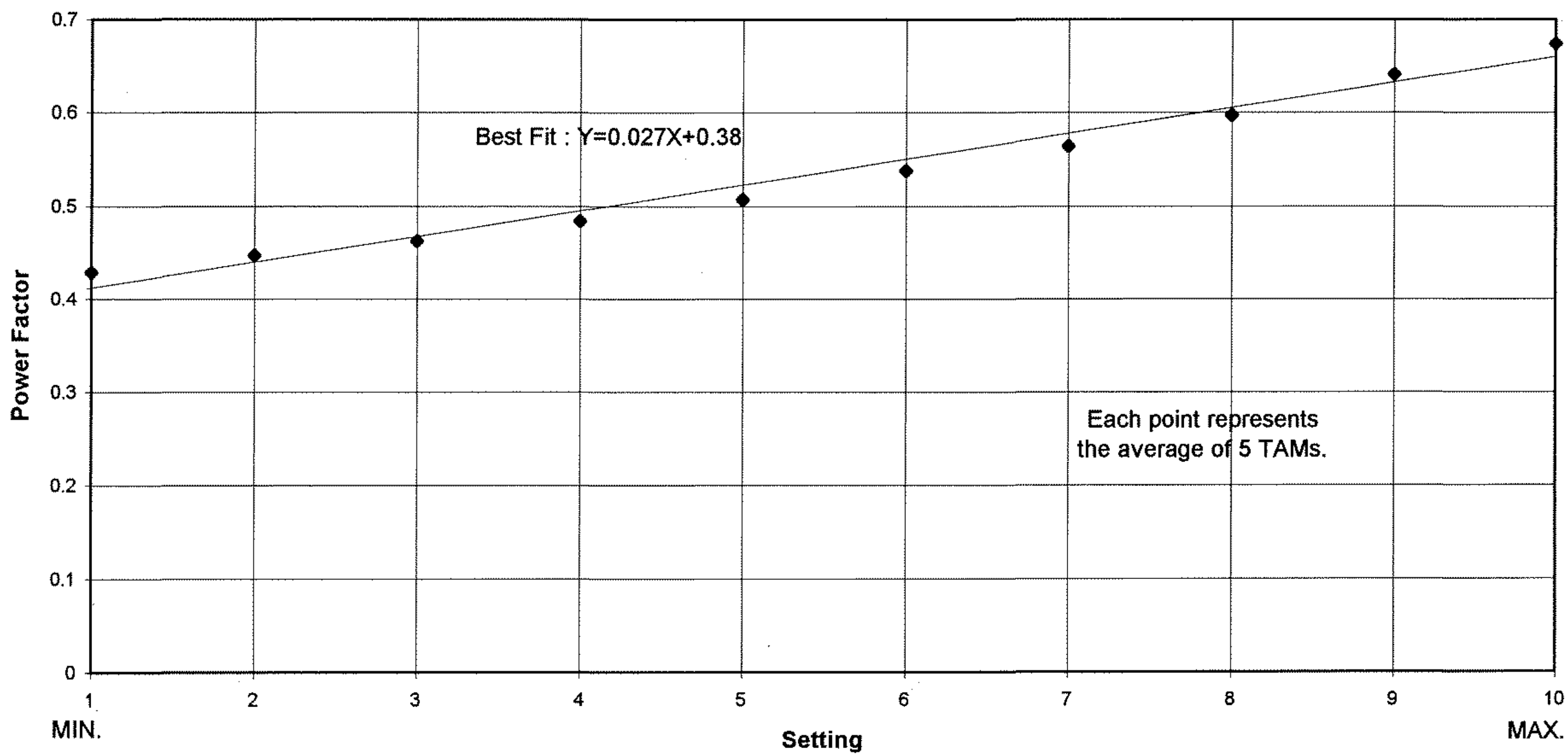


Figure 2c. Apparent Power and Real Power of TAMs

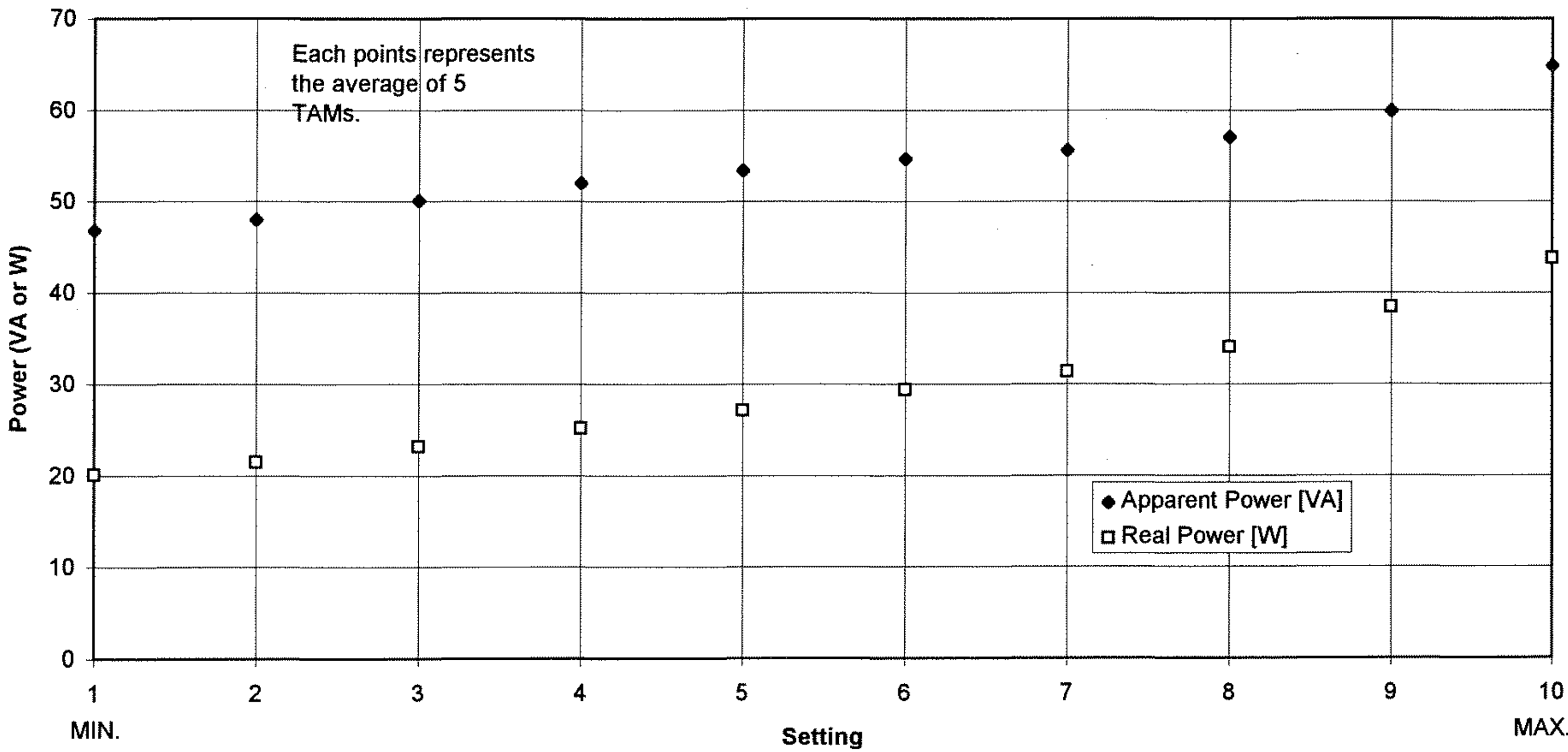


Figure 3. Power Factor vs Electrical Current with ACR Sensor: Combination of 5 TAMs

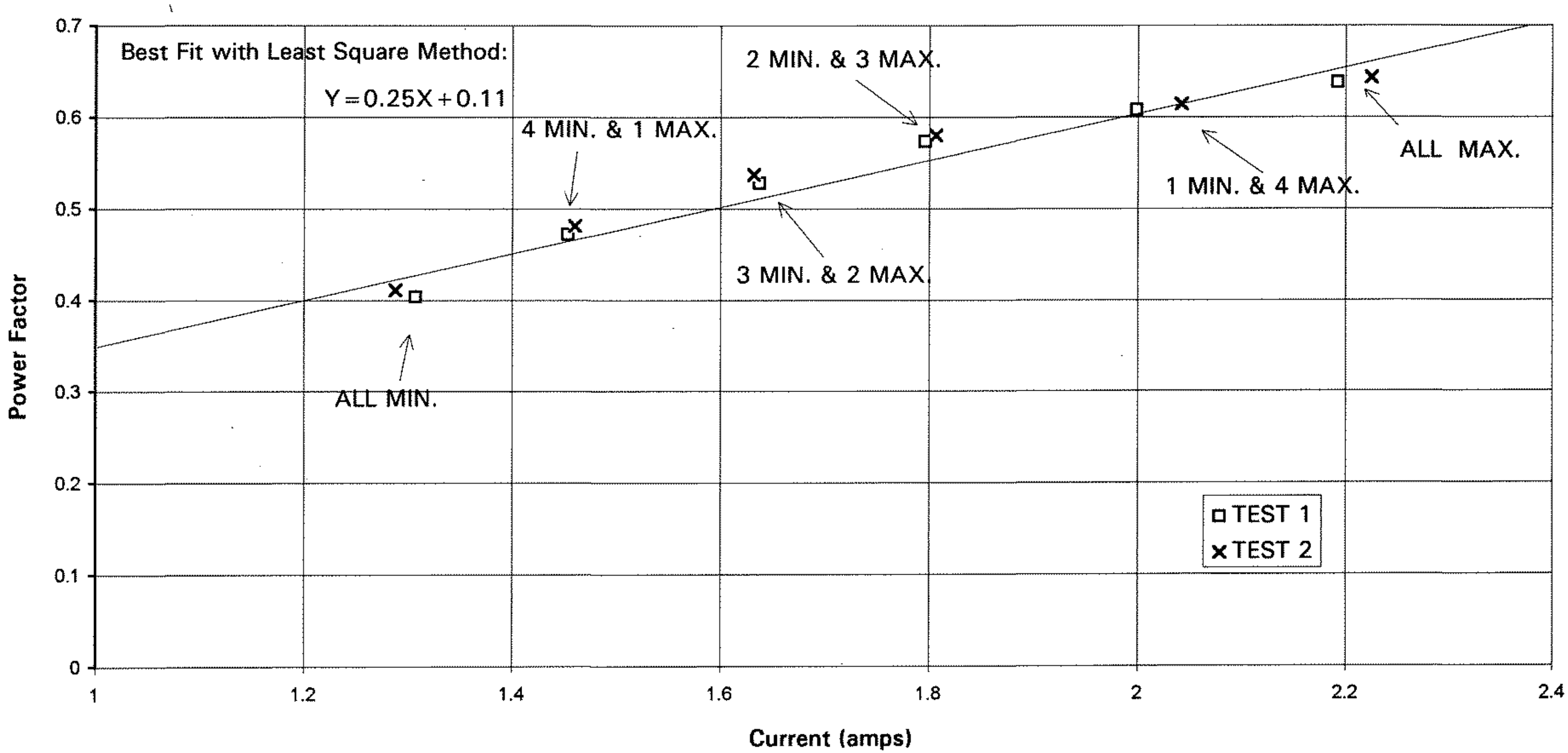


Figure 4. Adjustment of Task Air Module

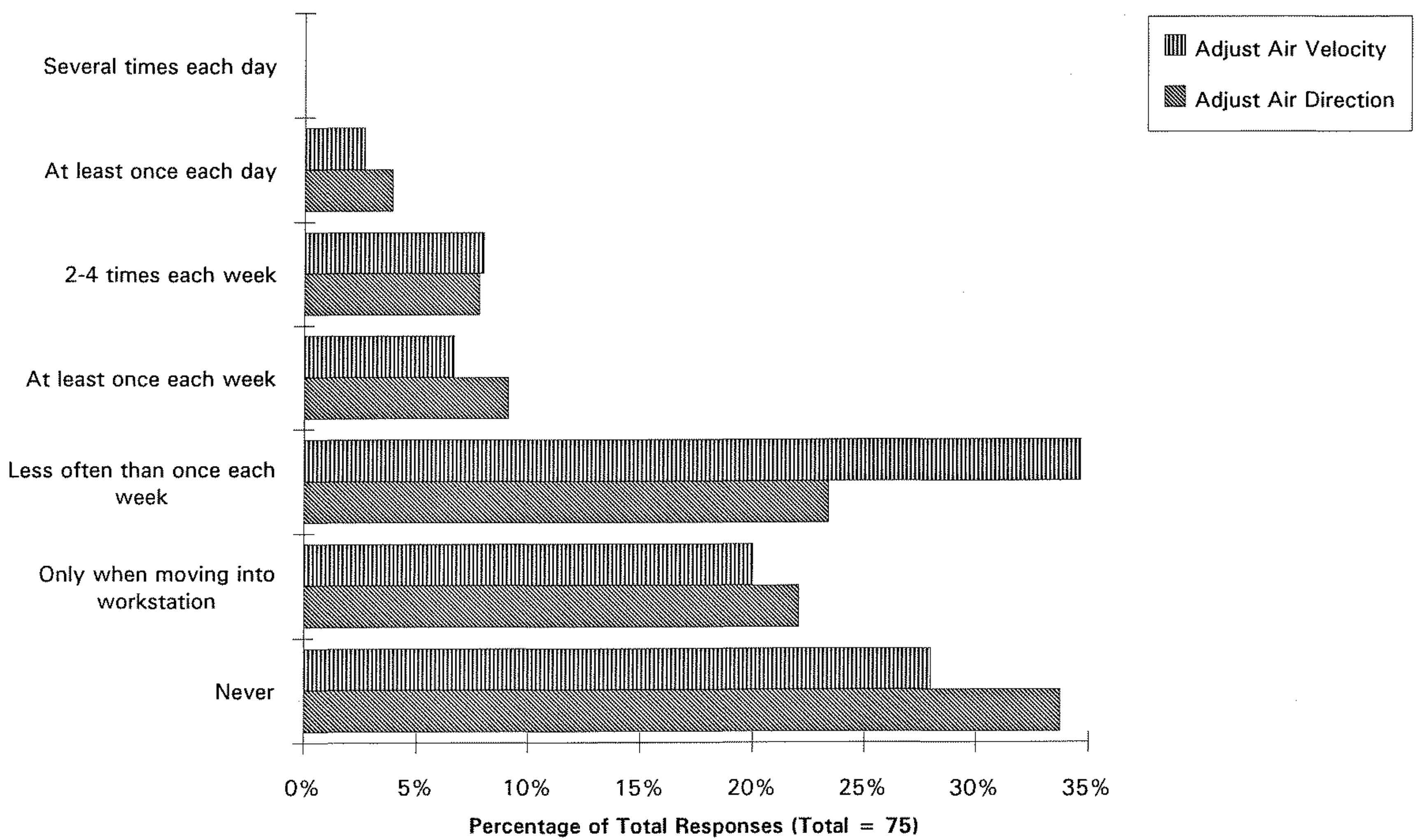


Figure 5. Task Air Module Operation Effectiveness:
uncomfortably cool and warm conditions

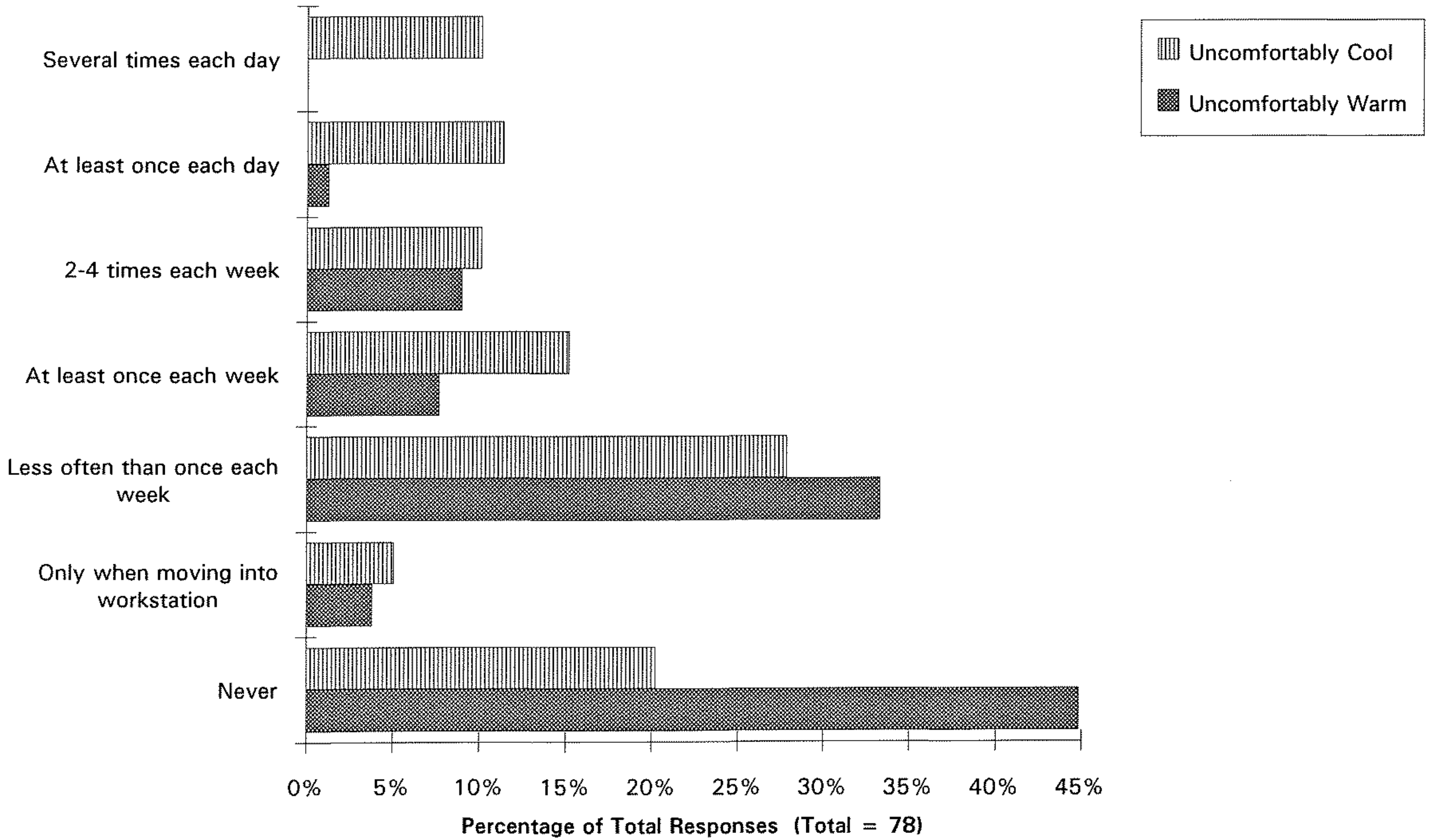


Figure 6. Task Air Module Operation Effectiveness:
air movement

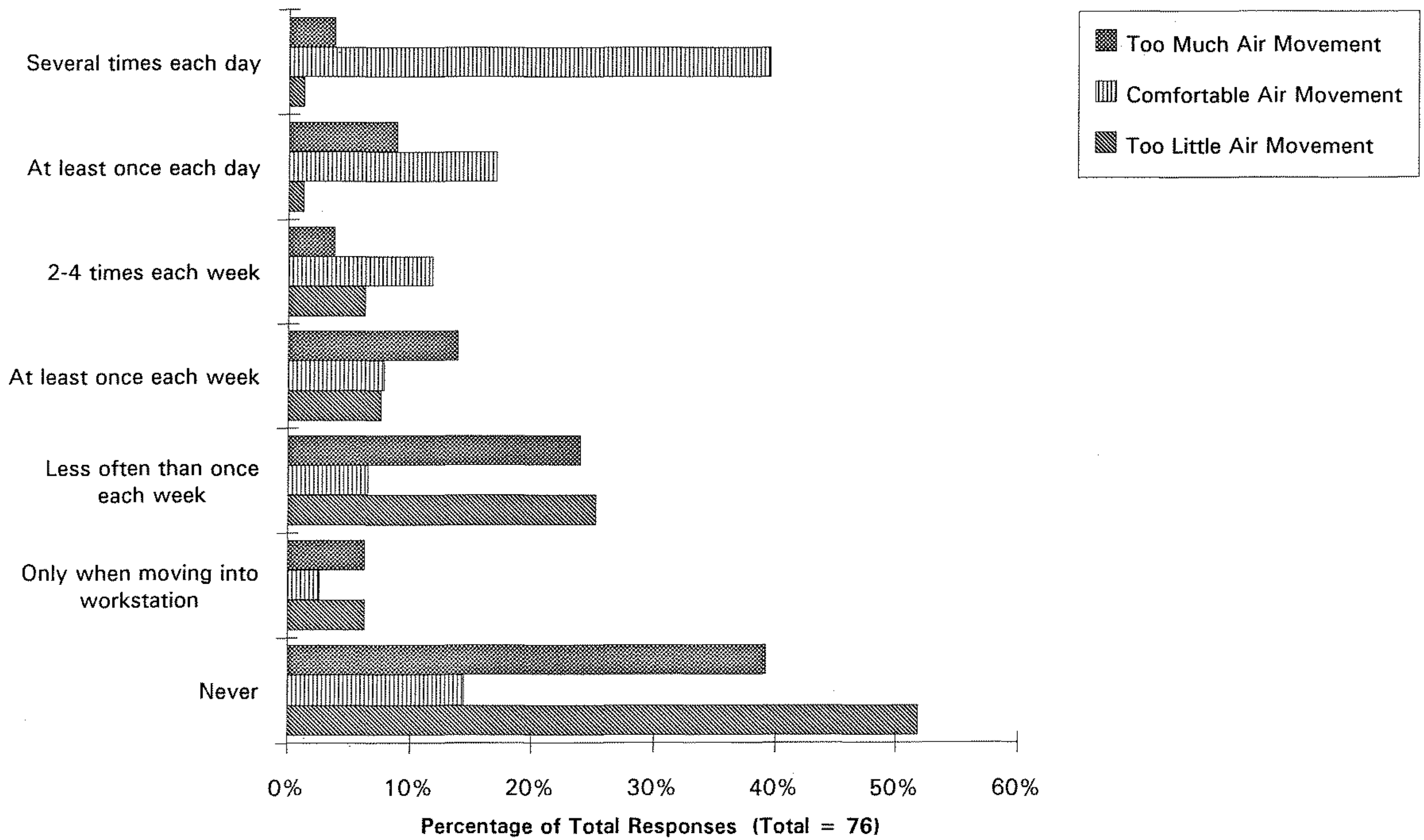


Figure 7. Comparative Performance of Task Air Module:
thermal comfort, temperature, air movement & circulation, air quality

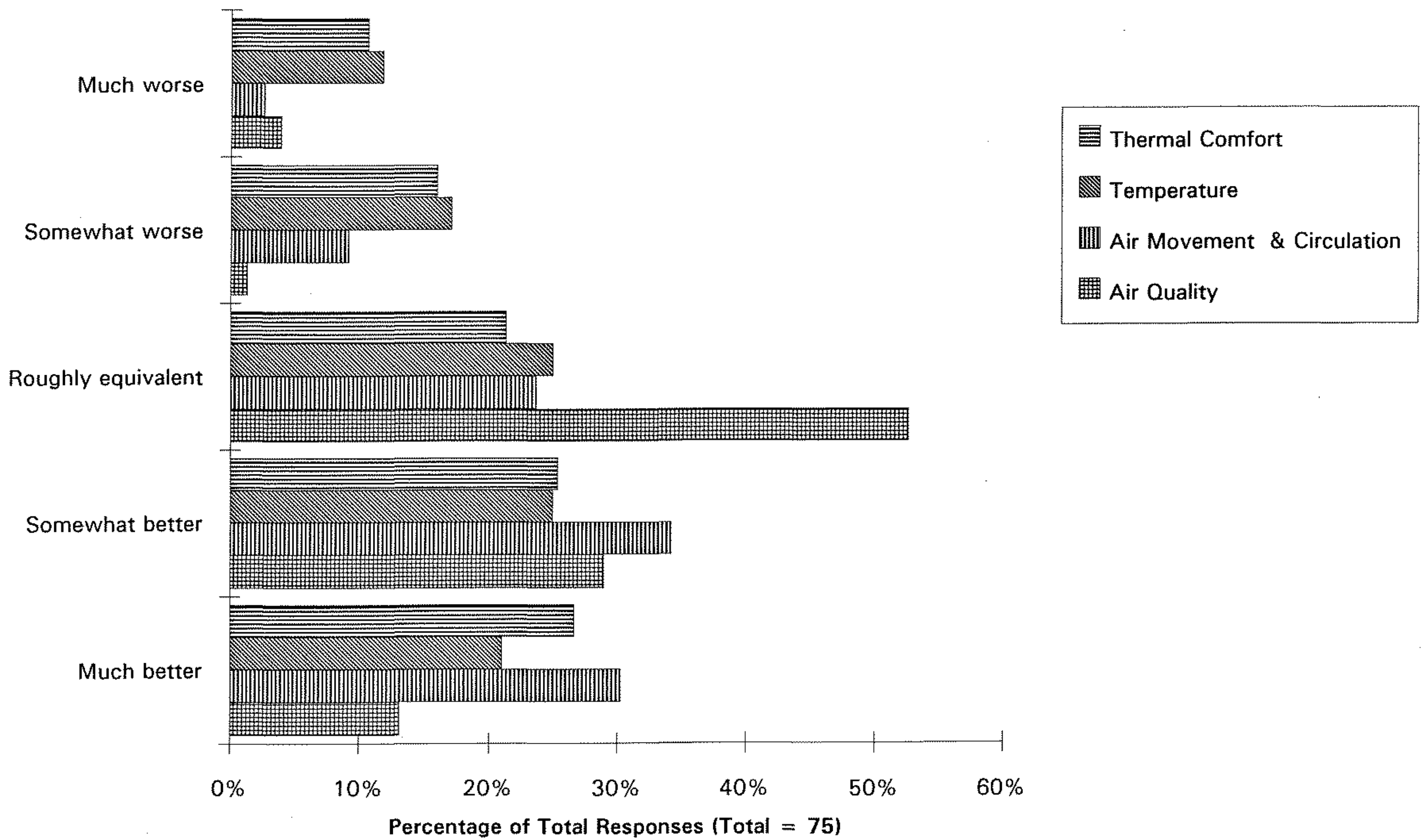


Figure 8. Comparative Performance of Task Air Module:
personal control, avoid draft, avoid overheating

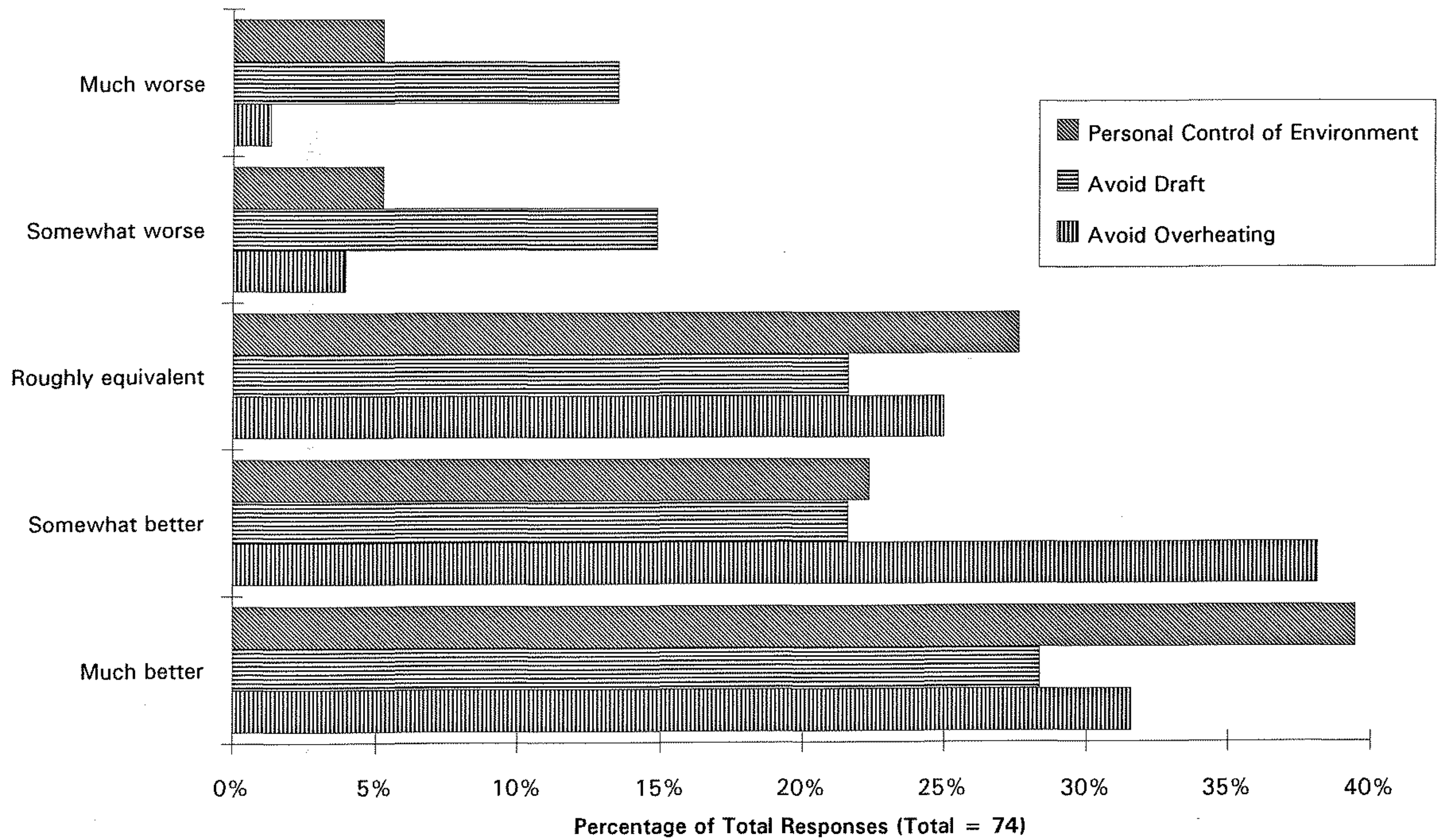


Figure 9. Thermal Comfort From Task Air Module:
comparative performance based on frequency of adjustment

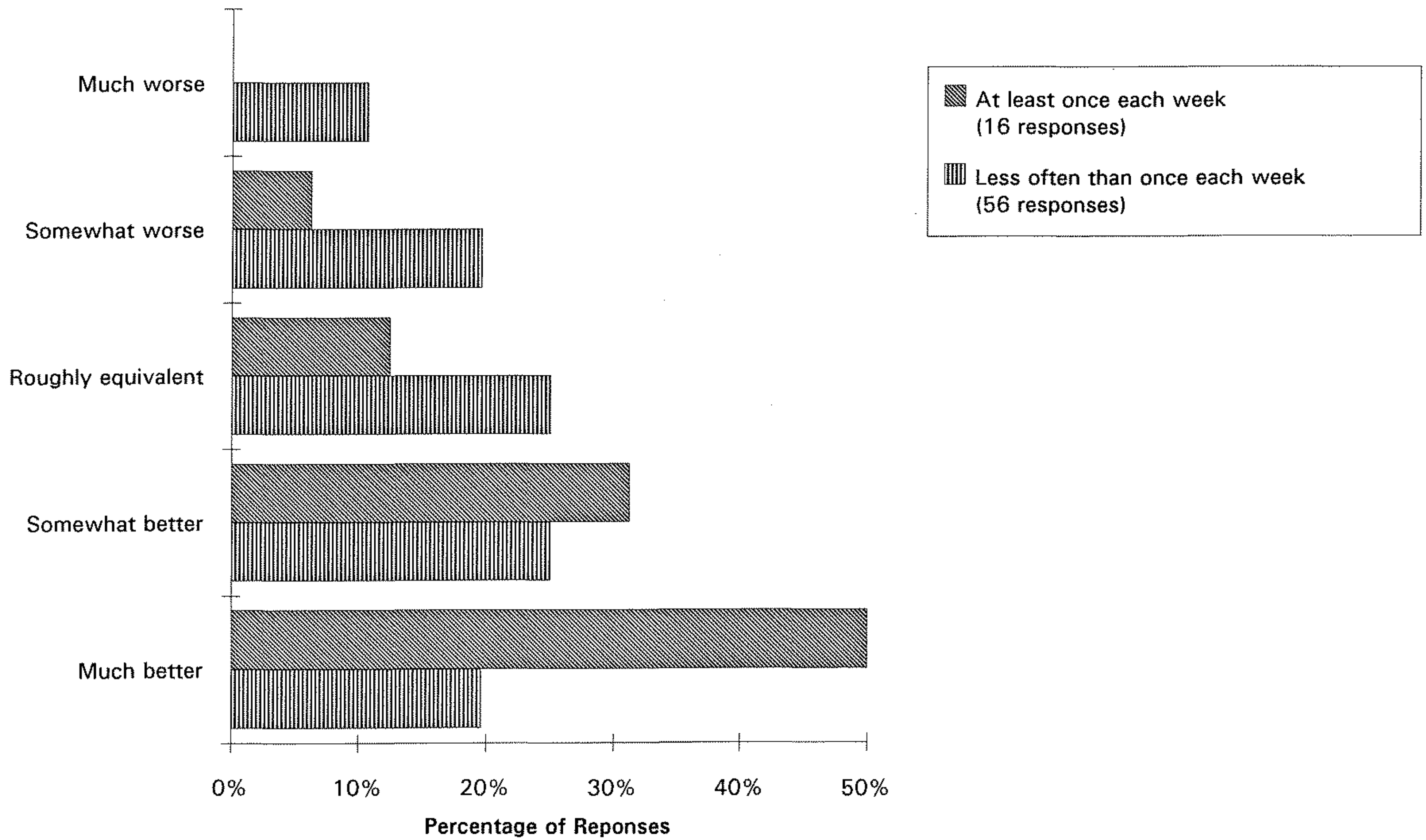


Figure 10. Productivity From Task Air Module:
comparative performance based on frequency of adjustment

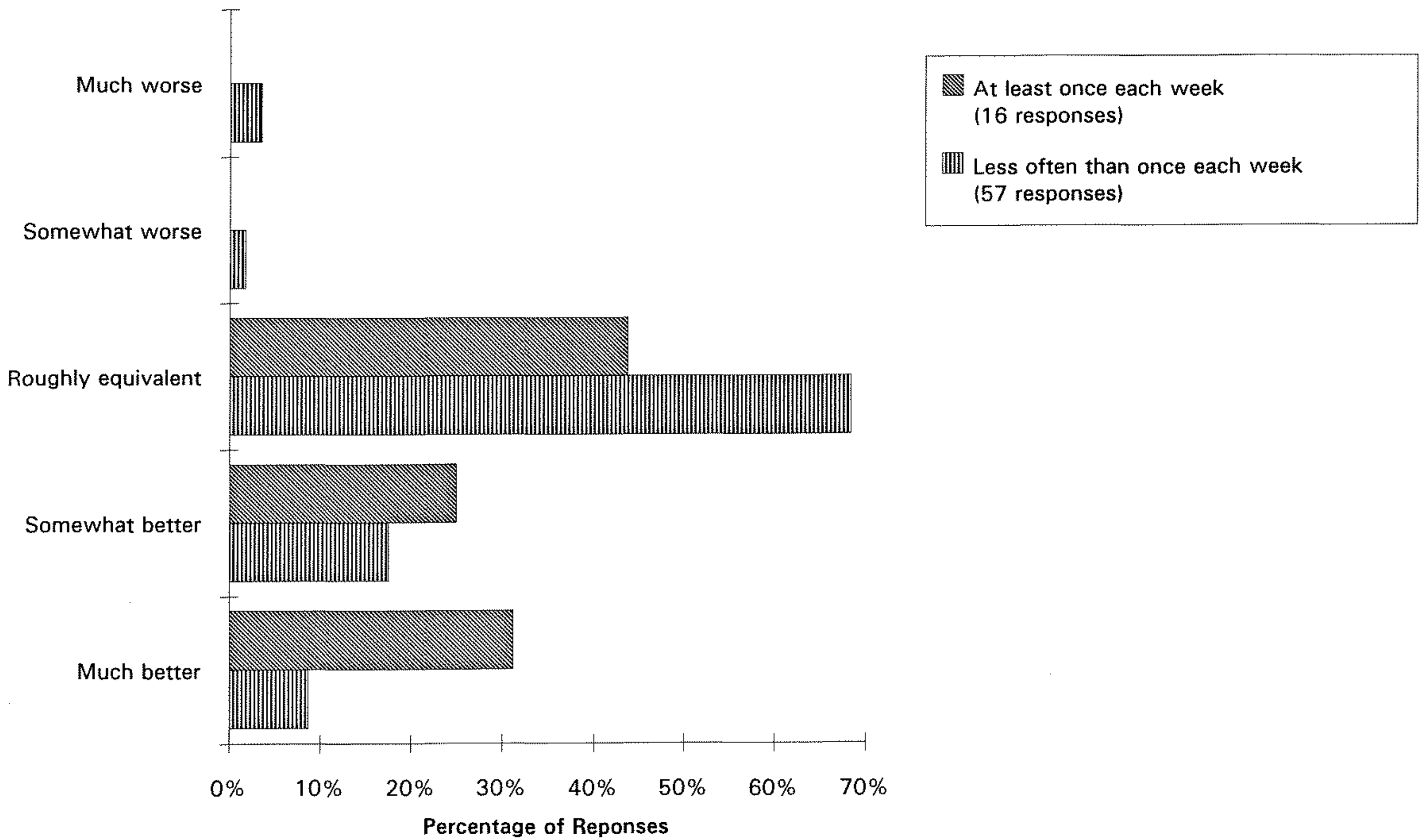


Figure 11. Personal Control by Task Air Module

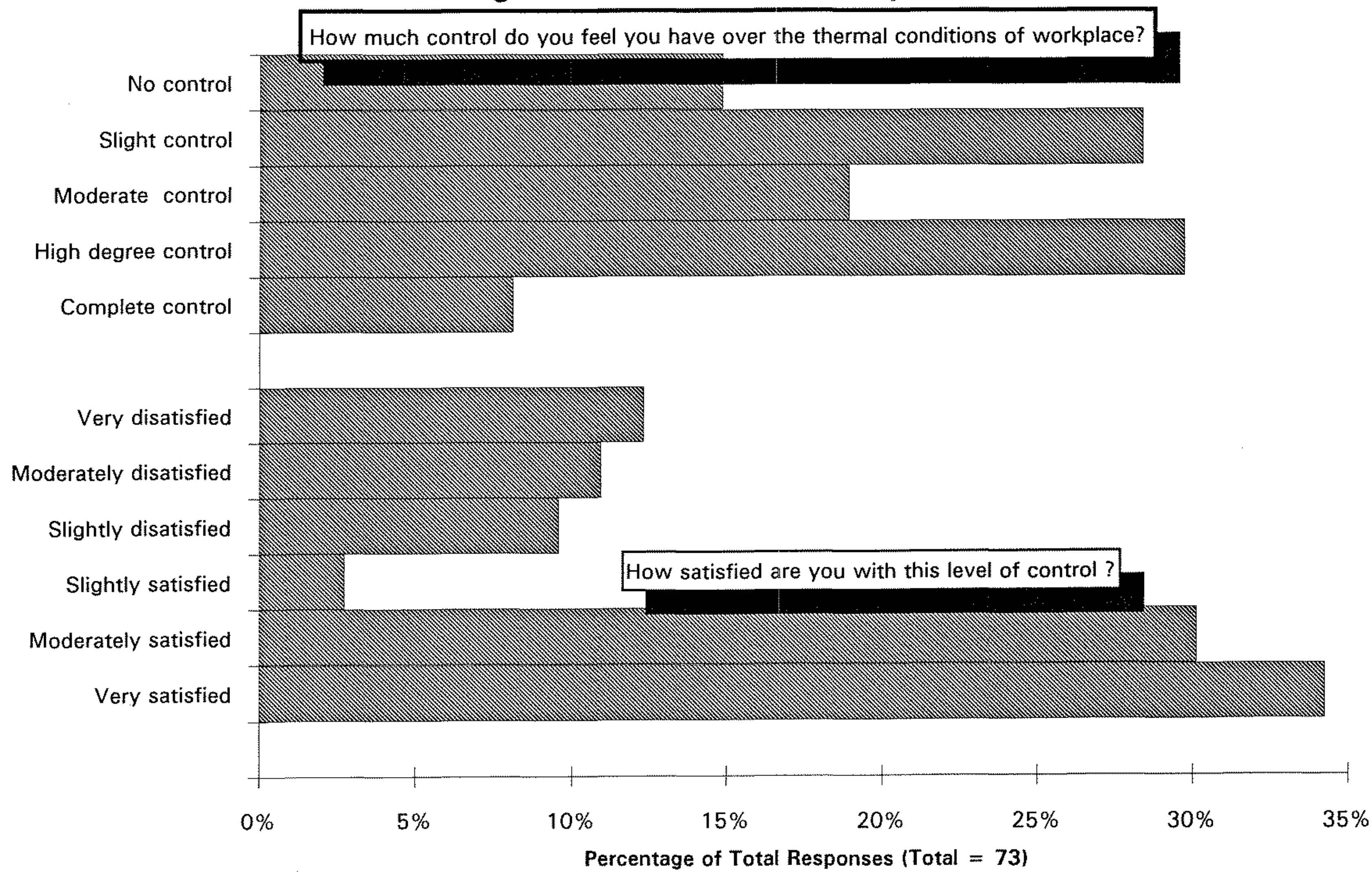
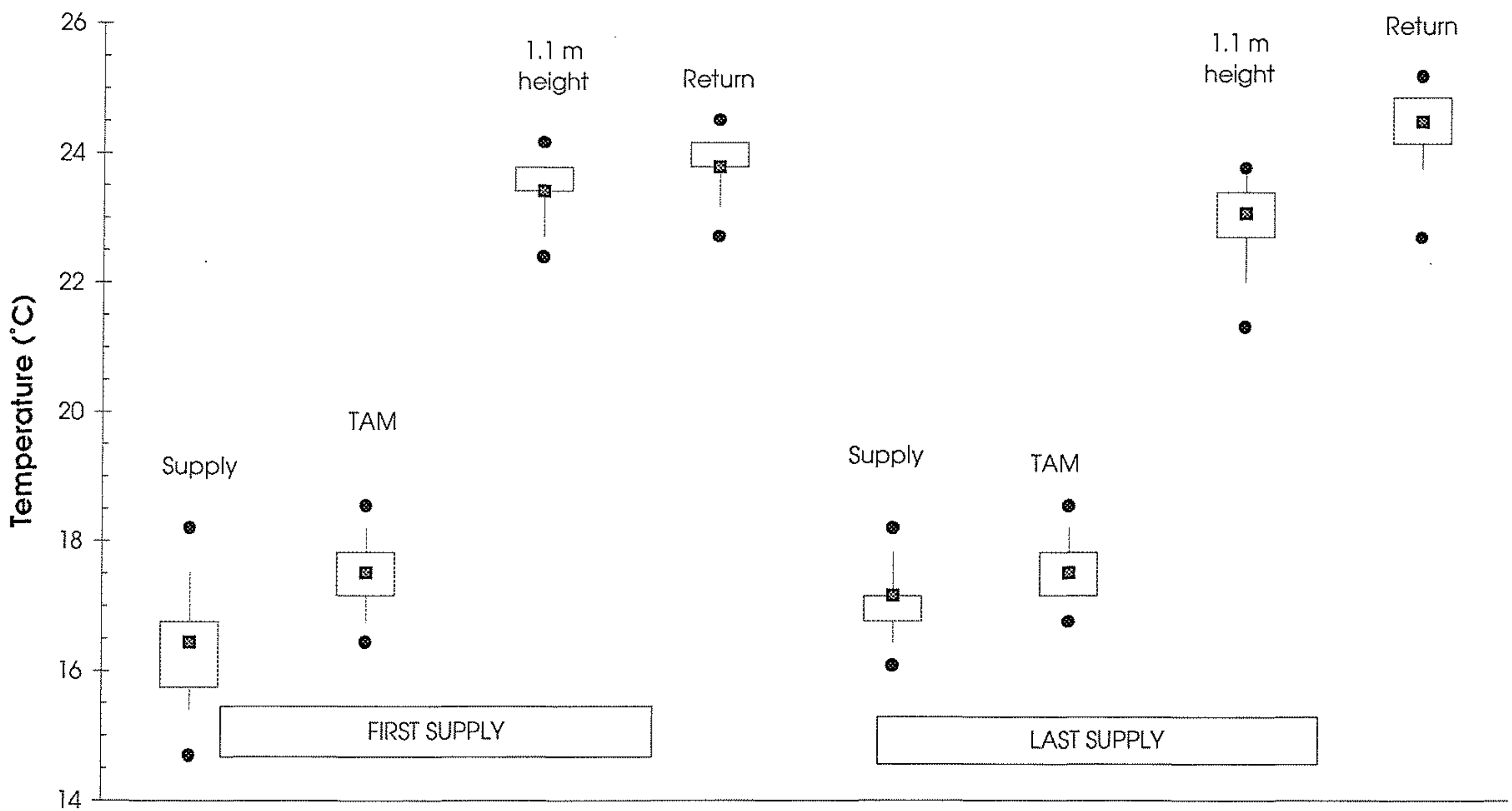
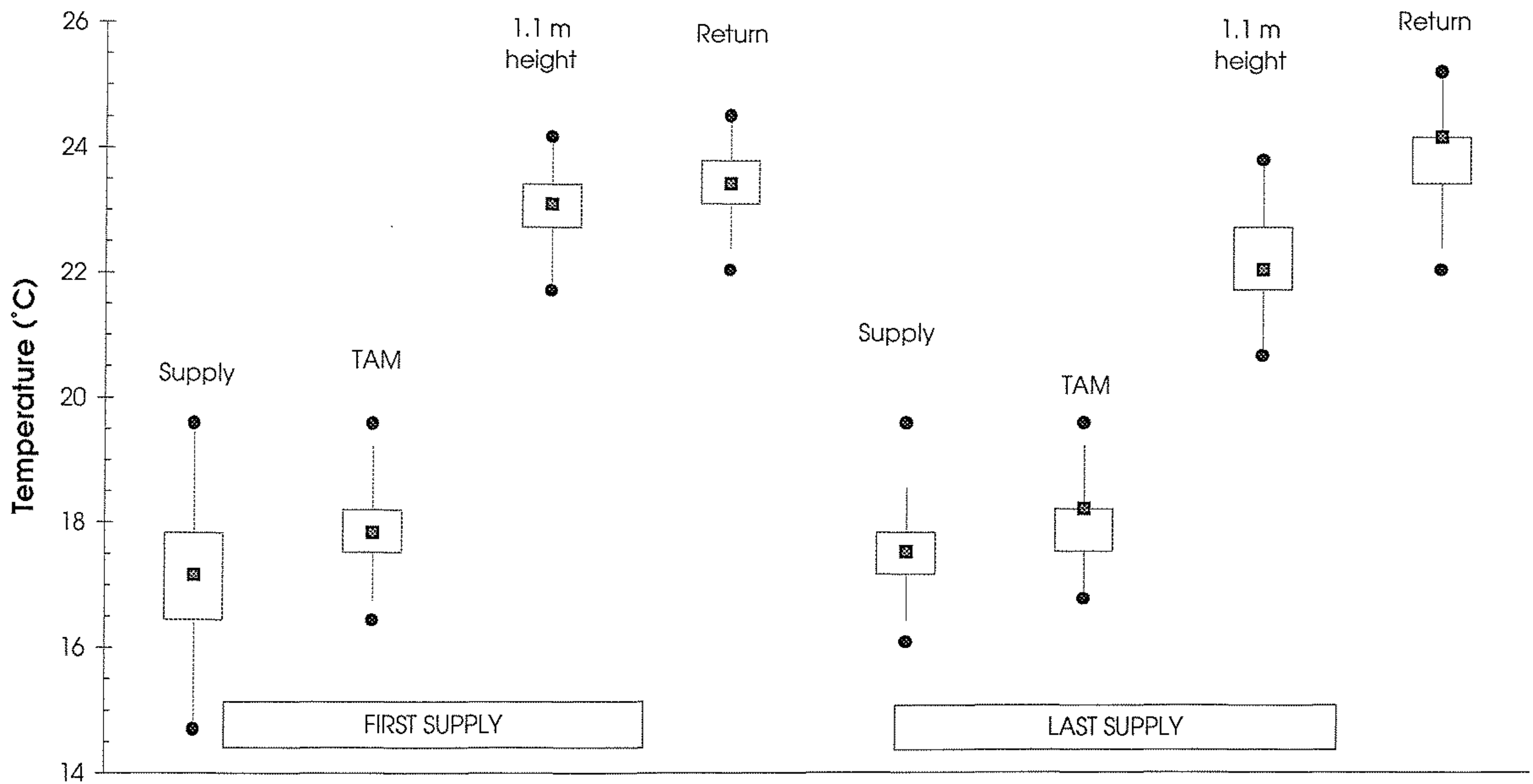


Figure 12. Test Building Temperatures: 28 Oct. - 12 Dec. 1993
Mon. - Fri., 8:00 am - 6:00 pm, excluding 25, 26 Nov.



Round points denote maximum to minimum, tails - 5th to 95th percentile, box - 25th to 75th percentile, square point - median

Figure 13: Test Building Temperatures: All Data, 28 Oct. - 12 Dec. 1993



Round points denote maximum to minimum, tails - 5th to 95th percentile, box - 25th to 75th percentile, square point - median

Figure 14. Temperature Results: Sunday, Nov. 7 - Saturday, Nov. 13

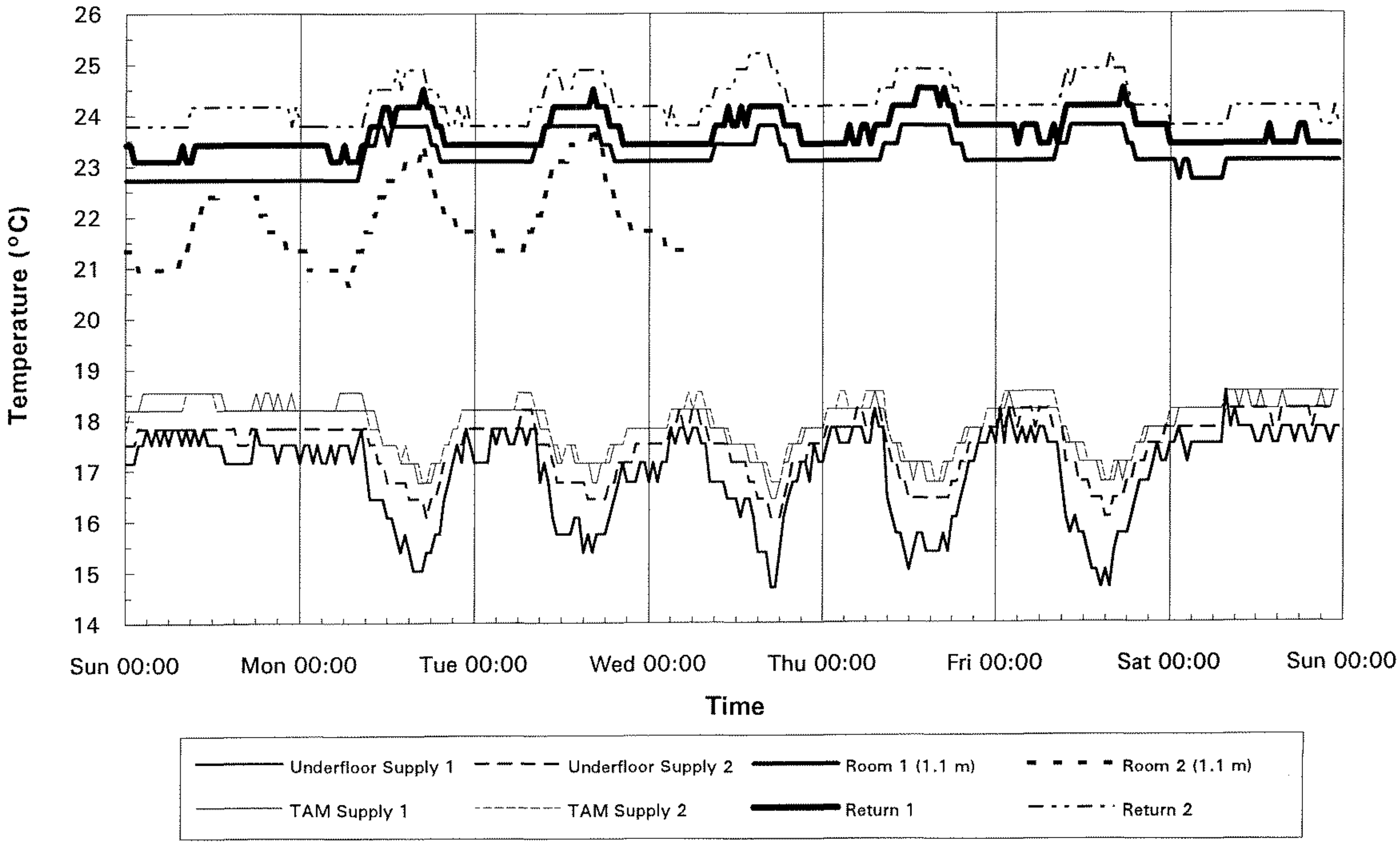


Figure 15. Total Power Used by TAM Fans: Oct. 28 - Dec. 12, 1993

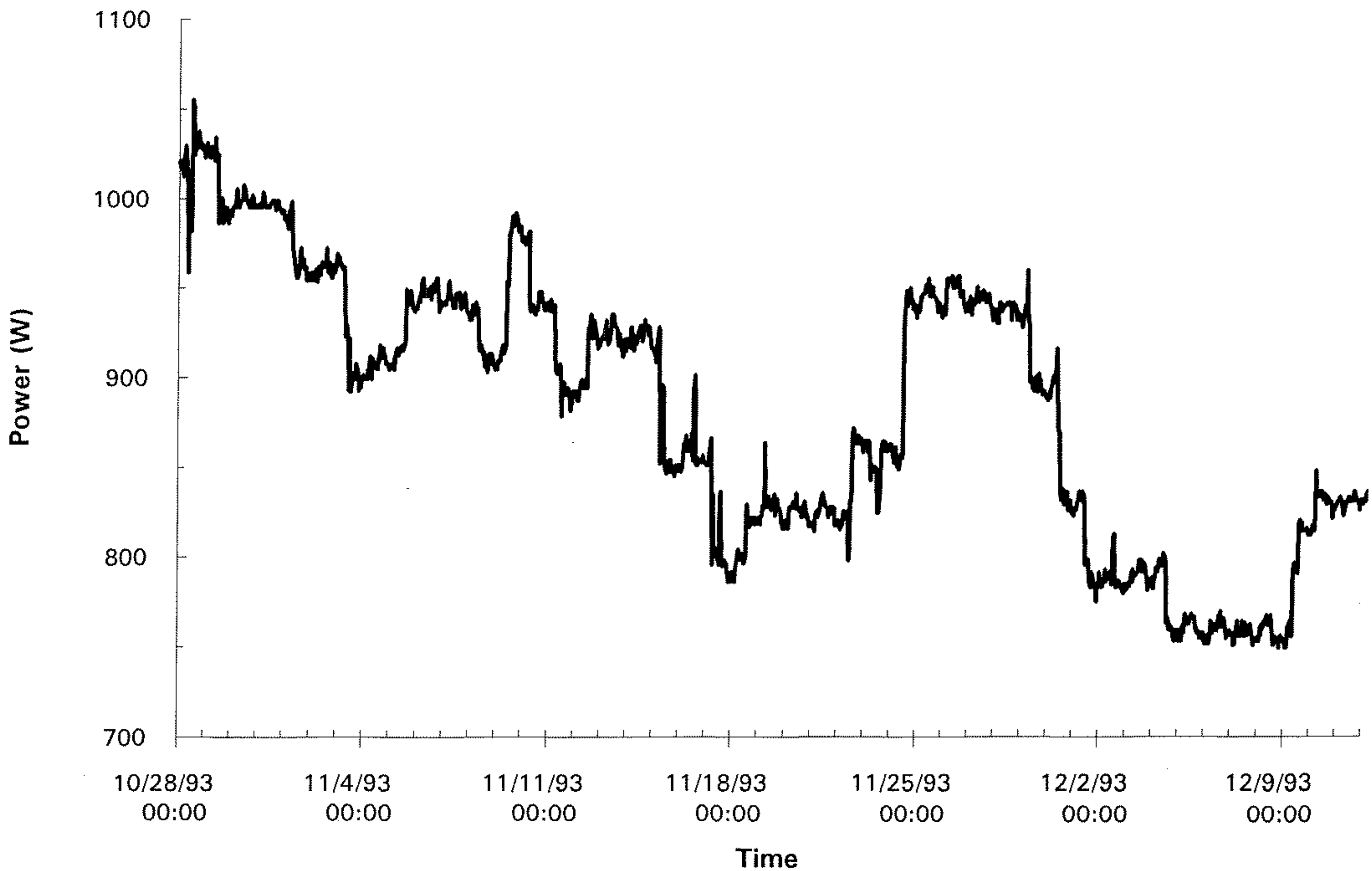


Figure 16. Total Power Used by TAM Fans:
Sunday, Nov. 7 - Saturday, Nov. 13

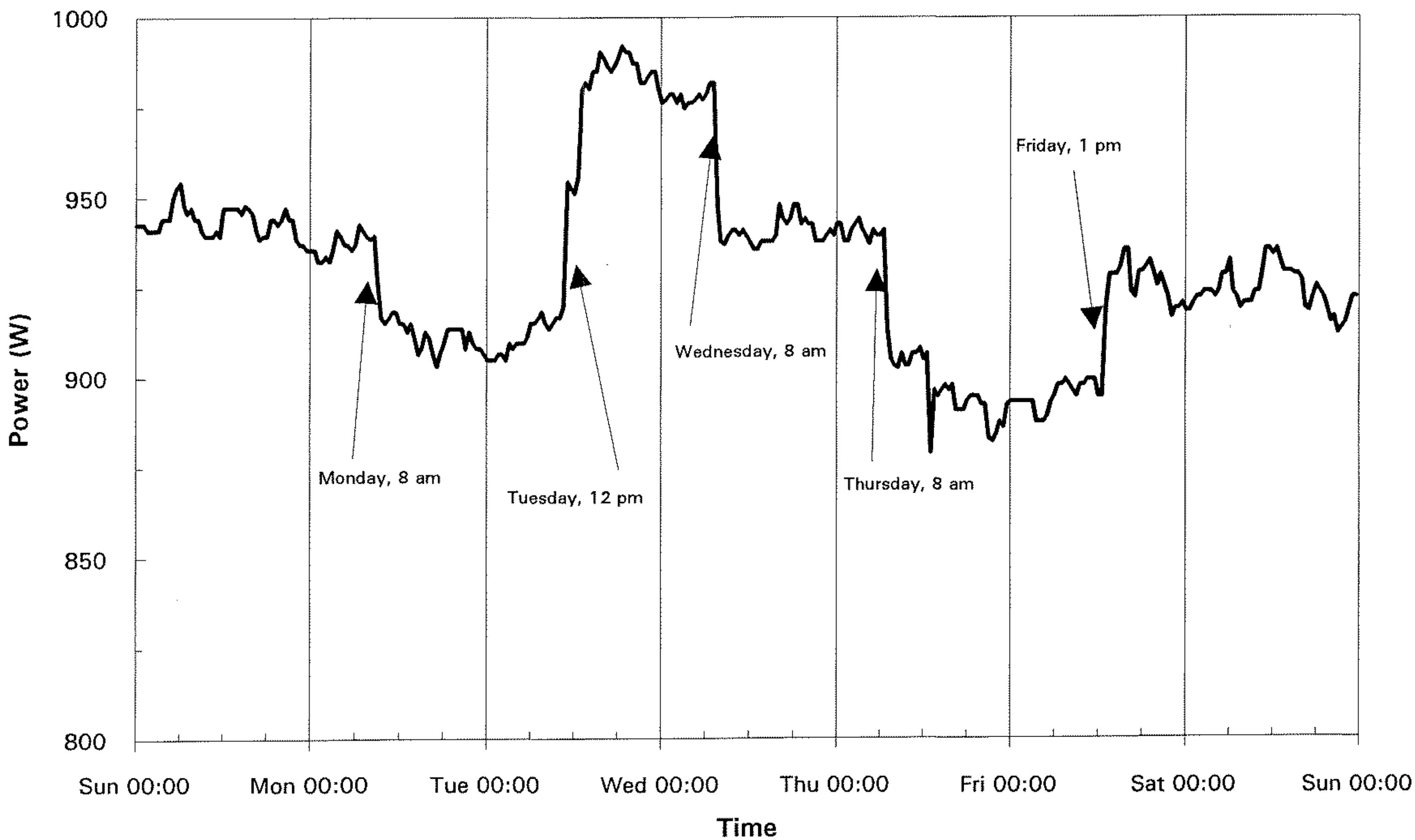


Figure 17. Total Power used by TAM Fans over Thanksgiving Holiday:
Wednesday, Nov. 24 - Monday, Nov. 29

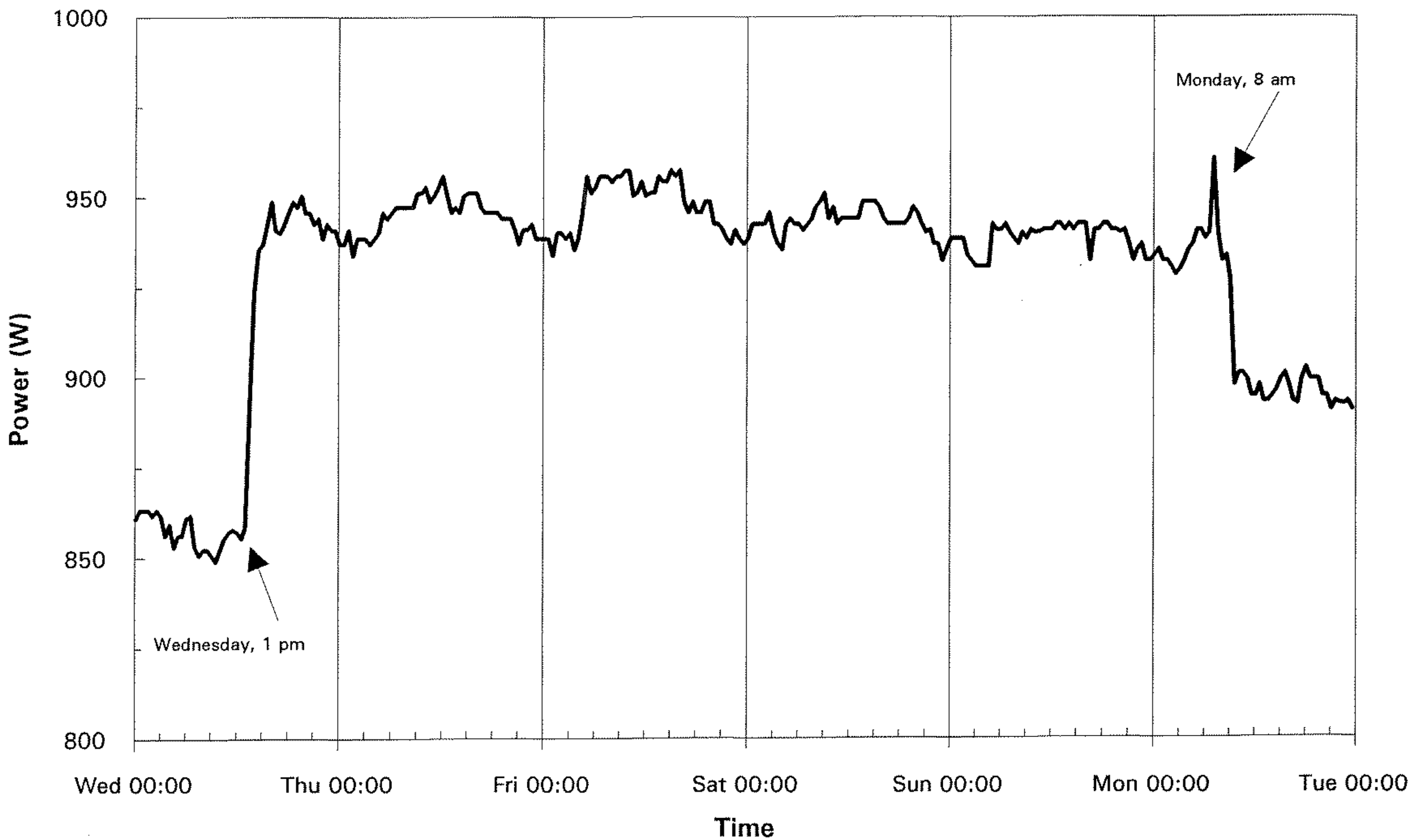


Figure 18a. Power Used by TAM Fan in WS #61: Oct. 28 - Dec. 12, 1993

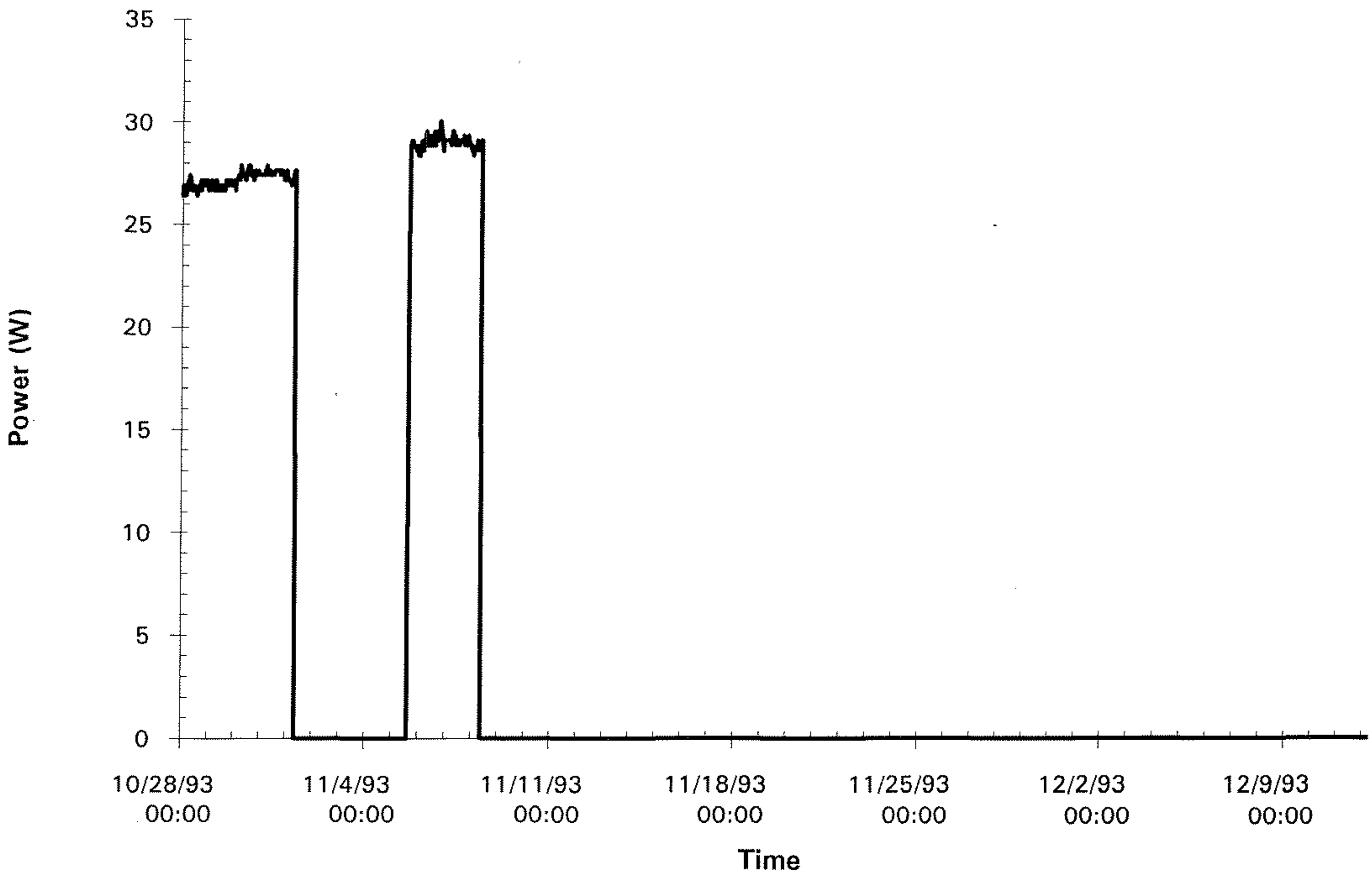
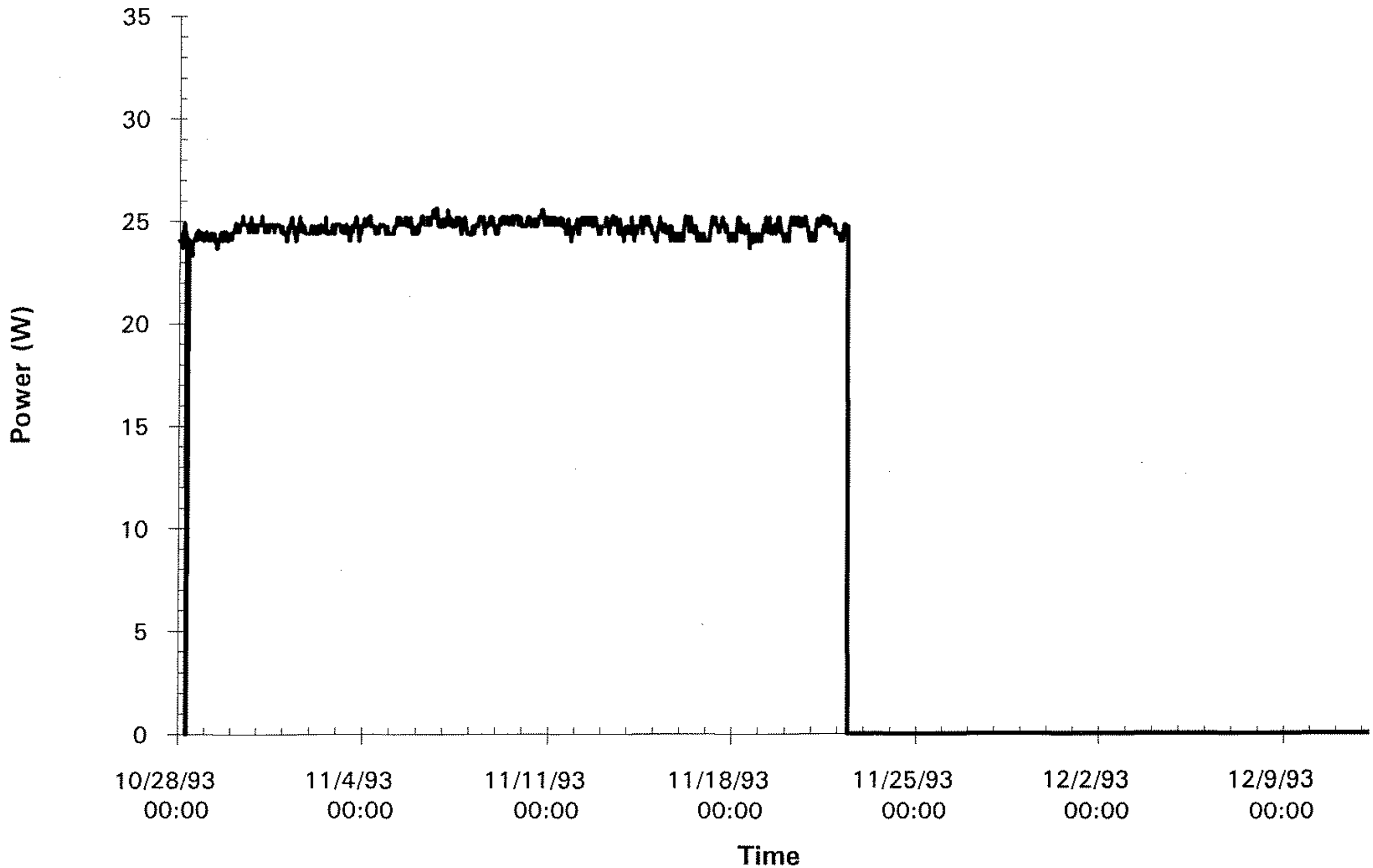


Figure 18b. Power Used by TAM Fan in WS #58 : Oct. 28 - Dec. 12, 1993



APPENDIX A

Individual Worker Survey

Individual Worker Survey

Dear Survey Participant:

The University of California at Berkeley is conducting a survey of the ventilation system in your building. You have been selected to receive this survey because you are located in a part of the building in which fresh air is delivered to the space through unusual floor supply units called Task Air Modules. Each Task Air Module contains four (4-inch) circular floor grills, which can be rotated to adjust the direction of air delivery. In addition, a thumb-wheel knob located in one of the grills allows the velocity of air delivery to be controlled by adjusting the speed of a small fan located underneath the floor unit. We are particularly interested in how you use your Task Air Module and your assessment of the environment produced by the ventilation system in this building.

We would like to ask you to take about five to ten minutes of your time to answer the questions in this survey. Our questions focus on the performance of the Task Air Module, how often you adjust its controls, your perception of your office environment, and your general health characteristics. We ask that you answer only a few personal questions (e.g., age, gender); this information will be used only in the standard procedure to describe the overall demographic characteristics of the respondents to our survey. Your name is not required, so please be assured that your identity will remain anonymous and all individual responses will be kept confidential.

The success of the survey is strongly dependent on receiving as many surveys as possible. We truly appreciate your time in filling out this survey.

Demographic Characteristics

3. On the average, how many hours per week do you work in this building? _____ Hours working

4. On the average, how many hours per day do you sit at your desk? _____ Hours at desk

5. How long have you worked in this building? _____ Years _____ Months

6. How long have you been using the Task Air Module? _____ Years _____ Months

Task Air Module Operation Effectiveness

Please circle one response for each question listed below.

7 At least several times each day
6 At least once each day
5 2-4 times each week
4 At least once each week
3 Less often than once each week
2 Only when I first moved into my workstation
1 Never

	never						at least several times each day
7a. How often do you adjust the direction of air delivery from your Task Air Module?	1	2	3	4	5	6	7
7b. If your answer to 7a is not 'never', when does this generally occur (e.g. time of day, day of week, after activity)? ________________							
8a. How often do you adjust the velocity of air delivery from your Task Air Module?	1	2	3	4	5	6	7
8b. If your answer to 8a is not 'never', when does this generally occur (e.g. time of day, day of week, after activity)? ________________							
9. How often do you experience uncomfortably warm conditions at your workstation?	1	2	3	4	5	6	7
10. How often do you experience uncomfortably cool conditions at your workstation?	1	2	3	4	5	6	7
11. How often do you experience too little air movement at your workstation?	1	2	3	4	5	6	7
12. How often do you experience too much air movement at your workstation?	1	2	3	4	5	6	7
13. How often do you experience comfortable air movement at your workstation?	1	2	3	4	5	6	7
14. How often do you experience too variable a temperature at your workstation?	1	2	3	4	5	6	7
15. How often do you experience a satisfactory temperature at your workstation?	1	2	3	4	5	6	7

Comparative Performance of the Task Air Module

Based on your experience, how would you rate the performance of the Task Air Modules in this building compared to the performance of ventilation systems in other buildings you have worked in that did not have Task Air Modules? Please circle one response for each item listed below.

5 much better
4 somewhat better
3 roughly equivalent
2 somewhat worse
1 much worse

	much worse				much better
16. Thermal comfort?	1	2	3	4	5
17. Air movement and circulation?	1	2	3	4	5
18. Temperature?	1	2	3	4	5
19. Air quality?	1	2	3	4	5
20. Your productivity?	1	2	3	4	5
21. Avoiding overheating problems?	1	2	3	4	5
22. Avoiding draft problems?	1	2	3	4	5
23. Personal control of the workstation environment?	1	2	3	4	5
24. Maintaining comfortable conditions?	1	2	3	4	5
25. Noise level?	1	2	3	4	5

Personal Control

26. How much control do you feel you have over the thermal conditions of your workplace, and how satisfied are you with this level of control? (check one in each column)

- ❑ **complete control**
- ❑ **high degree of control**
- ❑ **moderate control**
- ❑ **slight control**
- ❑ **no control**

- ❑ **very satisfied**
- ❑ **moderately satisfied**
- ❑ **slightly satisfied**
- ❑ **slightly dissatisfied**
- ❑ **moderately dissatisfied**
- ❑ **very dissatisfied**

In general, how often do you exercise any of the following options listed below to adjust the thermal environment at your workplace?

5 always
4 often
3 sometimes
2 rarely
1 never
0 not available

	not available					always
27. open or close a window	0	1	2	3	4	5
28. adjust a thermostat	0	1	2	3	4	5
29. adjust the drapes or blinds	0	1	2	3	4	5
30. turn a local space heater on or off	0	1	2	3	4	5
31. turn a desk fan on or off	0	1	2	3	4	5
32. adjust a Task Air Module	0	1	2	3	4	5

Work Area Satisfaction

A number of characteristics related to WORK AREA SATISFACTION are given below. Please rate your satisfaction with your workstation during the last month by circling the number that reflects how you feel.

4 very satisfied
3 moderately satisfied
2 slightly satisfied
1 not satisfied

(circle one number for each item)

How satisfied are you with:

	not satisfied			very satisfied
33. The type and levels of sounds?	1	2	3	4
34. The lighting?	1	2	3	4
35. The temperature?	1	2	3	4
36. The air quality?	1	2	3	4
37. The air movement and circulation?	1	2	3	4
38. The colors of walls or partitions?	1	2	3	4
39. The furniture and equipment?	1	2	3	4
40. The amount of space available to you?	1	2	3	4
41. The level of privacy?	1	2	3	4
42. The comfort of your chair?	1	2	3	4
43. Provision of non-smoking work areas?	1	2	3	4

Summary Comments

63. Do you notice particular problems at specific times of the day?

64. Do you notice particular problems at specific times of the year?

65. What do you think are the major advantages of the Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?

66. What do you think are the major disadvantages of the Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?

67. Please note any additional comments you have about the comfort of your office work area or your Task Air Module (Use the back of this page if neccesary).

Thank you very much for your time.

APPENDIX B

Survey Results:
Response Frequencies and Comments

Descriptive Statistics of **Demographic Characteristics** (Questions 3 through 6):

Statistics	working hours per week (hr)	sitting hours per day (hr)	working years in building (yr)	years using task air module (yr)
mean	41.9	6.6	3.8	3.1
maximum	53.0	9.5	10.0	8.0
minimum	5.0	1.0	0.3	0.0

Response Frequencies for Questions on **Task Air Module Operation Effectiveness**
(% of total number of respondents)

Question 7a. How often do you adjust the direction of air delivery from your Task Air Module?
Question 8a. How often do you adjust the velocity of air delivery from your Task Air Module?

Question No.	Operation	never	only when moving into workstation	less often than once each week	at least once each week	2-4 times each week	at least once each day	several times each day	number of respondents
7a	adjust air direction	34%	22%	23%	9%	8%	4%	0%	77
8a	adjust air velocity	28%	20%	35%	7%	8%	3%	0%	75

Response Frequencies for Questions on **Task Air Module Operation Effectiveness** (continued)
Answers from those who ever adjusted the TAM in workstation.
7b. If your answer to 7a is not 'never', when does this generally occur? (28 answers out of 79)
8b. If your answer to 8a is not 'never', when does this generally occur? (27 answers out of 79)

Question #7b	Question #8b
feel cold	feel cold
midday	every 3 minutes
no routine	no routine
I keep them covered	I keep them covered
first arrive in a.m. & after lunch	first arrive in a.m. & after lunch
morning	afternoon
change of season	change of season
spring-fall	spring-fall
seasonally/3 months	seasonally/3 months
start of morning and right after lunch	start of morning and right after lunch
.	when it feels too warm or too cold
I had them taken out! too cold.	.
vents have been plugged	.
.	very rarely
after lunch/morning	after lunch/morning
morning	morning/afternoon
after building re-entry (lunch,etc.)	after building re-entry (lunch, etc.)
no pattern. I turn main grill away when I feel draft (wiring causes it to aim my way naturally)	on rare occasions (<1 month) I turn unit on
.	morning
tried several times to shut the fan completely off and direct if away from me	tried several times to shut the fan completely off and direct if away from me
when it gets hot	when it gets hot
after I've been outside for a while I got pretty warm	after I've been outside for a while I got pretty warm
after activity	after activity
after activity	after activity- change in outside temp.
morning 9:00	morning 9:00
after lunch	after lunch

Response Frequencies for Questions on **Task Air Module Operation Effectiveness** (continued)
Answers from those who ever adjusted the TAM in workstation
7b. If your answer to 7a is not 'never', when does this generally occur? (28 answers out of 79)
8b. If your answer to 8a is not 'never', when does this generally occur? (27 answers out of 79)

Question #7b	Question #8b
morning and afternoon	morning and afternoon
after sitting for more than 2-3 hours	after sitting for more than 2-3 hours
random	random
when weather changes outdoors usually	when weather changes outdoors usually
Once a month or so. Generally based on weather seasons and dominant climate/building changes	Once a month or so. Generally based on weather seasons and dominant climate/building changes
have it blocked off	.

Response Frequencies for Questions on **Task Air Module Operation Effectiveness** (continued)
(% of total number of respondents)

Questions 9 through 15: How often do you experience the following **conditions** at your workstation ?

Question No.	Condition	never	only when moving into workstation	less often than once each week	at least once each week	2-4 times each week	at least once each day	several times each day	number of respondents
9	uncomfortably warm	45%	4%	33%	8%	9%	1%	0%	78
10	uncomfortably cool	20%	5%	28%	15%	10%	11%	10%	79
11	too little air movement	52%	6%	25%	8%	6%	1%	1%	79
12	too much air movement	39%	6%	24%	14%	4%	9%	4%	79
13	comfortable air movement	14%	3%	7%	8%	12%	17%	39%	76
14	too variable a temperature	32%	1%	42%	13%	4%	4%	5%	79
15	satisfactory temperature	6%	3%	12%	9%	17%	19%	34%	77

Response Frequencies for Questions on **Comparative Performance of the Task Air Module** (% of total number of respondents)

Questions 16 through 25: Based on your experience, how would you rate the performance of the Task Air Modules in this building compared to the performance of ventilation systems in other buildings you have worked in that did not have Task Air Modules?

Question No.	Performance	much worse	somewhat worse	roughly equivalent	somewhat better	much better	number of respondents
16	thermal comfort	11%	16%	21%	25%	27%	75
17	air movement & circulation	3%	9%	24%	34%	30%	76
18	temperature	12%	17%	25%	25%	21%	76
19	air quality	4%	1%	53%	29%	13%	76
20	productivity	3%	3%	61%	20%	14%	76
21	avoid overheating	1%	4%	25%	38%	32%	76
22	avoid draft	14%	15%	22%	22%	28%	74
23	personal control of environment	5%	5%	28%	22%	39%	76
24	maintaining comfortable conditions	9%	12%	21%	25%	33%	76
25	noise level	3%	5%	50%	18%	24%	76

Response Frequencies for Questions on **Personal Control**
(% of total number of respondents)

Question 26a: How much control do you have over the thermal conditions of your workplace?

Personal Control	complete control	high degree of control	moderate control	slight control	no control	number of respondents
control over the thermal conditions of workplace	8%	30%	19%	28%	15%	79

Question 26b: How satisfied are you with this level of control?

Personal Control	very satisfied	moderately satisfied	slightly satisfied	slightly disatisfied	moderately disatisfied	very disatisfied	number of respondents
satisfied with this level of control	34%	30%	3%	10%	11%	12%	73

Questions 27 through 32: In general, how often do you exercise any of the following options listed below to adjust the thermal environment at your workplace?

Question No.	Option	not available	never	rarely	sometimes	often	always	number of respondents
27	open/close a window	99%	1%	0%	0%	0%	0%	79
28	adjust a thermostat	77%	9%	9%	5%	0%	0%	79
29	adjust the drapes or blinds	95%	4%	1%	0%	0%	0%	79
30	turn a local space heater on or off	82%	4%	5%	6%	0%	3%	79
31	turn a desk fan on or off	92%	4%	3%	1%	0%	0%	78
32	adjust a task air module	5%	22%	29%	23%	11%	10%	79

Response Frequencies for Questions on **Work Area Satisfaction**
(% of total number of respondents)

Questions 33 through 43: Please rate your satisfaction with your workstation during the last month by circling the number that reflects how you feel.

Question No.	Work Area Characteristic	not satisfied	slightly satisfied	moderately satisfied	very satisfied	number of respondents
33	type and levels of sound	15%	18%	35%	32%	78
34	lighting	9%	11%	38%	42%	79
35	temperature	20%	13%	42%	25%	79
36	air quality	4%	13%	52%	32%	79
37	air movement and circulation	5%	10%	51%	34%	79
38	colors of walls or partitions	4%	21%	52%	23%	77
39	furniture and equipment	4%	11%	61%	24%	79
40	amount of space available	13%	19%	46%	23%	79
41	level of privacy	25%	27%	29%	19%	79
42	comfort of chair	8%	25%	44%	23%	79
43	provision of non-smoking work areas	1%	0%	23%	76%	75

Responses to **Question 63: Do you notice particular problems at specific times of the day?**

57 out of 79 respondents answered the question.

	Answer 'no' (35)	Answer 'cold' (11)	Answer 'other' (11)	Total answers (57)
Percentage of respondents	**62%**	**19%**	**19%**	**100%**

Statemen ts related to 'cold' response:

Question: Do you notice particular problems at specific times of the day?
Mid afternoon, it gets pretty chilly in the area.
Temperature too cold. Too much air movement from Task Air Module completely.
Air gets cooler as day progresses and very dry air.
During the winter months in the morning, it gets too cold.
Colder in morning.
I adjust really cold from time to time, no specific, some days.
It's always really too cold.
I get colder the longer I am in the building.
Morning, colder or warmer.
I get cool during long periods of relatively inactive desk work.
At lunch time it gets colder.

Statements related to 'other' response:

Question: Do you notice particular problems at specific times of the day?
Eyes are burning all day long.
Sometimes turn fans down and redirect air in the morning. Sometimes turn fans up and direct air toward me in the afternoon.
Many times after re-entering the building from outside activity will require adjustments to the cooling system to maintain comfort.
Work area is too noisy all the time, but that's because of the phones, fax machines, keyboards, etc., not because of the air modules.
It seems warmer and more stuffy in the afternoon.
I get sleepy at 2pm.
Building often is stuffy 1st thing in morning.
Can't cool-off when very hot outside.

Responses to **Question 64: Do you notice particular problems at specific times of the year?**

61 out of 79 respondents answered the question.

	Answer 'no' (24)	Answer 'cool' (21)	Answer 'allergy' (5)	Answer 'other' (11)	Total answers (61)
Percentage of respondents	**39%**	**35%**	**8%**	**18%**	**100%**

Statements related to 'cold' or 'cool' response:

Question: Do you notice particular problems at specific times of the year?
The relative feeling of being cold is probably worse in the summer. In winter, it is at least possible to dress warmly. In the summer you roast if you dress for the cold and go out into above 100 (degree F). I have stopped wearing skirts, as the air blowing up my skirt is NOT funny.
Yes, in winter radiant heater is directly overhead. I'm too hot while other further away are cold.
Whole building gets cooler in the fall- when the solar heating drops off until some master thermostat gets adjusted (my perception).
The building is over cooled in summer on a regular basis. Fluctuating in other seasons.
In summer it tends to get hot in the afternoon. In winter it tends to get cold in the morning.
Temperature is too cold during summer.
Yes, especially in summer, air conditioning is too cold, cold draft from task air makes it worse.
In general, temperature is sometimes over compensated - too cold in summer and too hot in winter.
Winter response: too cold in workstation.
Yes. It is way too cold in the building during the hot summer months. Sometimes I even turn on a heater to counter the cold AC. What a waste of energy & Dollars!!
Seems colder inside in the winter

Statements related to 'cold' or 'cool' response (continued):

Question: Do you notice particular problems at specific times of the year?
Summer response: hot outside temperature makes more adjustments necessary to the system. Winter response: often too much of a draft.
Much too cold in summer.
I'm just really cold from time to time, no specific, some days.
In summer it was really too cold.
Too cool in winter.
It's cold all year.
It's always too cold in the building. It's hard to dress for outside weather when it's always the same temperature in the building. They should not cool so much in the summer time.
I've only been upstairs for 6 months. Change of season or weather temperature.
Yes, in summer it's hotter and in winter colder.
Too cold in summer. Too warm on cold and rainy days.

Statements related to 'allergy' response:

Question: Do you notice particular problems at specific times of the year?
Yes- could be allergies.
Yes, allergies.
Allergy season.
Spring and Autumn seem to have many allergies in the air that are circulated through the building.
Spring and fall hay fever.

Statements related to 'other' response:

Question: Do you notice particular problems at specific times of the year?
Fall & Spring is a bad time for temperature control in the area.
Beginning of season changes- seems to take a while to get air adjusted.
Summer response: hot outside temperature makes more adjustments necessary to the system. Winter response: often too much of a draft.
When outside temperature changes, it seems that the building takes several days to react.
Can't cool-off when very hot outside.
Temperature seems to be more of a problem as outside conditions become more uncomfortable.
On cold winter days, it takes a while to warm up after arriving at the building.
When the outside temperatures change between seasons, I sometimes need to adjust Task Air Modules. Not a big deal.

Responses to **Question 65: What do you think are the major advantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?**

60 out of 79 respondents answered the question.

	Answer 'individual control' (37)	Answer 'air movement' (6)	Answer 'negative' or 'none' (12)	Answer 'other' (5)	Total answers (60)
Percentage of respondents	**62%**	**10%**	**20%**	**8%**	**100%**

Statements related to 'individual control' response:

Question: What do you think are the major advantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
Quiet, reliable, flow control, temperature control, direction of air control.
Individual control.
People that are hot blooded can cool off.
Adjustability in air flow & direction.
Individual temperature and air control.
The ability to have some control over the air flow (and consequently the temperature) of the immediate work environment. It gives a more distributed control.
Individual control of work environment.
Individual control of cubicle.
Individual control, however, if air conditioning sets at too cool a level -everyone has them shut off or blocked.
It gives me a greater degree of control over my personal work area.
You have more control over your working environment as opposed to calling facilities when you have a problem.
Temperature & RH control seems perfect all over the building- with the exception of areas near window.

Statements related to 'individual control' response (continued):

Question: What do you think are the major advantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
Supposedly individual control of air flow.
Individual control of air flow.
Individual control.
More individual control of environment. Airflow control helps even though there is no temperature control.
Ability to control the air flow.
Able to control temperature and air flow. Not available on personal level at other sites.
It is nice to be able to control air.
Some local control of temperature and air flow.
It's nice that people who get warm easily can use their Task Air Module to keep them cool. It also does a good job of circulating the air. I just wish there were a way for me to warm up my cubicle, because I'm usually cold.
I have individual control of my environment.
I can easily control the air circulation in my work space.
Individual control of temperature and direction of air flow.
Individual control, don't always have to call facilities.
Degree of control.
Some level of individual control is welcome.
Able to adjust air flow and temperature.
Control over air flow and direction.
Control, easy access.

Statements related to 'individual control' response (continued):

Question: What do you think are the major advantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
Control.
Personal control over air movement and direction.
Personal comfort control.
We control our own area for air flow and direction.
The ability to adjust the comfort level of your own work space.
Some control over air flow temperature
Local control.

Statements related to 'air movement' response:

Question: What do you think are the major advantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
Quiet. No draft.
Ability to regulate the air flow to cool down the area.
I'd like to have plenty of air available.
Air quality and air circulation.
You can get air (like a fan) when you are hot.
Good air flow and movement (especially odor dispersion). Some ability to the individual to adjust temperature to their needs (vs. large room common setting)

Statements related to 'other' response:

Question: What do you think are the major advantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
Yes.
Comfort.
If overall environment were warmer, I'd welcome the fast air capability of bringing in more cool air.
I can't recall any particular ongoing problems in any building I have worked in with Task Air Modules or not. I guess I'm just easy to please.

Statements related to 'none', 'N/A' and 'negative' response:

Question: What do you think are the major advantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
If we could arrive at a more comfortable temperature, I think the TAS would be quite nice. However - at previous job I have always had both in office with a door and control over the area's thermostat. For me, this is probably a bad comparison (unfair or biased). Nonetheless, I'm unhappy.
I've plugged ventilation vents above my head. I've plugged them below my feet. Not a whole but of difference. 'Personal' aspect is nice, however, general temperature of air from TAM tends to outweigh other advantages, makes it hard to take advantage of capabilities without freezing to death.
You can block them. I do not like this to be cold!
None- until you get the temperature right! Cold air blowing on your legs is NOT COMFORTABLE.
If overall environment were warmer, I'd welcome the fast air capability of bringing in more cool air.
Theoretical response: adjust direction and amount of air flow is a major advantage. Practical response: it did not work - it was always too cold.

Responses to **Question 66: What do you think are the major disadvantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?**

39 out of 79 respondents answered the question.

	Answer 'position' (18)	Answer 'operation and performance' (19)	Answer 'other' (2)	Total answers (39)
Percentage of respondents	**46%**	**49%**	**5%**	**100%**

Statements related to TAM 'position' response:

Question: What do you think are the major disadvantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
Floor Outlets often cause chair rollers to jam. Outlets partially covered by credenza - could or should be relocated.
Act like speed bumps for chairs.
The TAM is located in the middle of my cubicle. It is very annoying to roll (or attempt to roll) over this module when changing between workstations, which are located at opposite corner of my cubicle.
A woman in my group caught shoe heel in a module, fell, and missed a few days work.
Raised floors have more movement.
It becomes a nuisance when I roll my chair over the vents.
They cannot be easily moved under the workstation where they might do some good.
Office has to be arranged so feet or legs are not over the floor mounted air vents.
My chair doesn't always roll across the air vents easily.
Because they are floor mounted, it took a short period of time to become accustom to them.
The vents on the floor are sometimes in the way with the rolling of my chair.

Statements related to TAM 'position' response (continued):

Question: What do you think are the major disadvantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
The major disadvantage is that periodically it catches my high heel in one of the vents or the air catches my skirt and blows it around a bit- this system was not designed for female accouterments.
Yet it is another distraction from getting real work done.
Location vs. chair movement.
Sometimes chairs bang against them.
Rolling my chair around them. I frequently move around my cubicle and my wheels on my chair bang into them. This is sometimes annoying!
In way of chair movement. Draft conditions.
Sometimes they are placed directly under where you sit and the chairs have difficulty moving over vents.

Statements related to TAM 'operation and performance' response:

Question: What do you think are the major disadvantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
Too Cold!
I previously worked in buildings with smaller rooms (This room holds perhaps over 100 cubicles). As I am near a major return, I am always far too cold. It makes work uncomfortable. I have blocked up my vents (when I moved in), but air comes in from under the walls. I don't get any 'personalization' out of TAS, and personalization motivates the choice of TAS. It's a nice idea, but it doesn't work here. When I asked Facilities Engineer for help, they just stopped up the vents. I wrote an 'I recommend' (form), but it really didn't help.
I like the Task Air System and I can't think of any disadvantages as compared to other buildings. The Task Air System, however, only controls airflow and affects cooling more than heating so that in winter the overhead heaters must sometimes be adjusted. It would be nice to have more control over that aspect as well.
Air coming from the system is too cold, consequently fan is turned off and direction is rotated away from me unless I just came in from the outside & I am hot (and need to cool down).
They cannot be turned off. They cannot be turned to be away from your body.
General air temp always too cold. Task air, even when off still creates extra cold air draft making it worse. I have covered the holes with plastic to avoid this draft.
Too dirty. Too stuffy. Either too HOT or too COLD. NO ADVANTAGES!
No one ever advised or explained how to control the Task Air System when I moved into the office. I guess they assumed I was familiar with the system.
Sometimes you want to close off a vent.
- Still get some airflow even if turned off. - Draft around feet and ankles. - Difficult to set such that all desk working areas are draft free.
In two person work areas, one person's comfortable and the other one is screwed.
My office mate doesn't like air blowing as much as I do.
Temperature too low some days.
Continuous draft that can't be switched off.

Statements related to TAM 'operation and performance' response (continued):

Question: What do you think are the major disadvantages of Task Air System in this building compared to other office buildings you have previously worked in that did not have Task Air Modules?
I dislike air blowing from the floor. When I moved in my office I plugged the air task system up. I would just as soon it be taken out. I don't like air blowing on my feet. Ventilation in the ceiling is better as that's closer to your nose.
Because cold air tends to fall, it seems stupid to push it up, why not let it fall. If overall temperature was to a level where it could be tweaked with the Task Air System it might do something. I once measured the temp at different levels in my work place. 1. under the floor 56 degree . 2. at the floor 65 degree. 3.Above my desk 70 degree 4. On top of book case 76 degree . My feet freeze!
Sometimes it gets very cold and when you are working with high concentration you forget to turn it off. It may damage your legs.
There isn't a heat function on the fan.
Too hot or cold is common problem to most office buildings. The company should provide space heaters upon request. PS response: I am not a smoker, but I feel smokers have been unfairly and excessively punished and affected by the smoking policies.

Statements related to TAM 'other' response:

Too expensive to have the system moved around or add more modules.
I don't know of any. Perhaps more maintenance?

Responses to **Question 67: Please note any additional comments you have about the comfort of your office work area or your Task Air Module.**

34 out of 79 respondents (43%) answered the question.

Question: Please note any additional comments you have about the comfort of your office work area or your Task Air Module.
Nice place, but too sterile to be pleasant or attractive.
Too cold all the time. I have sealed the air flow, still too cold!
Many others have voiced the same complaints. The air vents appear in different relative locations in the cubicle depending on the cubicle. Mine are thankfully in the center of the cube; others' are in the corner, under the desk, etc. Final response: I love my job but the work environment is not good. I really appreciate the chance to be heard.
Overall temperature has been too low for months, despite repeated efforts by facilities to correct.
I tried to keep the fan off & vents rotated away for reason previously stated.
Since air conditioning is so powerful, I put 6 packs of soda on my outlets to cool them for drinking.
I have completely blocked the air output from the Task Air Module. I found it to be too cold and I didn't like the cold air blowing on me.
It would be nice if the vents were flush with the floor.
Individual air control is a real good idea! But this implementation is so flawed - it's a waste of money.
Sometimes the central thermostat seems to be set too low so that it feels very cold in the work area. I have to wear a sweatshirt when that happens. More individual control or better monitoring of the work area temperature is desired.
It would be a better device if I could shut the draft off completely or if the air under the floor was a source of warm air I could use to locally warm my office.
The air quality is terrible- causing my eyes to burn and headache.
Much too cold in ground floor of office area. Company could save money if controlled better.
This is too long of a survey. 67 questions on air modules? You might want to pare this down next time- we have other things to do.
Building should have windows. Windows should open so we can get fresh air.
Best that I have ever worked in.

Comment's response (continued):

Question: Please note any additional comments you have about the comfort of your office work area or your Task Air Module.
The extreme summer heat makes a temperature control desirable, but flow of air control does help significantly.
The raised flooring amplifies footsteps a great deal. That alone makes it a bad idea!
Furniture could be updated.
Very satisfied with work environment.
My major complaint is the overall temperature in the building. If it was too warm, the Task Air System (TAS) would be a great help. I usually think it is too cool, however, and the TAS is no help. I normally wear a long sleeve shirt and tie. On the days I wear a casual short sleeve shirt in the summer, I usually have to go outside by mid afternoon to warm up. I don't think I easily get cold.
Too small, no daylight, too cold. Quiet.
Why do they waste money to over cool the work place and make people uncomfortable and sick, and then pay money to doctors to set them well? Why do they have a problem with the rising cost of medical payments? Why is there not a switch that allows me to set warm air out? Because the Task Air System did nothing to make me comfortable I had them removed from my office, but I am still cold. I wear long sleeve shirts in the summer!
I was not aware of the Task Air Module until the man with survey came around. He showed me the adjustments. We found 3 out of 45 of the vents plugged with paper.
Make it a few degrees warmer in the building so I can make use of my Task Air Module.
Don't get rid of them.
Work station is killing my eyes. Due to this problem I get headache.
This is by far the most comfortable place I have worked here - Being able to individually adjust temperature meets everyone's different comfort levels.
Would be nice to open a window.
1. the boss would not authorize ergonomic evaluation of my office area even though there was a big production made on the bulletin board that it was available to all employees! 2. Not hot water available in the 2nd story restrooms!

Comment's response (continued):

Question: Please note any additional comments you have about the comfort of your office work area or your Task Air Module.
You don't want to know!
I think it's very efficient and nice to have around.
The Task Air Modules do not line up and match the cubicle walls and setup. This leads to lots of problems. I've moved cubes and work with others in their cubes a lot. The air flow and pressure under the floor vary too much. Some areas don't get enough air pressure and flow to cool adequately with fans on full. Most areas get too much air and even with vents off with paper and plastic covers under the vents, the TAMs still produce conditions too cold for comfortable work. I can not tolerate working at my office for hours on end. My upper body is OK, but feet gradually chill through down to the bone.
I felt the current cube dividers are dust collectors that can enhance allergies.

SECTION 3

Field Study #2 in PG&E's AOST Office Facility
San Ramon, California

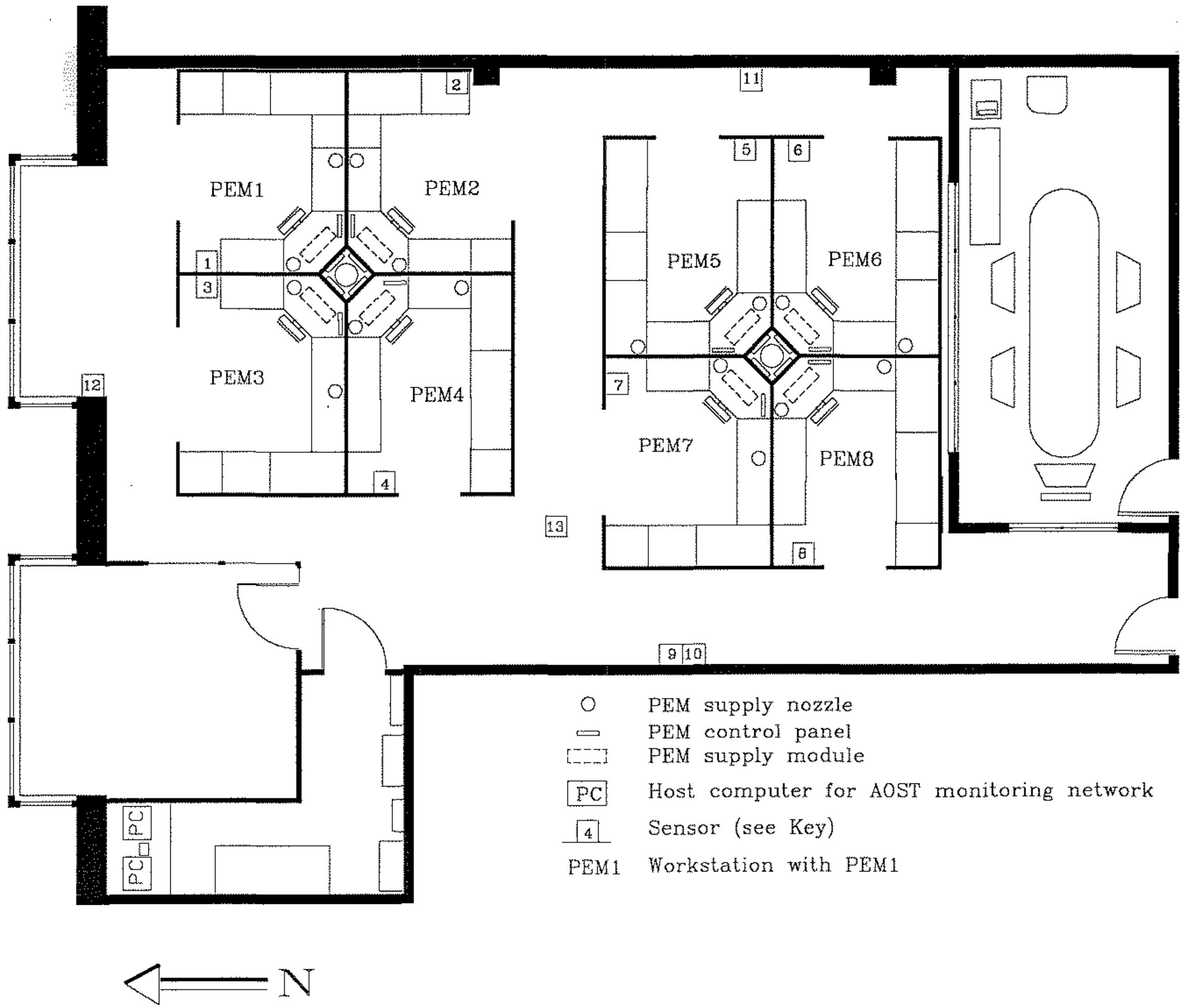
FIELD STUDY IN PG&E'S AOST OFFICE FACILITY

This field study will be performed in PG&E's Advanced Office Systems Testbed (AOST), an eight-workstation office located in the Sunset Building in San Ramon. Previous field measurements have been made in an earlier configuration of this office in which Personal Environmental Modules (PEMs) were installed in four of the workstations, with the remaining four workstations being conventional design (no PEMs). The results of this earlier work are described in detail by Bauman and McClintock (1993) and Bauman et al. (1993).

In late 1993 and early 1994, PG&E remodeled the AOST office to allow four more PEMs to be installed, so that all eight workstations now have PEMs. In addition, PG&E renovated the air distribution system serving the office to allow greater flexibility in our upcoming tests. The reconfigured air distribution system contains three variable air volume (VAV) terminal boxes that control the air flow into the office through three separate supply lines. (1) One serves only the eight PEM units. A flow switch allows the VAV box to completely close off this line when a second conventional overhead supply line is in use. (2) A second VAV box controls air supplied to six overhead diffusers, serving as a conventional base case configuration. This line is completely closed off at the VAV box when the PEM supply line is in use. (3) A smaller, continuously operating VAV box serves an overhead perimeter system (with reheat) for conditioning of the area adjacent to the exterior windows.

In conjunction with the renovation work by PG&E, the two previously installed permanent data acquisition systems (DAS's) have also been upgraded to accommodate the new office configuration. Endecon is responsible for the DAS that measures lighting and equipment electrical energy use. UC Berkeley is responsible for the DAS that measures PEM and workstation performance, supply and return conditions in the air distribution systems serving the office, and average room air conditions.

Figure 1 shows the floor plan of the AOST office. A 1,600 ft^2 office space has been subdivided into the 1,200 ft^2 main office, the subject of all field tests, and two side offices at the northwest corner of the space. The main office accommodates two very similar workstation clusters, each containing four workstations. A Personal Environmental Module (PEM) was installed in each of the eight workstations (PEM1 - PEM8). The workstations are divided by 65-in. high Center Core partitions. The Center Core cluster design provides a central access area that proved to be convenient for installing the PEM air supply duct and the workstation monitoring networks. This central core was extended to the ceiling, forming a hollow column through which the air supply duct was run down from the ceiling to serve the four PEM units in each workstation cluster. Entrance to the main office is from a central corridor adjacent to the south wall. The larger 250 ft^2 side office contains one employee and the smaller 150 ft^2 side office serves as the home base for the AOST data acquisition system. A conference room located to the south of the main office space is not a part of this study.



Advanced Office Systems Testbed: Floor Plan

FIGURE 1

Key for Figure 1

Sensor No.	Label	Description
1	T-P1	Air Temperature - PEM1 Workstation
2	T-P2	Air Temperature - PEM2 Workstation
3	T-P3	Air Temperature - PEM3 Workstation
4	T-P4	Air Temperature - PEM4 Workstation
5	T-P5	Air Temperature - PEM5 Workstation
6	T-P6	Air Temperature - PEM6 Workstation
7	T-P7	Air Temperature - PEM7 Workstation
8	T-P8	Air Temperature - PEM8 Workstation
9	T-TS/ TSP-TS	Room Air Temperature at Thermostat/ Thermostat Setpoint
10	RH-RM	Room Relative Humidity
11	T-RM1	Room Air Temperature 1
12	T-RM2	Room Air Temperature 2 (Perimeter)
13	T-CEIL	Near-Ceiling Air Temperature

In the previous AOST office, two air distribution systems, one serving the PEM units and one serving conventional overhead diffusers, operated simultaneously. With this configuration, the overhead system dominated the overall airflow in the office (the overhead supply air volume was typically four to six times that of the PEM system), making it difficult to extract meaningful conclusions about the PEM performance. However, with the renovated HVAC system in place, we now have much greater control over the thermal conditions in the AOST office. In the new AOST office, it will be possible to switch between (1) a configuration in which the conventional overhead air distribution system provides the dominant cooling to (2) a configuration in which all significant supply air to the office is provided by the PEM units. In both cases, the perimeter line will operate, but its influence will be secondary. During the upcoming field tests, we will set up system operating conditions that will encourage the increased use of the localized conditioning capabilities of the PEMs, leading to a more realistic demonstration of their energy performance.

The following field tests will be evaluated, and if feasible, experiments will be carried out in the renovated AOST office:

1. Using only PEM air supply, increase the setpoint/balance temperature by a few degrees in the space (by increasing internal heat loads) so that the local cooling from the PEM airflow is used more frequently to maintain comfort conditions in the workstations. Thermal conditions outside the workstations will be allowed to warm up somewhat and the acceptability of this nonuniform temperature distribution in the space will be investigated.
2. Using only PEM air supply, set up a diversified heat load distribution in which some workstations have high heat loads while others have small or no loads (unoccupied).

Investigate the performance of the PEMs as they are controlled to match the local cooling requirements of this configuration.

3. By switching to the overhead air distribution system for the same heat load configurations described above (1 and 2), the energy performance of a conventional HVAC system could be compared to that of the PEM system. This comparison would consider airflows and supply temperatures (cooling energy), fan energy, and auxiliary energy needed to maintain similar comfort conditions at the work locations in the office. Alternatively, the controlling wall thermostat would be set to the same temperature (presumably warmer than normal) as that maintained in the PEM experiments, and comfort conditions in individual workstations (without local airflow from the PEMs) would be compared to the results from the corresponding PEM tests.

The field tests are scheduled to be conducted during the summer of 1994. Results will be presented in a subsequent report.

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SECTION 4

Task/Ambient Conditioning Systems: Engineering and Applications Guidelines

TASK/AMBIENT CONDITIONING SYSTEMS: ENGINEERING AND APPLICATIONS GUIDELINES

OUTLINE

1. Summary

- *Definition of Task/Ambient Conditioning Systems*
  This will contain a clear and brief description of the major characteristics of task conditioning systems, including advantages and disadvantages. In particular, distinguishing characteristics in comparison to conventional air distribution systems will be identified. Potential benefits of these systems will be emphasized in terms of thermal comfort, ventilation and indoor air quality, energy, occupant satisfaction and productivity, and life-cycle costs.
- *Purpose/Outline of Guide*
  This will outline the various sections of the guide and describe the rationale for developing it (e.g., we want to promote intelligent design, installation, and operation of task conditioning systems that take maximum advantage of comfort, ventilation, and occupant satisfaction while minimizing energy use and costs). Since experience with task/ambient conditioning systems is still rather limited, the recommendations and guidelines contained in the guide represent our best estimates of sound engineering judgment.
- *Key Engineering and Design Issues*
  This will present a list of the most important issues that will be covered in greater detail in the guide.

2. Background

This will review the history of the motivation for and development of task/ambient conditioning systems, including notable installations (successes and failures), research (our CIEE work will be a major part of this), and references. The section will conclude with an assessment of the current status of task conditioning technology (e.g., what is needed to achieve wider acceptance by the industry).

3. Task/Ambient Conditioning Equipment

This will describe the commercially-available equipment, particularly the local supply units and outlets. It will also describe other system components that may not normally be included in conventional HVAC systems, but that play an important role in system performance (e.g., occupancy sensors, raised access floor, workstation-based cooling units, etc.).

4. Task/Ambient Conditioning System Performance

This will review the typical range of system performance in terms of thermal comfort, ventilation efficiency, energy use, and occupant satisfaction. In comparison to a conventional HVAC system, the performance can either be improved or reduced, depending on how the task/ambient conditioning system is designed and operated.

5. Task/Ambient Conditioning System Costs

As we know from our industry survey, concern about costs presents a major barrier to widespread acceptance of task conditioning technology. This section will summarize our understanding of the economic advantages and disadvantages of task conditioning systems. Such topics as the increased first cost versus life-cycle cost reductions of raised floors, the use of occupancy sensors to reduce operating costs, potential improvements in worker productivity due to greater satisfaction with the work environment, etc. will be discussed. Sources of information will be research results (e.g., our DOE-2 simulations) economic analyses presented in the literature, available field data, and manufacturers' data.

6. Guidelines for Task/Ambient Conditioning System Design and Operation

In this section we will discuss in as much detail as possible our recommendations for design and operation over a full range of topics. The discussion will draw upon the write-up entitled "Recommendations to Improve LTD System Performance" contained in the Phase II Final Report [Bauman et al. 1992]. These guidelines will focus on issues that are unique to task/ambient conditioning systems, while emphasizing differences in comparison with conventional HVAC design. The criteria upon which the guidelines are based will be identified (e.g., avoid discomfort, reduce life-cycle costs, improve energy performance, improve occupant satisfaction, etc.). A preliminary list of topics includes the following.

Design Issues

- local supply units and outlets (selection of type, size, number, and location)
- air distribution system configuration (ducted vs. plenum, overhead vs. underfloor)
- integration with total HVAC system (e.g., splitting the load between a task and ambient conditioning system, etc.)
- room air distribution (assumed value of air change effectiveness, implications for minimum outside-air supply, allowance for low supply flows to avoid drafts)
- selection of other system components
- water-based fan coil units for extreme cooling and heating loads that occur only occasionally and at specific locations (e.g., perimeter zones)
- energy use considerations (fan power, performance as a function of climate and economizer operation strategy, occupancy sensor control, other control issues [see below])
- compliance with building standards and codes (ASHRAE Standard 55-92, Thermal Environmental Conditions for Human Occupancy; ASHRAE Standard 62-89, Ventilation for Acceptable Indoor Air Quality; ASHRAE Standard 113-90, Method of Testing for Room Air Diffusion; proposed ASHRAE Standard 129P, Ventilation Effectiveness; CEC Second Generation Nonresidential Standards [Title 24])

Operation and Control Issues

In this section, differences will be pointed out between conventional system control and that of task/ambient conditioning systems. We will pull together as much information as possible (from the literature, field studies, industry contacts, etc.) on "system" control issues, even though very little performance data of this type is currently available. A description of the possible hardware configurations of occupant controls (simple manual controls, remote hand-held control unit, etc.) as well as the use of occupancy sensors to minimize excessive energy consumption will be presented here. Examples from field studies will be used to demonstrate approaches that work well, or that should be avoided. Hypothetical advanced control scenarios will be presented in which positive feedback from the operation of the local supply units (e.g., number of units on/off, average speed of local fans above a certain level, etc.) can allow adjustments to the central system operation (e.g., reset temperature or volume) to improve overall performance. Additional control issues include the following.

- range of permitted supply volumes
- minimum supply temperatures to avoid drafts
- controlling only supply volume or both volume and temperature
- flexibility in thermostatic temperature control
- combining individual and thermostatic control
- required performance of pressure and temperature sensors for plenum pressure control units
- allowing a limited degree of temperature stratification to occur in regions which do not affect occupant comfort
- due to increased air movement and controllability provided by the local supply units, maintain higher average space temperatures and allow greater temperature variations (slow drifts) to occur in response to the outside daily cycle
- use zoning control strategies in which temperature setpoints can be relaxed in less critical building zones, while occupied areas can be well conditioned by local supply units
- precooling of the building thermal mass (within an underfloor plenum) by nighttime venting to reduce daytime chiller demands (must consider short-term heating requirements during cold morning start-ups)
- commissioning procedures

7. Appendixes

Some additional sections will be presented as appendixes, if appropriate. These sections will present summaries of the results of the multiyear CIEE Localized Thermal Distribution research project, including (1) laboratory test results, (2) field studies, (3) DOE-2 whole-building energy simulations, and (4) industry survey findings.

Reference

Bauman, F., G. Brager, E. Arens, A. Baughman, H. Zhang, D. Faulkner, W. Fisk, and D. Sullivan. 1992. "Localized Thermal Distribution for Office Buildings; Final Report - Phase II." Center for Environmental Design Research, University of California, Berkeley, December, 220 pp.

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