A Study of Occupant Comfort and Workstation Performance in PG&E's Advanced Office Systems Testbed

Final Report

Fred Bauman and Maurya McClintock

CEDR-05-92

Susan Horgan, Project Manager
Pacific Gas and Electric Company
Research and Development
3400 Crow Canyon Road
San Ramon, CA 94583

Center for Environmental Design Research
390 Wurster Hall #1839
University of California
Berkeley, California 94720-1839

May 1993

CONTENTS

TABLES

ABSTRACT

This final report presents the results of research completed since June 1991 on PG&E's Advanced Office Systems Testbed (AOST) Project. The initial advanced office system selected for evaluation in the AOST office was the Personal Environmental Module (PEM), manufactured by Johnson Controls. The PEM represents one example of an emerging technology known as task conditioning, or localized thermal distribution (LTD). Workstation-based LTD systems that allow individuals a degree of control over their local environment 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.

Work was performed by UC Berkeley in the following task areas: (1) detailed field measurements of thermal comfort of the PG&E employees participating in the study, both before and after moving into the AOST office; (2) installation of a permanent data acquisition and information display system capable of recording and displaying the status of a selected number of performance parameters from the AOST office, including occupant use patterns from each of the eight workstations, supply and return conditions from the air distribution system serving the office, and average room air conditions; (3) analysis of the collected data; and (4) evaluation of the applied measurement methods.

INTRODUCTION

In the summer of 1991, Pacific Gas and Electric Company initiated a project to develop a prototype office to demonstrate and test the performance and energy use of advanced office furniture/environment systems, advanced lighting systems, and other innovative environmental control technologies. The project, originally entitled Office 2000, is now called the Advanced Office Systems Testbed (AOST). Listed below are the initial overall project objectives, including a summary of their current status.

1. **Develop a prototype office in which ergonomic, energy-efficient, and environmentally enhancing technologies can be installed, tested, and demonstrated.**

   The development of the prototype office was completed in early 1992. PG&E renovated an existing office space by modifying the existing air distribution duct system, installing new partitions and workstation furniture, subdividing the office with a glass partition wall and access door, and installing an efficient ambient lighting system. Due to the relatively small size of the office, the facility is less suitable as a general large-scale demonstration site and more appropriate as a testbed for learning how to monitor office environments and to what extent meaningful performance data can be obtained. In this regard, based on an analysis of measurements taken during the past year in the AOST office, additional modifications are now being considered to improve the usefulness and applicability of future tests and demonstrations. These proposed changes and future directions for the project are discussed at the end of this report.

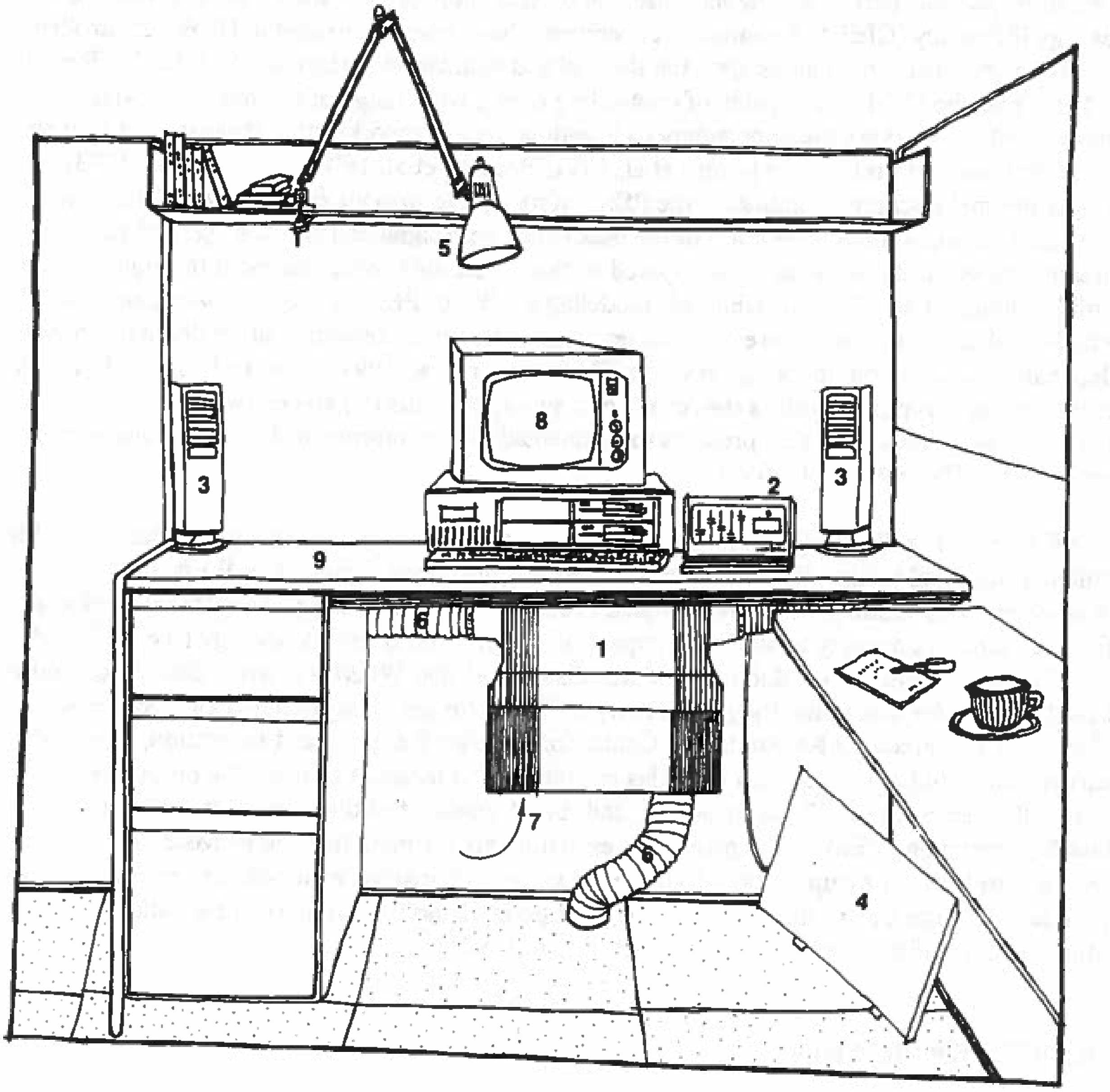
analysis of the two sets of data from Endecon's and UC Berkeley's permanent DAS's. UC Berkeley has completed three thermal comfort field tests as part of this project: (1) Baseline Test - 16, 17 October 1991, (2) First Post-Occupancy Test (Test 1) - 30 April, 1 May 1992, and (3) Second Post-Occupancy Test (Test 2) - 16, 17 September 1992.

Due to the small number of workstations and office workers participating in this study, the measurement database is not large enough to establish statistically significant conclusions, although obvious trends and examples can be noted. The analysis of measurement results presented here has focused on (1) identifying what general office performance characteristics (e.g., thermal comfort, energy use, occupant use patterns, and overall HVAC system operation) can be measured in an office environment, (2) identifying what are the distinguishing features of the PEM in this AOST office setting that falls somewhere between a realistic large-scale office and a controlled laboratory environment, and (3) evaluating how appropriate the applied measurement and analysis methods are for these purposes. The lessons learned from the AOST project have provided guidance for modifying the AOST office facility to improve its capabilities in future planned experiments, and, if funding becomes available, for setting up and conducting a scaled-up field study of PEM performance in a PG&E facility or elsewhere.

4. **Plan for the future by identifying one or more sites suitable for larger-scale field tests of advanced office technology using methods developed in the AOST project, and by identifying additional manufacturers to provide other office environmental technologies to be installed and tested in the AOST office.**

   PG&E has acquired from Johnson Controls a total of 20 PEMs, four of which are installed in the AOST office. Funding constraints have delayed plans to install the remaining PEM units in a renovated PG&E office building in San Francisco to allow the demonstration and testing of a more representative sample of advanced office technology. A scaled-back effort is now proposed to focus attention on how to improve the capabilities of the AOST office, and, in particular, how to most effectively use the facility and the data it produces to demonstrate potential energy savings from advanced office technologies. PG&E personnel are currently heading up efforts to identify new advanced office systems to be installed in the AOST office after testing of the PEM units has been satisfactorily completed.

In this final report, we describe the work completed by CEDR at UC Berkeley. Most of the work has addressed the second and third objectives described above: developing and installing a monitoring network to measure and display the PEM and office performance characteristics, using the installed network to collect data, and performing thermal comfort measurements using our in-house portable measurement system. The hardware and software installations associated with the PEM/thermal monitoring and display network are described in detail, including network configuration, monitoring display screens, software operating instructions, sensor calibration, and system troubleshooting. The portable thermal comfort measurement system is also described in detail, including physical measurement system, subjective surveys, and measurement protocol. Measurement data have been analyzed to coincide with the three thermal comfort field tests. Results are presented and discussed for thermal comfort, PEM occupant use and energy use



1 PEM supply module
2 PEM control panel
3 PEM supply nozzle
4 radiant heating panel
5 task light
6 flexible supply duct
7 recirculated room air
8 personal computer
9 desk

Figure 1. Personal Environmental Module (PEM)

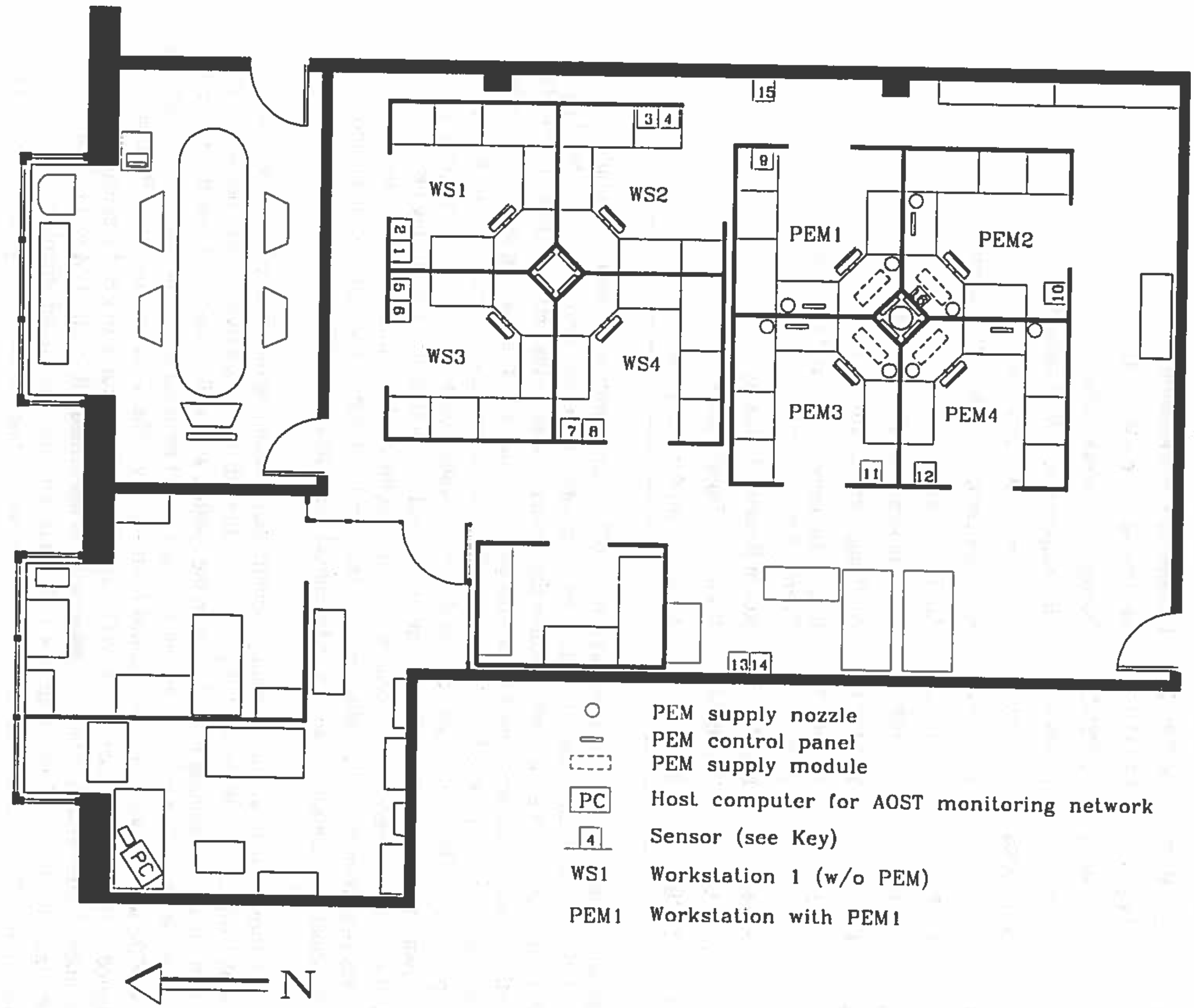


Figure 2. Advanced Office Systems Testbed: Floor Plan

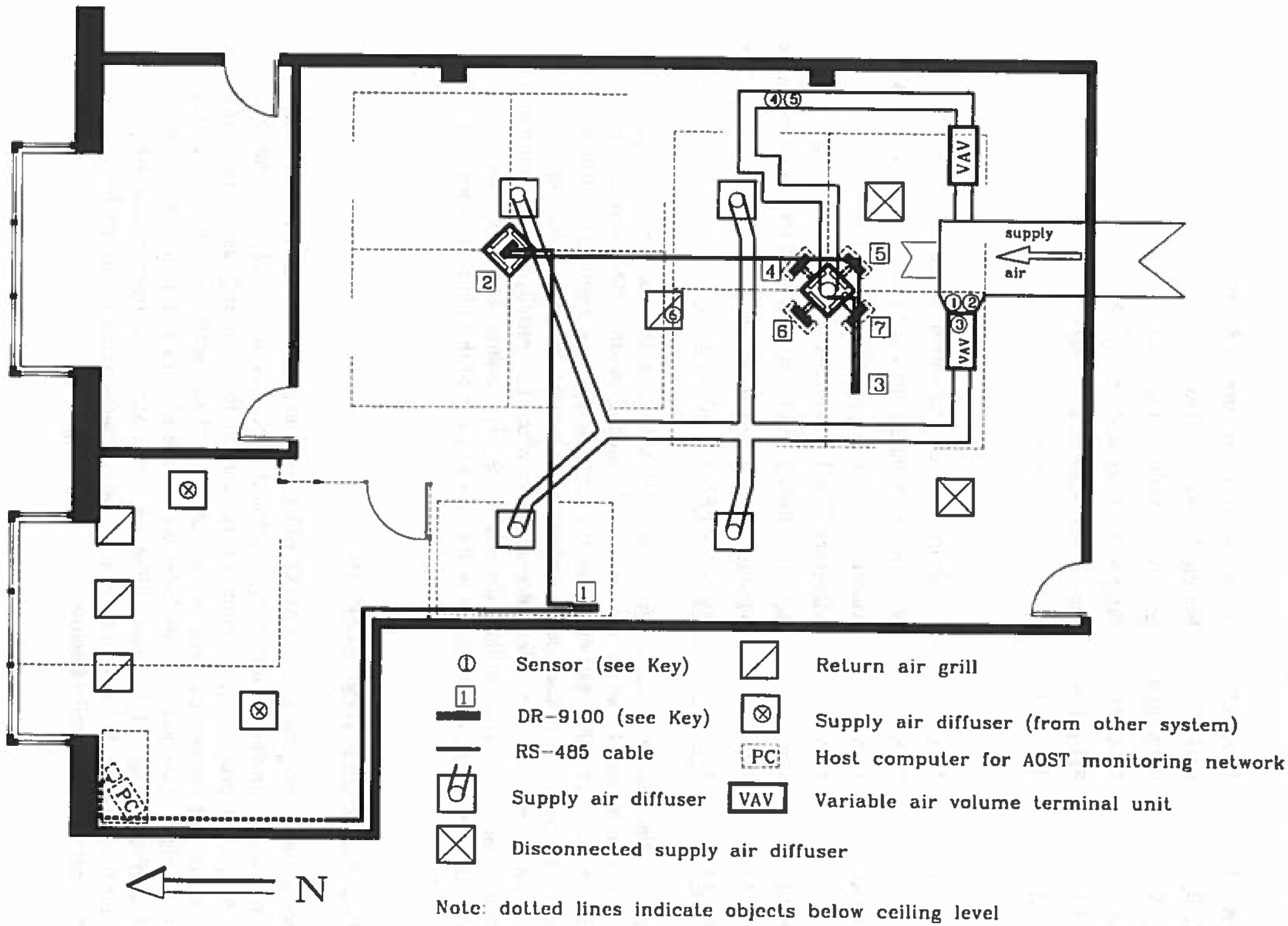


Figure 3. Advanced Office Systems Testbed: Ceiling Plenum Plan

With the selection of the PEM as the initial advanced technology to be evaluated in the AOST office, we were presented with a unique opportunity to directly monitor the occupant use patterns and performance characteristics of individually-controlled PEM units by utilizing a network communication capability provided by the PEMs. We modeled our AOST monitoring network after the Personal Environmental Module Monitoring and Control System previously developed by Johnson Controls (described in proprietary internal reports by Johnson Controls). Johnson Controls used this system in their 1988 Advanced Office Design Demonstration, in which 24 PEMs were installed in a demonstration office in their Milwaukee headquarters building. In their installation, Johnson Controls implemented an object-oriented programming language for purposes of creating color graphic displays to demonstrate the PEM performance and allow visual analysis of the collected data. These display capabilities are also well suited to the objectives of the AOST project. We are extremely grateful to Johnson Controls for agreeing to provide us with the necessary technical support to configure the monitoring network hardware and to adapt the network software to serve the specific needs of our installation.

Network Hardware Description

The key hardware component of the AOST monitoring network is the DR-9100 Digital Room Controller contained within each PEM unit. The DR-9100 can accept six analog and six digital inputs and can provide up to seven outputs of various types, including analog, incremental, on/off pulse width modulating, and phase cut [Johnson Controls 1988, 1990]. These controllers can be networked together using an RS-485 communication link, providing a convenient configuration for monitoring PEM performance from a single host personal computer. Additional DR-9100 controllers and monitoring points can be easily added to expand the network. All monitoring software is executed from the host computer. The software enables data from connected DR-9100 controllers to be collected and stored in ASCII data files, and collected data from the files to be displayed on the computer monitor using attractive color graphic images.

Figure 4 presents a schematic diagram of the AOST monitoring network used to measure PEM and office thermal performance. A Dell System Model 325P (Intel 386 microprocessor) serves as the host computer. The monitoring software is written using three computer languages: Digitalk's Smalltalk/V 286, Spectra Publishing's PowerBasic 2.0, and Microsoft's Assembler. The software operation is described in greater detail below. A total of seven DR-9100 controllers are networked together using an RS-485 link. As shown in the figure, four of the controllers are contained within the four PEM units (PEM1 - PEM4) installed in the AOST office. For purposes of monitoring additional sensors, three more DR-9100s were added to the network. The host computer uses one of its serial (RS-232) ports to communicate with the RS-485 network via a Black Box RS-232 <--> RS-485 Interface Converter.

Within each PEM unit, the DR-9100 allows the status of several PEM control parameters to be monitored. In the PEM's original factory-shipped configuration, we were able to read over the network the following parameters: (1) discharge air temperature (a built-in sensor measures the temperature of the air leaving the main under-desk PEM unit), (2) discharge air temperature setpoint (from control panel), (3) radiant panel setpoint (from control panel), and (4) occupancy sensor status (from control panel). In addition, by making some wiring modifications to the auxiliary circuit board, we were able to utilize the three remaining unused analog input channels on the PEM's DR-9100 to monitor: (5) fan speed setpoint (from control panel), (6) task light setpoint (from control panel), and (7) workstation air temperature (a compatible temperature sensor [RS-9100] was mounted on the partition in the workstation and connected to the DR-9100 inside the PEM unit).

To monitor selected HVAC and room air conditions, we utilized the analog and digital input capabilities of three additional DR-9100s that were connected to the network. These DR-9100s served as remote signal conditioners for a group of sensors, providing power to each connected sensor requiring 15 VDC, and receiving the sensor's output signal (typically 0-10 VDC). An itemized list describing the AOST monitoring network configuration in detail is presented in Appendix A. For each monitored parameter, the list specifies the DR-9100 connection, the variable name, the sensor name, location, and output characteristics, and the sensor power requirements. The manufacturer's specifications for the sensors and equipment used in the monitoring network were previously described by Bauman (1992). A total of 47 parameters were monitored. Two sensors (SAV-1 and SAV-2) required a separate 24 VDC power supply that was shared with Endecon. The output from these two sensors was also shared with the Endecon monitoring system. All other sensors were powered by the DR-9100 units, except the occupancy sensors installed in the four conventional workstations, which used their own 24 VDC power packs.

Referring back to Figures 2 and 3, the actual locations of the host computer, main RS-485 cable, measurement sensors, and DR-9100s are shown. The host computer is located in the side office, at the northwest corner of the AOST facility. In this same area, several large electrical boxes housing all monitored energy use circuits, a multi-channel datalogger, and a second host computer for the energy use monitoring network have been installed by Endecon (described elsewhere). DR-9100 #1 is located above the ceiling along the west wall and monitors room temperature and humidity sensors. DR-9100 #2 is located at the bottom of the central column serving the conventional workstation cluster and monitors temperatures and occupancy in these four workstations. DR-9100 #3 is located above the ceiling as shown and monitors supply and return conditions in the HVAC system. DR-9100s #4-#7 are contained in the four PEMs and monitor PEM conditions and air temperature in each PEM workstation.

Network Software Description

The network monitoring and display software was written using a combination of three computer languages: Digitalk's Smalltalk/V 286, Spectra Publishing's PowerBasic 2.0, and Microsoft's Assembler. Smalltalk, an object-oriented programming system (OOPS), is the user-friendly interface and master controller for all functions of the AOST monitoring network. The Smalltalk program controls the AOST data acquisition, and runs the data display including mouse-driven menus, facility map displays, and trend data displays. As the master controller, Smalltalk can initiate the polling process over the network. At a scanning interval specified by the user, Smalltalk calls an executable PowerBasic program that accesses the connected DR-9100 controllers with Assembler routines. Scan rates as quick as 6 seconds (10 scans per minute) can be specified. After receiving the measurement data over the network, the PowerBasic program

TABLE 1: DATA FILE FORMAT FOR AOST PROJECT
Personal Environmental Module (PEM) Monitoring Network

HEADER (row 1)	Seconds since midnight	Adapter Status (1=con; 0=discon)							
DR-9100 LABEL	ID No.	**SENSOR LABEL** (units)							
WS (row 2)	1	T-WS1 (°C)	T-WS2 (°C)	T-WS3 (°C)	T-WS4 (°C)	OCC-WS1 (0,1)	OCC-WS2 (0,1)	OCC-WS3 (0,1)	OCC-WS4 (0,1)
ROOM (row 3)	2	T-TS (°C)	TSP-TS (°C)	T-CEIL (°C)	T-RM (°C)	RH-RM (%)			
HVAC (row 4)	3	SAV-1 (cfm)	SAV-2 (cfm)	SAT-1 (°C)	SAT-2 (°C)	RAT (°C)	SARH (%)		
PEM1 (row 5)	1	SAT-P1 (°C)	TSP-P1 (%)	RAD-P1 (%)	FAN-P1 (%)	LITE-P1 (%)	T-P1 (°C)	OCC-P1 (0,1)	
PEM2 (row 6)	2	SAT-P2 (°C)	TSP-P2 (%)	RAD-P2 (%)	FAN-P2 (%)	LITE-P2 (%)	T-P2 (°C)	OCC-P2 (0,1)	
PEM3 (row 7)	3	SAT-P3 (°C)	TSP-P3 (%)	RAD-P3 (%)	FAN-P3 (%)	LITE-P3 (%)	T-P3 (°C)	OCC-P3 (0,1)	
PEM4 (row 8)	4	SAT-P4 (°C)	TSP-P4 (%)	RAD-P4 (%)	FAN-P4 (%)	LITE-P4 (%)	T-P4 (°C)	OCC-P4 (0,1)	
	col 1	col 2	col 3	col 4	col 5	col 6	col 7	col 8	col 9

Figure 6 shows workstation temperatures (°C) at 1:38 pm for all eight workstations. This screen is generated by selecting "Workstation Temps" under the "Room Air Conditions" menu to display the four non-PEM workstations, and then selecting "PEM Workstation Temp" under the "Air Temps" sub menu of the "PEM Parameters" menu to display the four PEM workstations simultaneously.

Figure 7 shows the status of the four PEM fan speed setpoints (%) at 1:38 pm. This is generated by selecting "Fan" under the "PEM Parameters" menu. Other PEM parameters that can be displayed in this same manner include temperature setpoint (%), discharge temperature (°C), radiant panel setpoint (%), and task lighting setpoint (%).

The user can also choose to display the occupancy status of the eight workstations by selecting "Occupancy" under the "Occupancy Conditions" menu. Figure 8 shows the occupancy status (IN, OUT) at 1:38 pm. The user can access a complete workstation pop-up display by clicking with the mouse within the desired workstation outline on the facility map to list data particular to that workstation. The workstation-specific data include limited occupant information (name, gender, age, etc.), date and time, occupancy status, and workstation temperature. If the selected workstation contains a PEM, as in the example shown in Figure 9, the additional PEM parameters are also displayed.

Figure 10 lists room air conditions, including temperatures (°C) and relative humidity (%), at 1:38 pm. This is generated by selecting "Room Temp and Humidity" under the "Room Air Conditions" menu. Various performance parameters from the HVAC system can also be displayed, including supply air volumes, supply air temperatures, supply air relative humidity, and return air temperature. Figure 11 lists supply air temperatures (°C) for the overhead (ROOM) air distribution system and the PEM air distribution system at 1:38 pm. This is generated by selecting "Supply Temps" under the "HVAC parameters" menu.

A "Trend Data" display can be accessed to show a series of graphs plotting PEM control parameters versus time for a selected date. The trend data graphs are plotted for a time interval of 7 am to 5 pm, a typical office working day. Figure 12 shows an example of such a display for one of the PEM workstations on 30 April 1992. The trend data display shows PEM discharge temperature, workstation temperature, occupancy status, and PEM setpoints for fan speed, task lighting, and radiant panel use.

System Installation, Troubleshooting, and Calibration

Prior to installing the monitoring network in the AOST office, we obtained all the hardware (PEMs, DR-9100s, sensors, host computer, etc.) and assembled the entire network for testing and troubleshooting in our laboratory at UC Berkeley. Since we were adapting someone else's hardware and software for our own application, this was an important step to become familiar with the system. Johnson Controls and several affiliated consultants provided valuable assistance to us during this phase of the project.

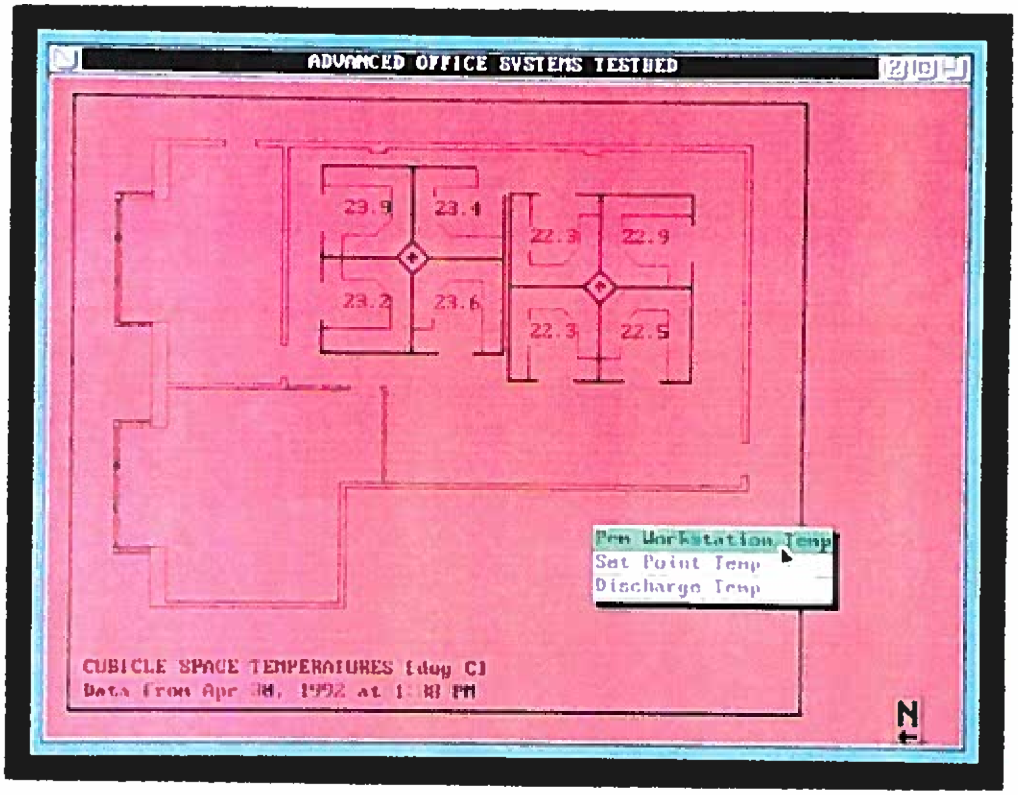


Figure 6. Smalltalk Display Screen: Workstation Temperatures

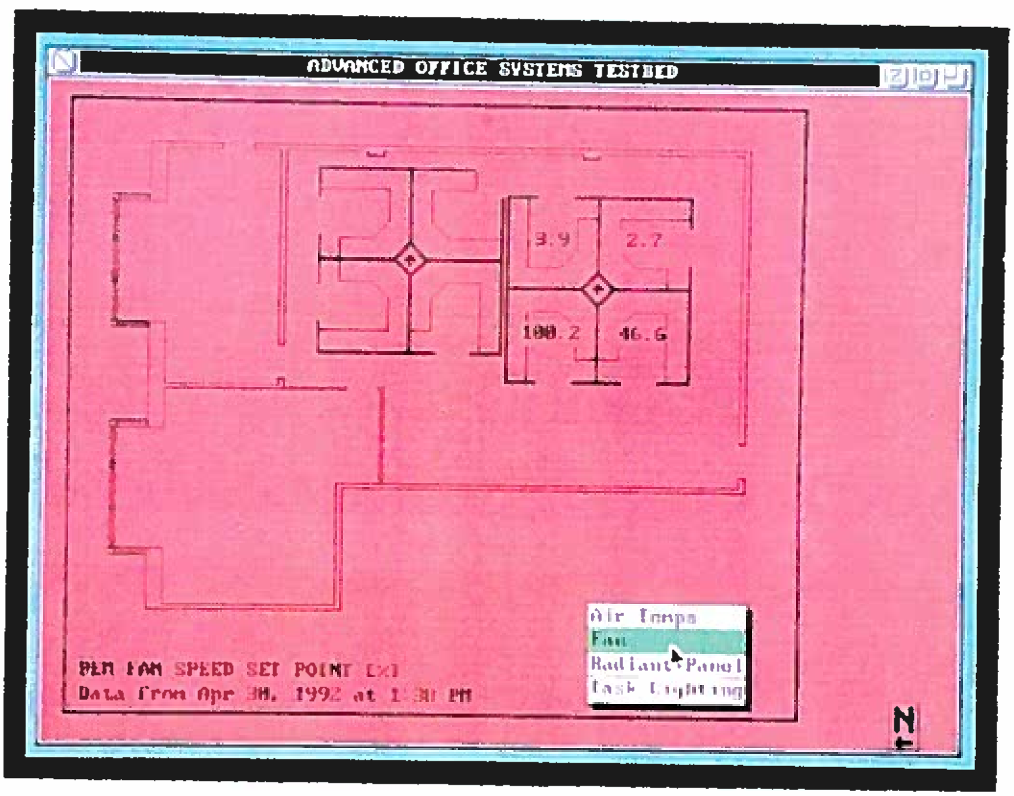


Figure 7. Smalltalk Display Screen: PEM Fan Speed Setpoint

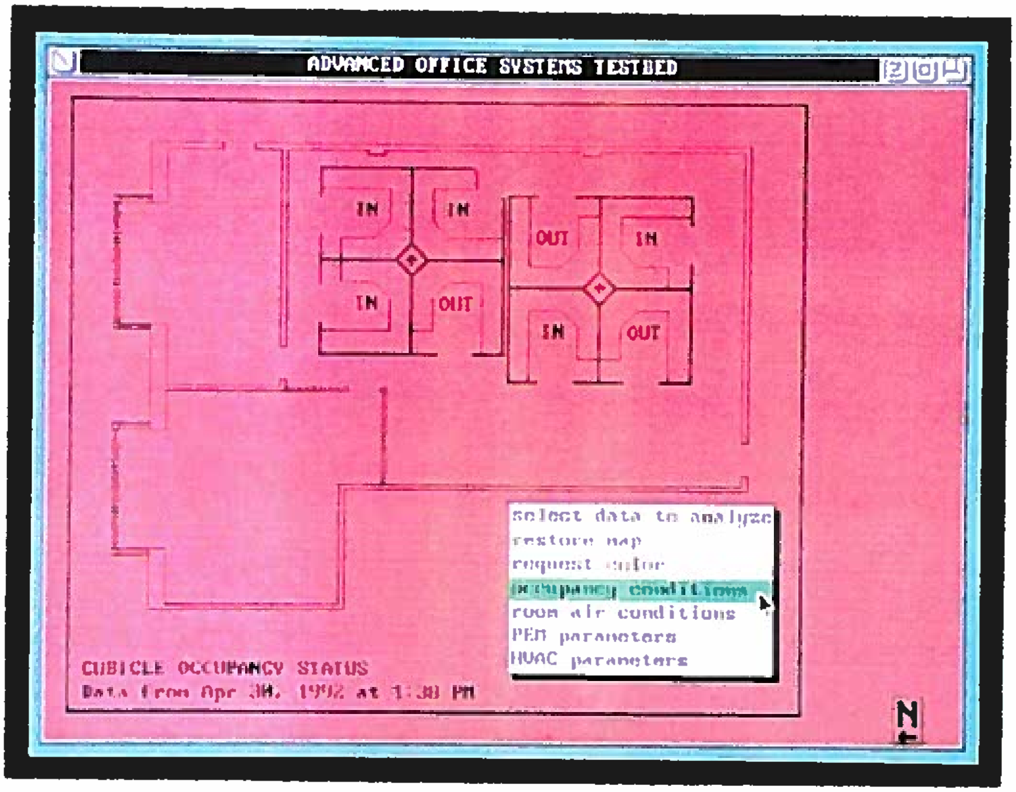


Figure 8. Smalltalk Display Screen: Occupancy Status

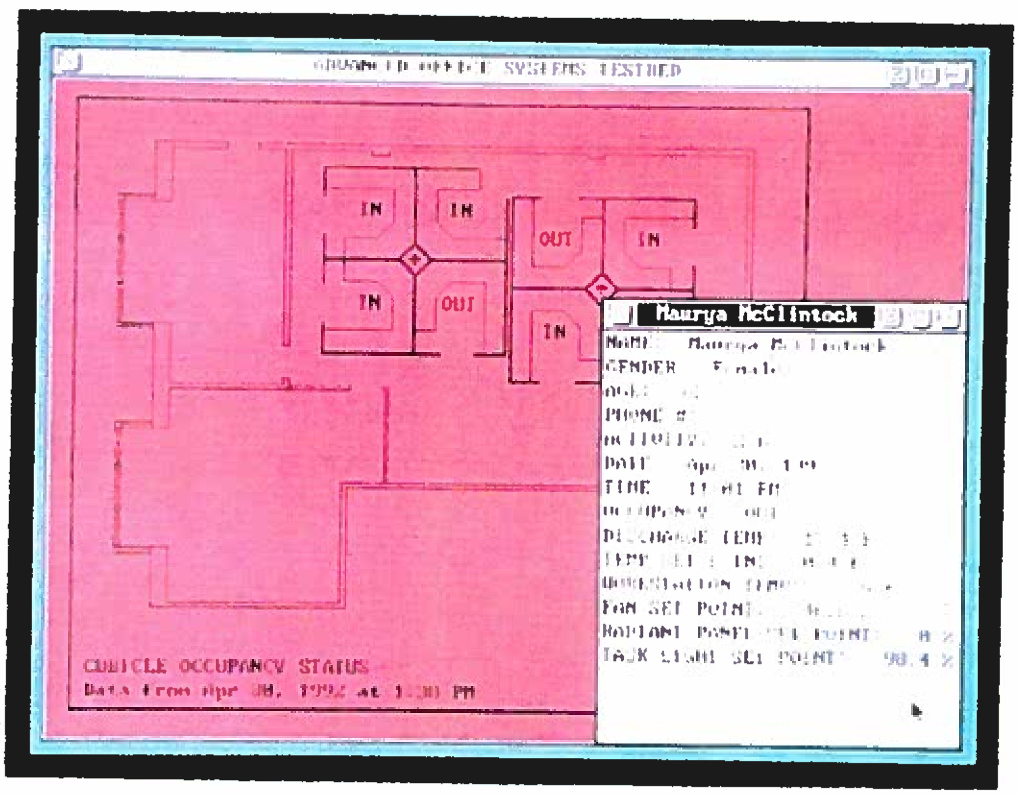


Figure 9. Smalltalk Display Screen: Complete Workstation Pop-up Display

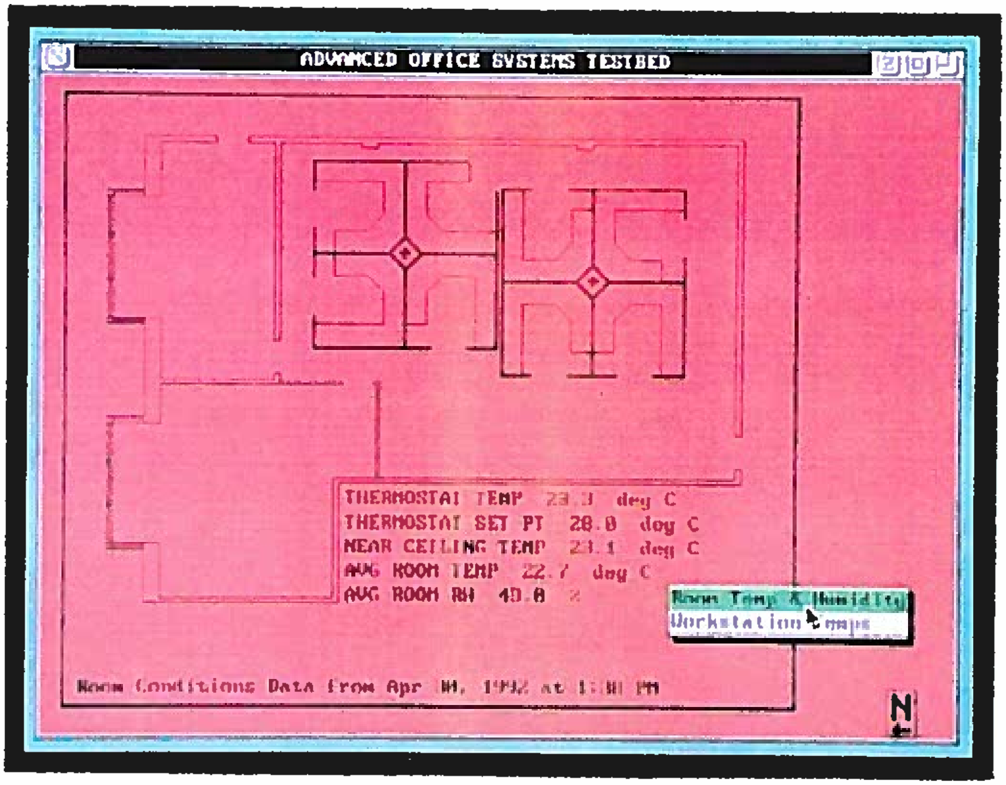


Figure 10. Smalltalk Display Screen: Room Air Temperatures and Humidity

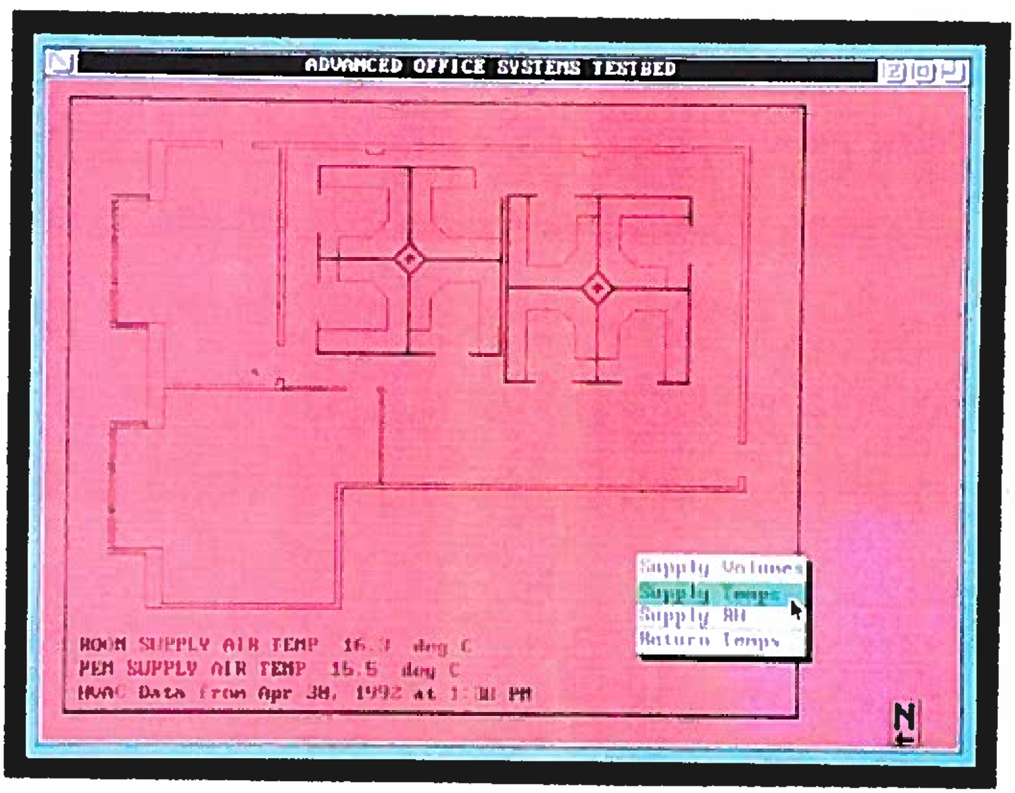


Figure 11. Smalltalk Display Screen: Supply Air Temperatures

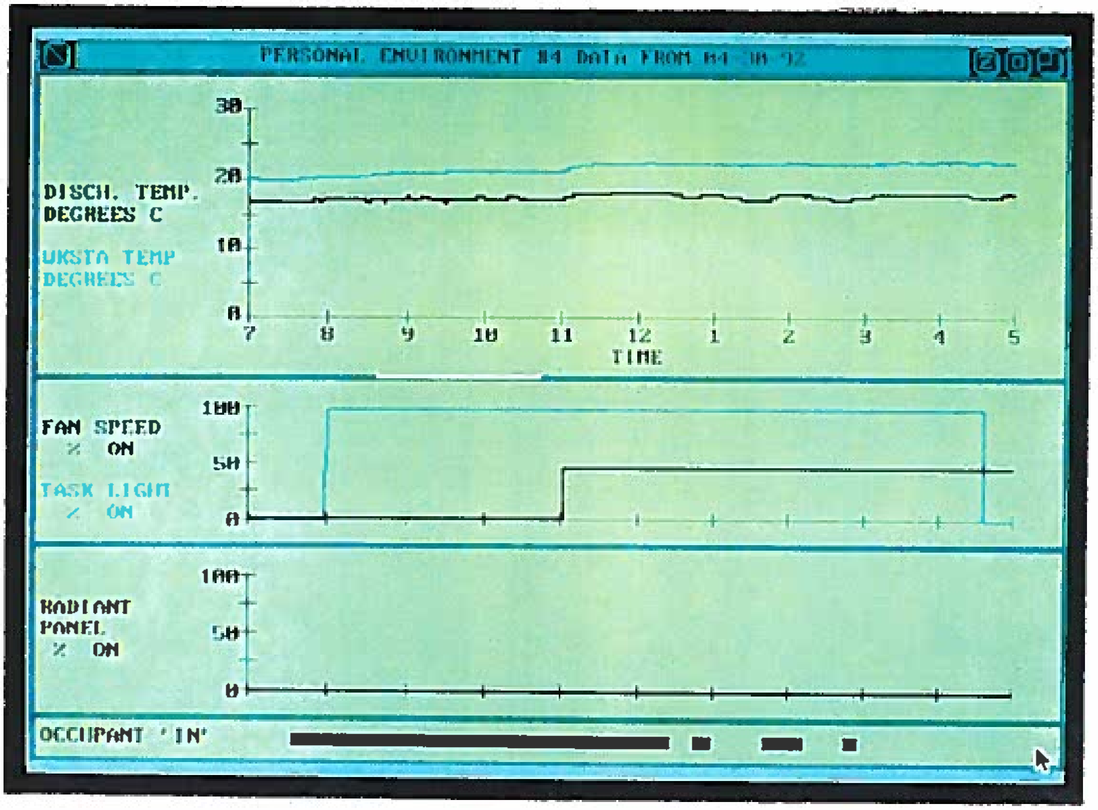


Figure 12. Smalltalk Display Screen: Trend Data

Using the assembled network, we performed preliminary calibration checks of all sensors using side-by-side comparisons with high-quality in-house reference sensors. These checks confirmed the correct connection and operation of the network hardware. Since installing the monitoring network in the AOST office in San Ramon, the accuracy of all sensors has been checked and the sensor calibration equations (contained in the PowerBasic program) have been modified, if necessary. The work performed to carry out the network calibration is described further below.

The measurement accuracy's discussed below refer to total system accuracy (sensor plus DAS). All workstation and room air sensors (RS-9100) appear to be reading to within ±1°C of the expected value. These sensors were checked by side-by-side comparison with two high quality laboratory reference temperature sensors whose accuracy was rated at ±0.2°C. The duct-mounted supply air temperature sensors (TS-9100) were initially found to have slightly larger errors because the lower temperatures being measured were below the range previously checked in our laboratory. New calibration coefficients were installed for these sensors and agreement is now also to within ±1°C of the expected value. Both the wall-mounted (RH-RM) and duct-mounted (SARH) relative humidity sensors have been checked with a sling psychrometer and agree to within ±3% of the expected value, matching the manufacturer's specifications. The discharge air temperature sensors contained in the PEM units are relatively inaccurate and only agree to within (±2-3°C) of the reference sensor. All occupancy sensors are operating correctly. The response time (time delay until the sensor status switches to 'unoccupied') of the sensors after the workstation is vacated is approximately three minutes for the PEM sensors and six minutes for the WS sensors.

Measurement of supply air volume to the ceiling-based diffusers (SAV-1), utilizes the existing variable-volume terminal unit serving that duct line. The terminal unit (Titus Model ESV-3000) features a multi-point center-averaging pressure sensor located at the inlet. Monitoring the pressure difference between the high and low pressure leads from the inlet sensor allows the total flow through the unit to be measured. During the first calibration check of this supply line (August 1992), two 8-point traverses were performed in the duct immediately upstream of the terminal unit with a hand-held anemometer. The flow measured by the traverses was found to agree to within about 10-20% of the flow measured by the inlet pressure sensor. The disagreement between these results was accounted for by two factors: (1) the incoming flow was quite nonuniform due to the upstream duct configuration; and (2) during the measurements, the flow was observed to fluctuate repeatedly (cycle) over a 45-second period with an amplitude of ±10%, making accurate measurements more difficult. At the same time, a flowhood was used to measure the air being supplied by the four diffusers served by this line. The total flow from the diffusers was found to be significantly less than that measured at the terminal unit. An inspection of the duct system in the ceiling plenum found that the flexible duct that had previously been disconnected and capped from the diffuser above the PEM2 workstation (see Figures 2 and 3) had reopened, allowing supply air to flow freely into the plenum area. The duct has since been resealed. A second calibration check of this supply line (March 1993) found the flow reported by the monitoring network agreeing to within 10-15% of the total flow measured with a flowhood at the four supply diffusers. Considering the time (1-2 minutes) required to complete the flowhood measurements, this is an acceptable comparison, indicating that no major leaks exist in the supply ducts.

Measurement of supply air volume in the duct line serving the four PEM units (SAV-2) is accomplished with an Eldridge Products Series EP-8831 thermal mass flowmeter. As shown in Figure 3, the duct was configured to accommodate a straight length of duct (approximate ten duct diameters) upstream of the measurement location. This produced a well-developed velocity profile within the 12-in. round duct, allowing reliable flow measurement at a single point. A ten-point traverse with the EP-8831 at this measurement location (March 1992) confirmed the effectiveness of the straight duct configuration. Table 2 presents the results of the traverse performed under minimum flow conditions (all PEM fan setpoints set at minimum); the measurement positions are determined to represent the centers of equal concentric areas. The total flow is simply the average of the ten readings. The results demonstrate the flat, well-developed velocity profile in the duct. The EP-8831 sensor was permanently installed at the center of the duct and read 135 cfm, equal to the average result from the traverse. Also shown in the table for comparison are the results of flow measurements at each of the eight PEM supply nozzles made with a hand-held anemometer. The disagreement between the two results for total PEM supply volume is less than 10%, a good result for this type of measurement.

In general, the measurement accuracy's described above are quite adequate for the intended use of the collected data: to observe overall trends in the performance of the HVAC system and to identify any significant thermal events in the AOST office that may account for unexpected PEM and thermal comfort results.

Troubleshooting the operation of the system software that controls the data collection process also proved to be challenging for a number of reasons.

During the troubleshooting and calibration period described above, we spent some time studying and evaluating the performance of the HVAC system serving the AOST office. We identified several HVAC issues requiring further attention. These issues are described briefly below.

1. As mentioned above, an uncapped duct line allowed cool primary air to be supplied directly to the ceiling plenum. Although the line has since been recapped, we do not know how long this line was open. It may have been open during the first comfort field test in the AOST office (30 April - 1 May 1992). Under these circumstances, it is difficult to make an accurate assessment of HVAC performance. There is a high probability of short-circuiting with an unknown amount of supply air being delivered directly to the return plenum.

2. Also mentioned above, the airflow through the VAV box serving the ceiling diffusers fluctuated rather significantly over a 45-second cycle. This would seem to indicate a flow control problem at the VAV box or at the main air handling unit.

3. The Titus VAV box serving the ceiling diffusers was originally sized and installed to handle the load from a larger office space. After the renovation of the AOST office and the addition of a second supply line serving the four PEM workstations, the required flow through this VAV box was significantly reduced. VAV boxes are known to have difficulty throttling down below about 20% of maximum flow. The correct operation of the VAV box should be checked, as it may account for the fluctuating flow described above in (2). Future plans to test the AOST office under elevated thermostat setpoint conditions (reduced airflow) also make it desirable that a properly sized VAV box be installed.

4. During the renovation of the HVAC system for the AOST office, it was planned to separate, to the extent possible, the operation of the supply lines serving the two workstation clusters in the office. This was done by disconnecting two ceiling diffusers that were located above the PEM workstations, and leaving the other four to condition the remaining areas of the office. However, as shown in Figure 3, one of the remaining diffusers is directly above the PEM1 workstation, providing little chance (if one ever existed) that the operation of two supply systems can be distinguished. This configuration may also tend to overcondition the PEM workstation area, reducing the need to use the PEM air supply. If additional improvements are made to the AOST office, we recommend that the operation of the two supply lines be completely separated. By allowing one or the other supply line to be closed off, the effect of the PEM air supply (or the overhead supply) on the thermal performance of the office can be more clearly investigated.

- The physical measurement transducers and their interrogation meets the ASHRAE 55-81 (1981) and ISO 7726 (1985) standards for accuracy and response time.

- Physical measurements are made as close as possible to the exact physical position of the subject completing the subjective questionnaire, and as soon as possible after completion of the questionnaire.

- The survey process, including subjective responses and physical measurements, is completed in approximately 10 minutes per workstation visit.

- All physical and subjective data are collected in machine-readable form. Compiling data in digital files during the collection process eliminates keypunch errors and expedites daily summary sheets for error checking.

- The instrumentation package is mobile and portable, its battery power capable of a full day's operation without recharge.

- The data acquisition system provides a real-time display of measured values for error-checking purposes. These values are hidden from the sight of test subjects to avoid bias in their answers to subjective questions.

- The field equipment is automated to the extent that student assistants with modest training could contribute to the daily data collection effort.

To meet these specifications, we assembled an array of transducers, constructed an integrated signal processing and data acquisition system, and programmed two laptop computers for data reduction and display in real-time. All equipment is mounted on a two-wheeled chassis of 3 inch by 1 inch aluminum tubing with a wooden "chair" attached to the front (see Figure 13). In addition to battery storage, the "seat" of the chair shields the sensors and carries the laptop computer that issues the subjective survey questionnaire at each workstation visit. We had several signal processing devices custom-built to our specifications for this application and they are mounted under the seat and in the seat back. Behind the seat back is a second laptop computer that provides the cart operator with a real-time view of the transducer values and presents a stripchart-format time history of the previous ten minute's data.

The cart's transducer specifications and the heights of each from the floor are listed in Table 3. These sensors were chosen to meet the response time and accuracy requirements of ASHRAE Standard 55-81 and ISO Standard 7726 for thermal assessment. In general, the temperature sensors are accurate to within 0.2°C and have a time-constant of several seconds. The sensors we used are YSI Series 700 probes having a vinyl-coated tip on a flexible signal wire. Where globe temperature was measured, we mounted a table tennis ball on the cart with one of the YSI temperature sensors in the center of the "globe". The globe is painted gray for the proper emissivity and responds to the balance between radiation and convection in the physical environment. In an office environment where the differences between workstations are relatively small, the globe should reach equilibrium well within the 5 minute measurement period. A short

TABLE 3
Transducer Specifications

QUANTITY	SENSOR DESCRIPTION	SENSOR LOCATION	MEASUREMENT ACCURACY: ASHRAE 55-81	MEASUREMENT ACCURACY: ISO-7726	MEASUREMENT ACCURACY: MANUFACTURER	MEASUREMENT ACCURACY: CALIBRATION	RESPONSE TIME
Air Temperature	shielded composite thermistor	0.1, 0.6, 1.1 m	± 0.2°C	Required: ± 0.5°C Desired: ± 0.2°C	± 0.1°C over range 0 to 40°C	± 0.2°C over range 20.7 to 28.5°C	5 sec (90%)
Globe Temperature	composite thermistor inside 38 mm diameter table tennis ball (painted grey)	0.1, 0.6, 1.1 m;	Desired: ± 0.2°C (for MRT)	Required: ± 2.0°C Desired: ± 0.2°C (for MRT)	± 0.1°C over range 0 to 40°C (for thermistor)	± 0.1°C over range 18.7 to 25.1°C (for thermistor); ± 1°C (for operative temp.)	2.5 min (63.2%); 5.8 min (90%)
Air Velocity	spherical omnidirectional temp. compensated anemometer	0.1, 0.6, 1.1 m	± 0.05 m/s over range 0.05 to 0.5 m/s	Required: ± 5% ± 0.05 m/s Desired: ± 2% ± 0.07 m/s over range 0.05 to 1.0 m/s	± 0.01 m/s over range 0.05 to 1.0 m/s	factory calibration checked by intercomparison	< 0.1 sec (63%);
Humidity	chilled-mirror dew point sensor	0.6 m	± 0.6°C (for dew point temp.)	± 0.15 kPa (for water vapor partial press)	± 0.5°C (for dew point temp. over range: -18°C to 38°C)	factory calibration checked with sling psychrometer	10 sec
Radiant Temperature Asymmetry	opposing plane radiant temperature sensors	1.1 m	± 1.0°C	Required: ± 1.0°C Desired: ± 0.5°C	± 0.5°C for $\lvert T_{pr} - T_{air} \rvert \leq 15°C$	± 0.4°C over range 18.7 to 25.1°C (for plane radiant temp.)	60 sec (90%)
Illumination	silicon photovoltaic photometer	1.1 m	N/A	N/A	± 5%	factory calibration checked by intercomparison	instantaneous

The Campbell Scientific datalogger also controls the timing and sequence of measurements. A data-collection sequence is initiated by the operator flipping a switch mounted on the top of the cart. This instructs the datalogger to begin storing data from the sensors and is indicated by an LED glowing solid green near the cart switch. The laptop computer continuously displays data in a stripchart fashion with an indicator showing whether the data is being stored or not. After one minute of monitoring the transducers as they come into equilibrium with the physical environment at the workstation, the datalogger shifts into "burst" mode. Burst mode is the only state in which the datalogger can sample the anemometers quickly enough to measure turbulence intensity. During the next three minutes, the datalogger is completely occupied with the air velocity measurement, collecting 60 data points per second while the LED blinks green. After the burst measurement is complete, the 21X collects data from the other sensors at the rate of one sample per second for the remaining one minute. During the last minute of data collection, the LED glows solid red and turns off when the measurement sequence is complete and the cart can be safely moved. The total number of air velocity readings taken during the three minute measurement burst is 7,200, too much data to process in real-time. So, as the cart is being moved to the next workstation, a post-measurement processing sequence reduces the 7,200 readings to engineering units, calculates turbulence intensity, and stores the final values on the hard disk with data from the other transducers.

Subjective Survey System

As in our previous thermal comfort fieldwork, the subjective survey system is divided into two parts, background and online. The background survey is a 10 page paper survey with questions relating to demographics, job satisfaction, work area satisfaction, health, and characteristic emotions. It is issued to and collected from the subjects before any workstation visits. The online survey is given before each workstation visit and has questions relating to current thermal sensation, environmental satisfaction, emotions, clothing, and activity level. The new subjective survey laptop is carried in the cart seat, has a adjustable back-lit screen, a 80286 processor, and battery power for a full day.

To reduce the online survey completion time, several changes were recently made to the content of the survey instruments. The most notable is that a section on coping strategies was added to both the background and online surveys. Coping strategies represent ways in which the subject can make changes to the local thermal environment. In the background survey, available coping strategies were listed by the subject and those available to him/her were presented during each online visit and their status was recorded, e.g. fan on, blinds half open, etc. Coping strategies are particularly applicable to the four participants in the AOST office who have PEM units in their workstations. Copies of the background survey and the online survey computer screens are presented in Appendixes C and D.

Field Measurement Protocol

Eight PG&E employees were originally selected to participate in the study, including three females and five males. During the baseline field test, one male subject was unavailable to be measured. Although this particular subject participated in the second field test (first post-

Occupancy (Test 2) tests to selected buildings studied in ASHRAE RP-462, a field study of ten office buildings in the San Francisco Bay area [Schiller et al. 1988]. Since we found a significant seasonal variation in conditions during the ASHRAE study and the first two AOST tests occurred during what could be considered swing seasons, Table 4 is shown in two parts. Table 4a shows a comparison to our previous winter measurements and Table 4b shows a comparison to our previous summer measurements. Table 5 shows a comparison of the three AOST tests and the ASHRAE RP-462 buildings to the ASHRAE 55-81 comfort standard. The results are discussed below.

Our measurements to establish baseline conditions for the AOST comfort study indicated that the major physical variables affecting comfort were substantially within normal ranges. Air temperature averaged 22.2°C through our workstation visits, a value only slightly lower than the winter and summer averages of the ASHRAE RP-462 field study. Indoor air velocities, averaging 0.10 meters per second for the Baseline test, were equal to the summer averages measured in our previous ten-building field study, falling within the zone considered to be "still-air". Radiant effects in the Sunset Building were insignificant. Dewpoint temperatures, which had been found to be low during a previous ACT^2 baseline test, were all within the limits specified by the ASHRAE 55-81 comfort standard, presumably due to corrective action during ACT^2 renovation work. The clothing insulation values reported by the AOST study participants were in the normal range and fell between the winter and summer averages of the ASHRAE RP-462 field study.

Baseline results for effective temperature (ET*) and operative temperature (both indices that combine other physical parameters into a "temperature" index) were slightly below the winter averages and more than 1°C lower than the summer averages calculated for the ASHRAE RP-462 field study. Values for effective temperature index fell within ASHRAE 55-81 specifications for 100% of our workstation visits compared to 83.9% of the winter workstation visits in the ASHRAE RP-462 field study (see Table 5). For summer conditions, however, this percentage dropped to only 23.1% due to the lower temperatures being maintained in the Sunset Building. This value was substantially lower than the 68.3% of acceptable ET* values achieved during the summer measurements of the ASHRAE RP-462 field study. Table 5 indicates that, except for a small percentage of air velocity results, the AOST baseline data were substantially within the ASHRAE winter comfort zone.

Physical measurement results from the two post-occupancy comfort studies (AOST Tests 1 and 2 in Tables 4 and 5) are very similar and indicate that the average air temperature in the AOST office is nearly 1°C higher than the baseline result (23.0°C and 22.9°C versus 22.2°C). Calculated temperature indices such as ET* and operative temperature are also higher than the baseline, primarily due to the higher air temperature. This improves the agreement with ASHRAE 55-81 specifications for summer conditions, as 69.2% for Test 1 and 78.9% for Test 2 of the calculated ET* values fall within the acceptable range compared to 23.1% for baseline results (see Table 5). In fact, Table 5 indicates that the results for dew point temperature, ET*, and air velocity from both AOST Tests 1 and 2 demonstrate generally equal or improved agreement with ASHRAE 55-81 compared to the average results from both the winter and summer data from the ASHRAE RP-462 field study. Clothing level in the AOST office is slightly lower than baseline conditions (0.47 and 0.50 versus 0.55).

TABLE 4b

Distribution of Physical Data: Comparison of AOST Baseline - Oct. 1991 (A-B), Test 1 - May 1992 (A-1), and Test 2 - Sept. 1992 (AC) to selected ASHRAE RP-462 summer measurements

Building	Pilot	A	B	C	D	E	F	G	H	I	All	A-B	A-1	A-2
Sample Size	123	119	92	108	115	123	107	117	23	107	1034	39	39	38
Clothing (clo)														
mean	0.47	0.50	0.47	0.54	0.53	0.54	0.55	0.55	0.50	0.53	0.52	0.55	0.47	0.50
std. dev.	0.12	0.13	0.10	0.16	0.11	0.10	0.13	0.12	0.14	0.11	0.12	0.13	0.10	0.10
minimum	0.16	0.23	0.25	0.20	0.26	0.27	0.24	0.28	0.22	0.34	0.16	0.36	0.26	0.36
maximum	0.71	0.92	0.64	1.44	0.97	0.98	0.87	0.99	0.74	0.81	1.44	0.92	0.62	0.69
Air Temperature (°C) (mean of 3 heights)														
mean	24.6	22.6	23.4	22.6	22.4	24.3	24.4	22.7	22.4	22.8	23.3	22.2	23.0	22.9
std. dev.	1.6	0.5	0.5	1.0	0.8	1.0	1.2	0.6	0.8	0.6	1.3	0.6	0.3	0.3
minimum	21.8	21.1	22.4	20.1	20.5	21.7	21.0	21.0	21.3	21.4	20.7	20.5	22.4	22.2
maximum	29.5	23.6	25.0	24.5	24.6	26.3	27.6	24.2	24.1	25.4	29.5	23.3	23.6	23.5
Vapor Pressure (torr)														
mean	11.2	12.0	13.2	11.6	13.2	13.6	15.0	13.8	13.3	12.9	12.9	9.6	9.3	9.8
std. dev.	0.7	0.5	0.8	0.5	0.8	0.8	0.6	0.9	0.4	0.6	1.3	0.5	0.1	0.3
minimum	8.6	11.2	11.3	10.7	11.8	10.6	13.2	12.2	12.5	12.0	8.6	8.4	9.1	9.3
maximum	12.7	13.0	16.6	12.9	15.8	15.2	16.7	16.9	14.6	17.7	17.7	10.4	9.6	10.3
Dew Point Temperature (°C)														
mean	13.0	14.0	15.5	13.5	15.5	16.0	17.5	16.2	15.6	15.1	15.1	10.5	10.2	10.9
std. dev.	0.9	0.6	0.9	0.6	0.9	0.9	0.6	1.0	0.5	0.7	1.6	0.8	0.2	0.4
minimum	9.0	12.9	13.1	12.3	13.7	12.1	15.5	14.3	14.7	14.0	9.0	8.6	9.8	10.1
maximum	14.9	15.2	19.1	15.1	18.3	17.7	19.2	19.4	17.0	20.2	20.2	11.8	10.6	11.7
Air Velocity (m/s) (mean of 3 heights)														
mean	0.20	0.11	0.11	0.10	0.11	0.12	0.11	0.16	0.11	0.11	0.10	0.10	0.10	0.10
std. dev.	0.19	0.02	0.03	0.01	0.03	0.03	0.02	0.09	0.02	0.02	0.09	0.04	0.03	0.04
minimum	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.05	0.02	0.01	0.00	0.04	0.05	0.05
maximum	1.24	0.20	0.24	0.18	0.25	0.30	0.22	0.67	0.19	0.23	1.24	0.21	0.18	0.31
Operative Temperature (°C) (mean of 3 heights)														
mean	24.7	22.8	23.6	22.8	22.6	24.5	24.5	23.0	22.6	22.8	23.5	22.3	23.1	23.1
std. dev.	1.6	0.5	0.5	1.0	0.8	1.0	1.1	0.6	0.7	0.6	1.2	0.6	0.3	0.4
minimum	22.1	21.6	22.6	20.3	20.8	22.1	21.3	21.3	21.5	21.4	20.3	21.0	22.6	22.2
maximum	29.5	23.7	25.2	24.6	24.6	26.4	27.6	24.5	24.1	25.4	29.5	23.4	23.5	23.6
ET* (°C) (mean of 3 heights)														
mean	24.5	22.7	23.7	22.7	22.7	24.6	24.8	23.1	22.7	23.0	23.5	22.3	23.0	23.0
std. dev.	1.4	0.5	0.5	1.0	0.8	1.0	1.2	0.6	0.7	0.7	1.3	0.6	0.3	0.3
minimum	22.0	21.3	22.7	20.2	20.9	21.8	21.3	21.4	21.7	21.6	20.2	20.9	22.5	22.2
maximum	29.0	23.7	25.0	24.6	24.9	26.5	28.0	24.5	24.4	25.8	29.0	23.3	23.4	23.5

Table 6 shows a comparison of overall average values of landmark variables of subjective response and comfort. Results are presented for the AOST Baseline, Test 1, and Test 2. Thermal sensation vote is a subjective declaration of thermal sensation on a -3 (cold) to +3 (hot) scale. On this scale, the central value of 0 represents thermal neutrality and ASHRAE considers the central three values of -1 (slightly cool), 0 (neutral), and 1 (slightly warm) to be thermally acceptable. Average thermal sensation vote was -0.04 for the Baseline test, representing a result that was very near the neutral point. The average thermal sensation vote for Test 1 was 0.22, a slightly higher value, perhaps reflecting the increased air temperatures in the AOST office. However, for Test 2, the average thermal sensation was 0.04, again very near the neutral reading of zero.

The McIntyre thermal preference scale is a three-point scale in which subjects are asked if they would prefer to be warmer (-1), have no change (0), or be cooler (+1). As shown in Table 6, average results from the thermal preference vote found only a very slight preference to be cooler for the Baseline and Test 1, but no desire to change (0.00) for Test 2, implying that on average all subjects were satisfied with their thermal environment. The calculated comfort indices of SET* (Standard Effective Temperature), DISC (Discomfort), and PMV (Predicted Mean Vote) from all three tests were very similar and well within reasonable bounds.

Table 7 presents a comparison of most of the same variables contained in Table 6, but in this case broken down into groups of subjects with and without PEMs in their AOST office workstation. Although subjects did not have PEMs during the Baseline test, results for these groups of PEM and non-PEM subjects are shown for all three tests to identify any trends or obvious differences. Average thermal sensation is slightly warmer for PEM subjects (0.14) compared to non-PEM subjects (-0.19) during the baseline. This trend is reversed during Test 1 (0.02 vs. 0.44), a result that may be attributable to the local air supply characteristics of the PEMs. However, in Test 2, the trend of thermal sensation vote again resembles that of the baseline data with PEM subjects claiming to be slightly warmer (0.18) than the non-PEM subjects (-0.11). The difficulty in establishing a clear pattern over the three tests is not unexpected due to the small number of subjects involved in the study.

Nevertheless, a few more obvious observations are worth mentioning. The general comfort scale is a six-point scale ranging from very uncomfortable (1) to very comfortable (6). During Test 1, shortly after the subjects occupied the AOST office, those with PEMs voted a noticeable increase in general comfort compared to the Baseline (5.30 vs. 4.93). However, the non-PEM subjects voted a significant drop in general comfort compared to the Baseline (4.58 vs. 5.33). The higher general comfort exhibited by PEM subjects over non-PEM subjects in Test 1, was no longer evident in Test 2, perhaps indicating that an initial highly positive response to the PEM was somewhat reduced over time.

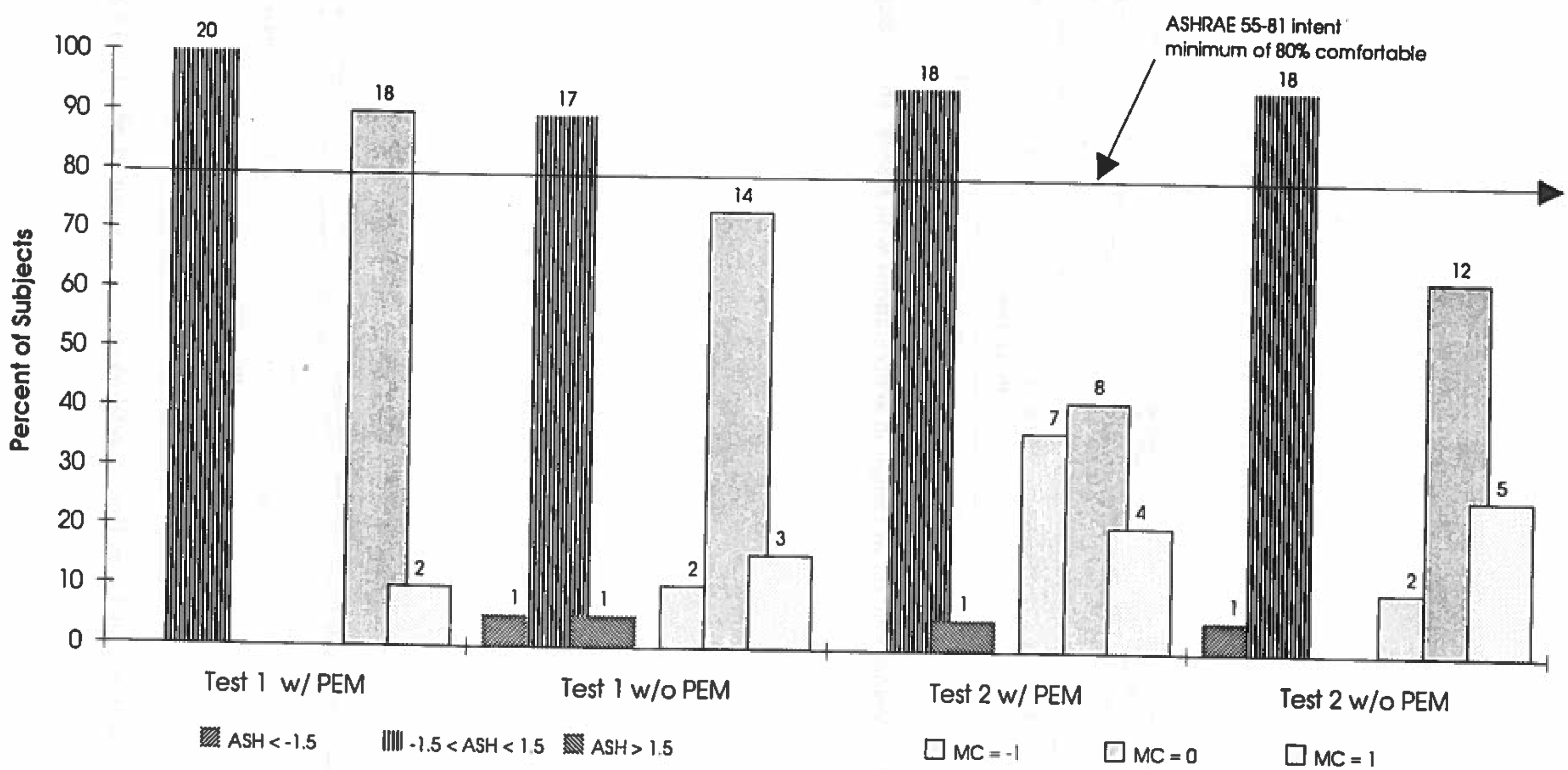
Ventilative comfort is a six-point scale in which the subjects describe their ventilative environment as being stuffy (1) to breezy (6). During the Baseline, when no PEMs were available, both groups had very similar ventilative comfort votes. After occupying the AOST office, as expected, the PEM subjects have a higher average ventilative comfort rating than the non-PEM subjects do in both Tests 1 and 2.

TABLE 7

Comparison of Landmark Variables of Subject Response, Comfort Averages, and Air Velocities for AOST Baseline, Test 1, and Test 2

	Baseline		Test 1		Test 2	
Variable	**PEM (3)**	**Non-PEM (4)**	**PEM (4)**	**Non-PEM (4)**	**PEM (4)**	**Non-PEM (4)**
Thermal Sensation	0.14	-0.19	0.02	0.44	0.18	-0.11
Thermal Preference	0.21	-0.06	0.10	0.05	-0.16	0.16
General Comfort	4.93	5.33	5.30	4.58	4.79	4.74
Ventilative Comfort	3.79	3.83	3.95	3.37	3.95	3.74
Lighting Comfort	4.00	4.44	3.90	4.58	4.21	4.63
Metabolic Rate	1.1	1.1	1.1	1.1	1.2	1.1
Clothing Level	0.51	0.59	0.50	0.44	0.51	0.49
ET* (°C)	22.5	22.1	22.9	23.0	23.0	23.1
DISC	-0.05	0.01	-0.02	-0.03	-0.02	-0.03
SET* (°C)	21.6	21.3	21.9	21.7	22.3	22.1
PMV	-0.24	-0.27	-0.21	-0.23	-0.20	-0.18
Velocity at 1.1 m (m/s)	0.11	0.09	0.18	0.10	0.19	0.11
Velocity at 0.6 m (m/s)	0.12	0.11	0.12	0.08	0.10	0.09
Velocity at 0.1 m (m/s)	0.08	0.09	0.06	0.07	0.07	0.07

Figure 14. Comfort Votes on the ASHRAE Thermal Sensation (ASH) and McIntyre (MC) Scales



PEM Performance

Data have been collected on a daily basis since April 1992 from both the UC Berkeley and Endecon permanent monitoring networks. We have analyzed the network measurement results to coincide with the first and second post-occupancy comfort tests (Tests 1 and 2) in the AOST office. In this section, we present and discuss findings regarding the performance of the PEMs, including occupant use patterns, power quality, and power consumption.

As described earlier, the PEM monitoring network records a set of data that describes in detail for each PEM workstation the occupant's use of the desktop control panel. The monitored PEM control parameters include: (1) discharge air temperature setpoint, (2) fan speed setpoint, (3) radiant panel setpoint, (4) task light setpoint, and (5) occupancy sensor status. Figures 16a and 16b show examples of the occupant use patterns from two PEM workstations between the hours of 7 am and 7 pm on 30 April 1992. In both figures setpoint position (0-100%) for the task light, fan, radiant panel, and temperature are shown on the left axis, while occupancy (0-1) is shown on the right axis. Ten-minute average data are shown. In Figure 16a, the light is turned on 100% all day long. The fan setpoint stays at 20% during the morning and jumps to 100% when the occupant returns from lunch (playing basketball). After another hour, the fan is turned down to 60% until the end of the day. Radiant panel and temperature controls are unused all day long. The short occupancy peaks during the later morning and noontime hours may in fact be due to visits to the workstation by office workers other than the occupant. In Figure 16b the only evidence of setpoint adjustment is with the task light. All other control setpoints are unused all day long.

To investigate the energy performance of the PEM units on a component basis, we performed detailed energy measurements using the Endecon monitoring network in March 1993. Since the current Endecon network monitors the total plug load from all four PEMs, we unplugged all but one PEM at a time, and then recorded current, voltage, and power readings in response to different PEM control settings. This allowed us to develop empirical relationships between power and control setting for the three major energy-consuming components, the fan, task light, and radiant panel. The other two available PEM control parameters (discharge air temperature and white noise) had a negligible impact on energy use. The empirical power relationships could then be applied to the recorded occupant use patterns (from UC Berkeley's monitoring network) to produce a time-based image of PEM energy performance broken down by PEM components and individual workstations. The energy measurement data are presented in Figures 17 to 19 and discussed briefly below.

The results of the detailed energy tests indicated that the minimum power consumption of the PEM is about 5 W/unit, when the occupancy sensor is off (PEM deactivated). This minimum value increases to about 20 W/unit, when the workstation is occupied, even with all other control settings at their minimum levels. Figure 17 presents the measured power vs. PEM fan control settings (all other controls are at minimum). Figure 17a shows real power (W), Figure 17b shows apparent power (VA), and Figure 17c shows power factor (real power/apparent power). The PEM fan uses 90 W of real power at its maximum setting (including the PEM base power of 20 W) and is quite linear in nature, with a power factor approaching 95% at its maximum speed. The

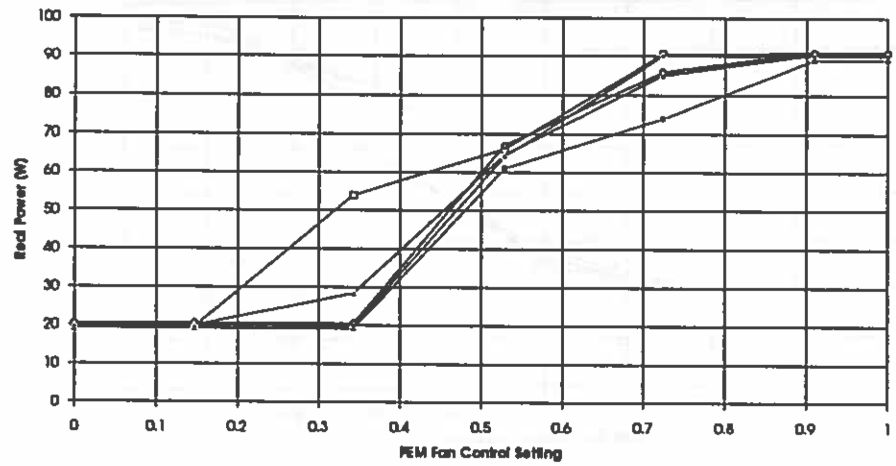


Figure 17a. Real Power (W) vs. PEM Fan Control Setting

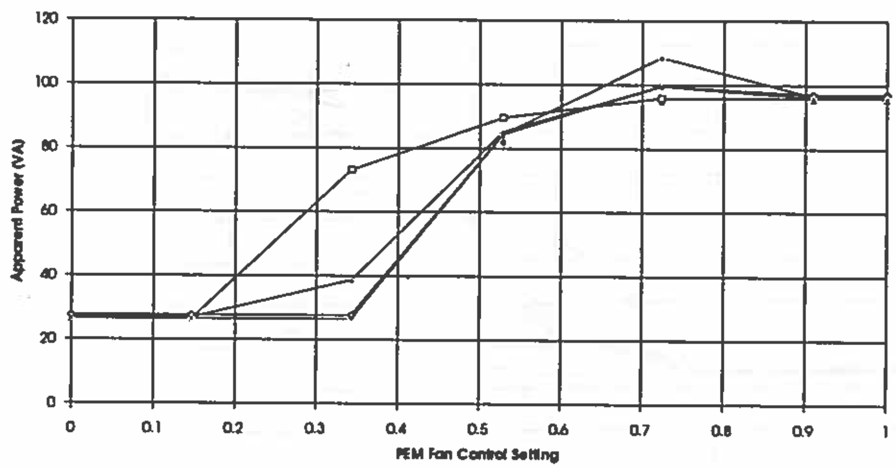


Figure 17b. Apparent Power (VA) vs. PEM Fan Control Setting

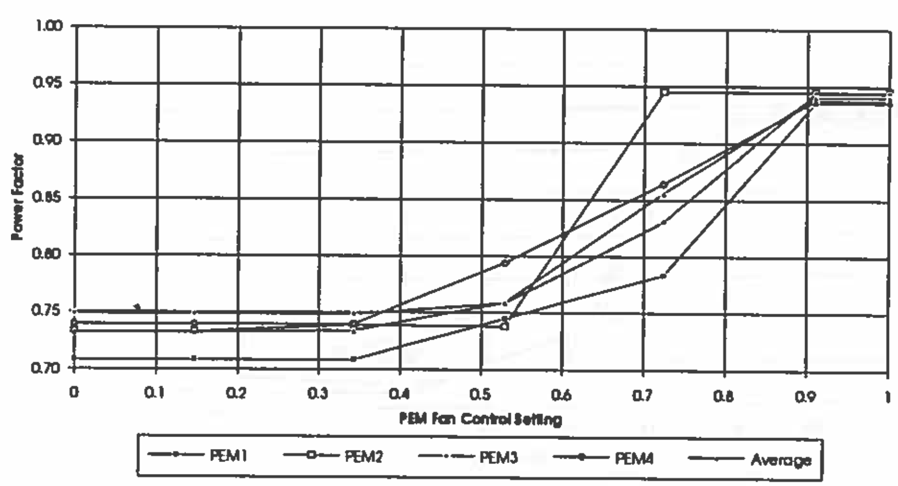


Figure 17c. Power Factor vs. PEM Fan Control Setting

data also indicate, that most of the actual control operation of the fan is confined to the middle third of the control setting span. In most cases, there is little variation in power usage over the bottom and top ranges of the control setting.

Figure 18 presents the measured power vs. PEM task light control settings (all other controls are at minimum). Figure 18a shows real power, Figure 18b shows apparent power, and Figure 18c shows power factor. All except one of the task lights consume about 70 W of real power at their maximum setting (including the PEM base power of 20 W). The power factors were quite poor for the task lighting control, with most units falling below 50% at their maximum setpoint. This was consistent with the rather unsatisfactory performance of the PEM dimming control (e.g., flickering, buzzing, premature failure of lamps), indicating that the PEM dimmer was incompatible with the installed task lights in the workstations.

Figure 19 presents real and apparent power versus PEM radiant panel control settings (all other controls are at minimum). At its maximum setting, the radiant panel consumes by far the most energy of any PEM component, using about 225 W/unit of real power (including the PEM base power of 20 W). The radiant panel is evidently quite linear with power factors approaching 100%. There is no variation in power factor over the span of control settings because the panel operates in an on/off mode with the percentage of on-time being proportional to the control setting.

Figure 20 presents the real power use pattern for the four monitored PEMs between the hours of 7 am and 8 pm on 16 September 1992, during Test 2. The ten-minute-average data are broken down by the amount of power used by each PEM component: base, fan, task light, and radiant panel. The pattern of use takes into account the status of the occupancy sensor in each

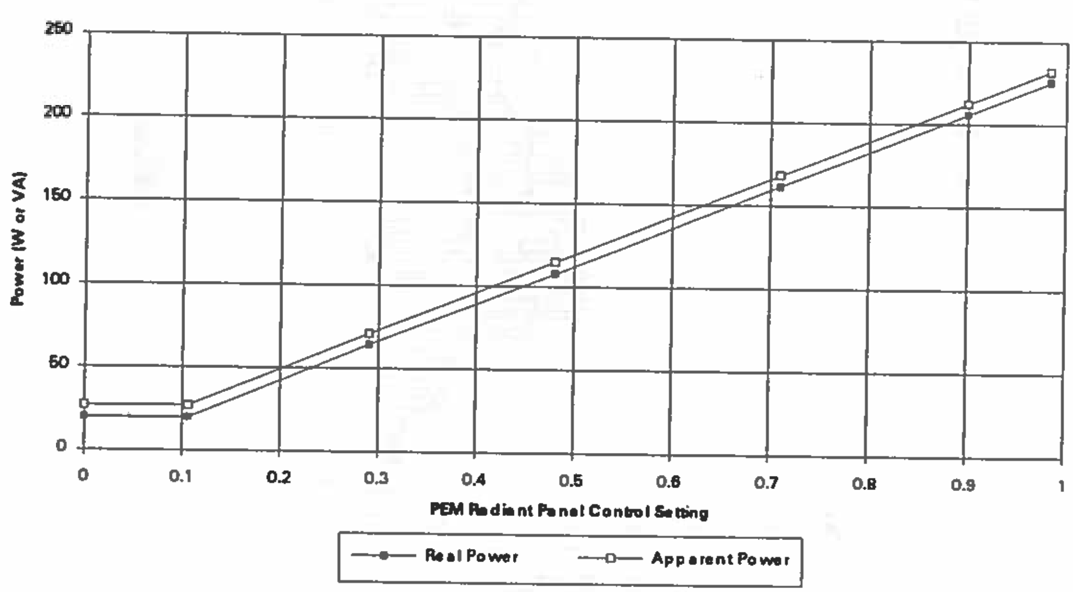


Figure 19. Real (W) and Apparent (VA) Power vs. PEM Radiant Panel Control Setting

workstation. Also shown for comparison is the total real power as measured by the Endecon data acquisition system on that date. The agreement in total power is acceptable considering that the empirical power data were obtained from short-term readings of a variable signal. The fact that the component-based results consistently exceed the real time Endecon measurements (averaged over a ten-minute period) suggests a bias in the short-term readings that could be corrected. Nevertheless, the accuracy with which the component-based calculations track the highly variable time history of power consumption is remarkable.

Figure 20 demonstrates how the base power consumption for the four PEMs varies between a minimum of 20 W when all PEM workstations are unoccupied at the beginning and near the end of the day, and its maximum value of about 80 W. On average, lights tend to use the largest amount of energy, despite the fact that one of the four task lights was disconnected on this day and did not contribute to the measured total. The total fan load is fairly low and shows up only after lunch and throughout the afternoon. The radiant panel was used only during one ten-minute period near 2 pm (perhaps only as a test?) and contributes to the days maximum total power measurement of 304 W.

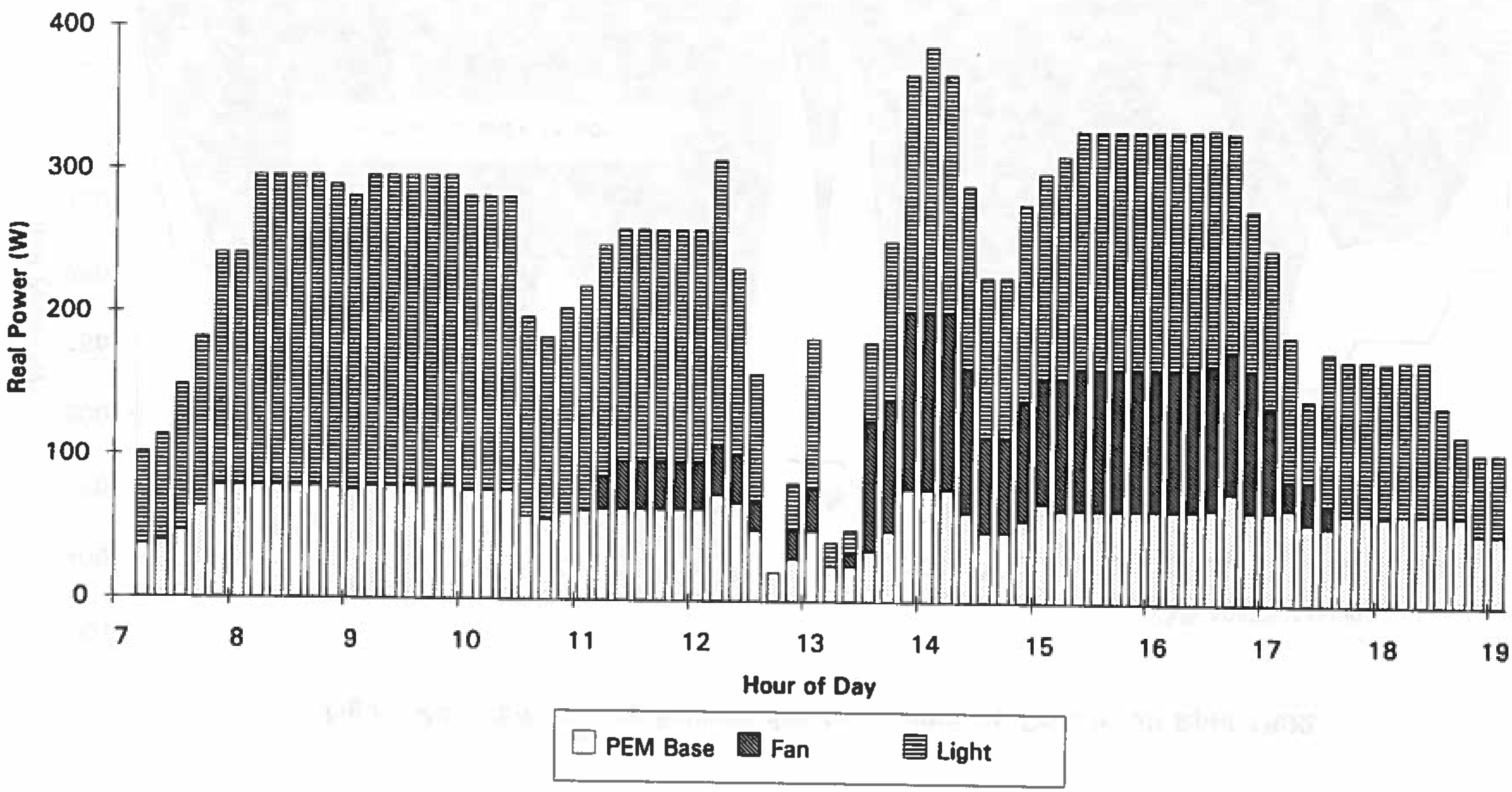
Figure 21 presents the same data shown in Figure 20, except in this case the results are broken down by individual PEM units. In this example, PEM2 usually uses at least half of the total measured power, due to the fact that the occupant was in the workstation with his light on for most of the day, and also used the fan during the afternoon. In comparison, PEM4 uses no more than 20 W during the entire day, because the task light was disconnected, and no other controls were used.

Figure 22 presents the energy use pattern for the four monitored PEMs between the hours of 7 am and 7 pm on 30 April 1992, during Test 1. On this day, only lights and fans were used. The lighting load is higher than that shown in Figures 20 and 21 due in part to the fact that all four task lights were in use. The majority of the fan use occurs after lunch and during the afternoon, although a small amount of fan energy is used during the hour before lunch time. The peak power consumption reaches 388 W around 2 pm, coinciding with the peak fan energy usage.

If one assumes that task lights would be present in a typical office environment, the additional localized heat load imposed by the PEM units is generated only by the base PEM energy usage (5-20 W/unit) and the fans. As observed by our measurements, radiant panel usage would be expected to be absent or minimal for most interior office zones in which cooling is the dominant space conditioning energy requirement. In this example, the additional load imposed by the PEM units averages between 20 to 50 W per workstation, when occupied, representing a heat load density of 0.3 to 0.7 W/ft^2 for a typical 72 ft^2 (8.5 ft by 8.5 ft) workstation in the AOST office.

The energy-saving capability of the occupancy sensor is demonstrated in Figure 23. Two energy use patterns are shown for the four monitored PEMs on 30 April 1992. One takes into account the effect of the occupancy sensor ("with occupancy sensor") and shows the same pattern of use displayed in Figure 22. The second higher energy use pattern ("without occupancy sensor") is produced by applying an occupancy weighting factor of one to all control settings after the workstations are first occupied at the beginning of the day. This is equivalent to having the lights

Figure 22. PEM Energy Use Pattern: 30 April 1992



and fans continue to operate at the same level, even when the workstations are vacant during the day. In this example, 25% of the PEM energy use is saved by the capability of the occupancy sensors to turn off the PEM units when the workstations are unoccupied.

HVAC Performance

In this section we present and discuss findings regarding the performance of the HVAC system serving the AOST office, including supply air temperature and volume, and room temperatures and humidity.

In Figure 24, the total PEM supply air volume (measured in the duct serving the four PEM units) is compared to the total PEM fan setpoints for 30 April 1992. The total occupancy-weighted fan setpoints are calculated by summing up the result for each workstation based on a value between zero and one, corresponding to the minimum to maximum setpoint on the control panel, and multiplied by one when the workstation is occupied and zero when it is unoccupied. For example, if all four fan setpoints were at their maximum setting, but only two workstations were occupied, the total weighted fan setpoint would equal two. The setpoint and supply volume profiles follow similar patterns. As described previously, even when its internal fans are turned off (minimum setpoint) a flow of approximately 40 cfm is maintained through each PEM unit for ventilation purposes. Figure 24 indicates a flow of between 130 and 140 cfm when the total PEM fan setpoints are at or near their minimum, in agreement with design conditions. PEM fan usage reaches its peak shortly after lunch when two of the PEM subjects return from playing basketball and turn up their fans to cool off. They maintain a higher fan usage for most of the afternoon. The PEM supply air volume also increases during the afternoon, indicating that the VAV box controlling the flow to the PEMs is operating properly.

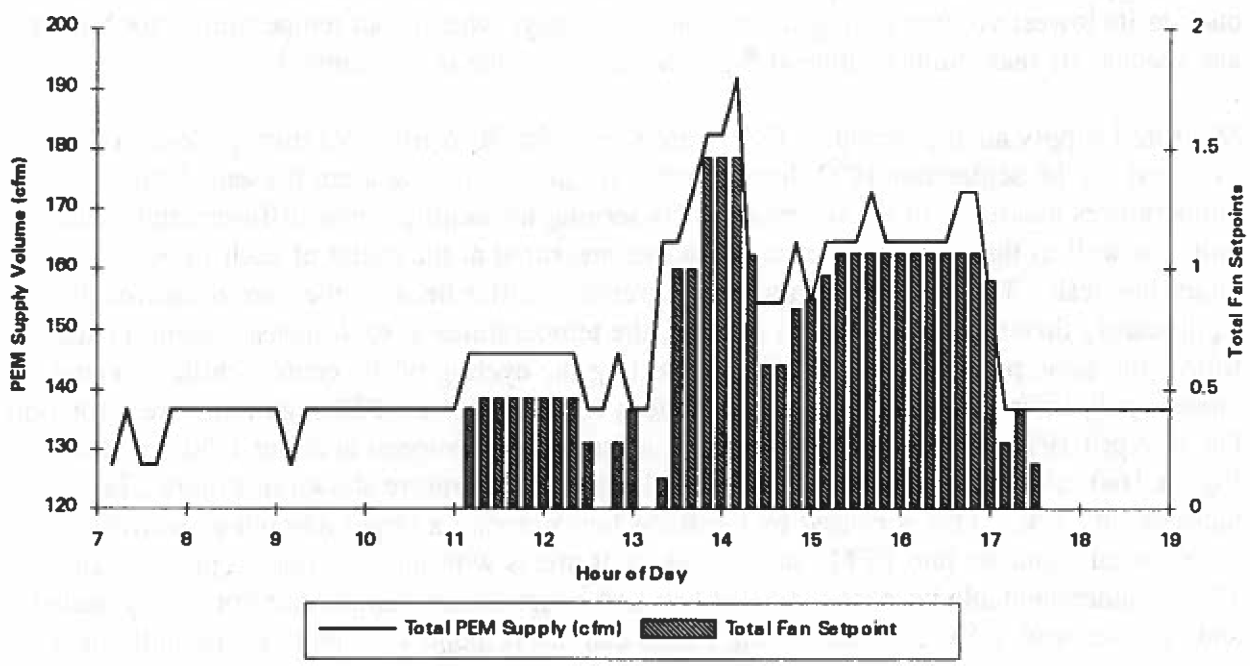


Figure 24. PEM Supply Air Volume and Occupancy-Weighted Fan Setpoints

Figure 25. Workstation and Room Air Temperatures and Relative Humidity: 30 April 1992

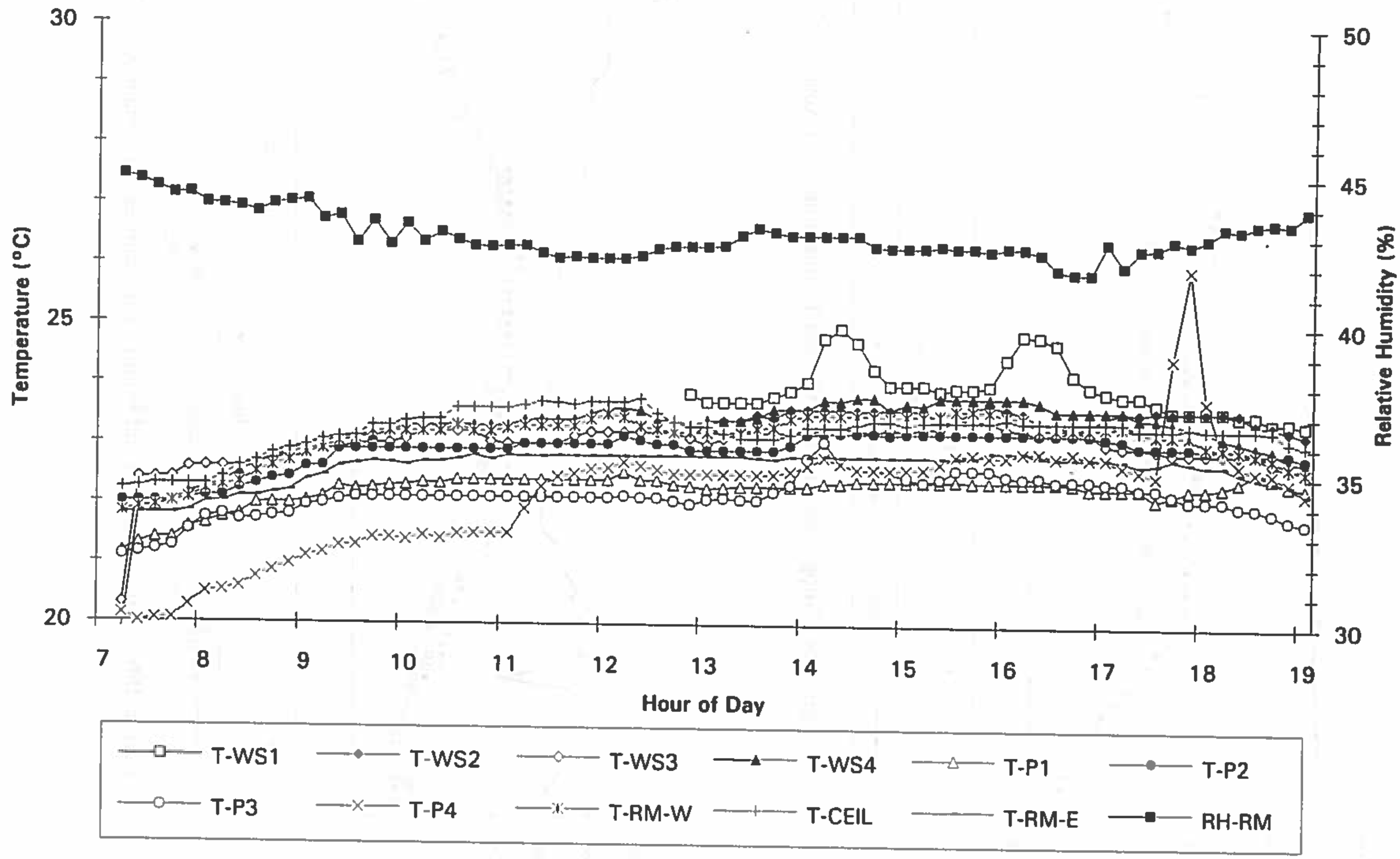
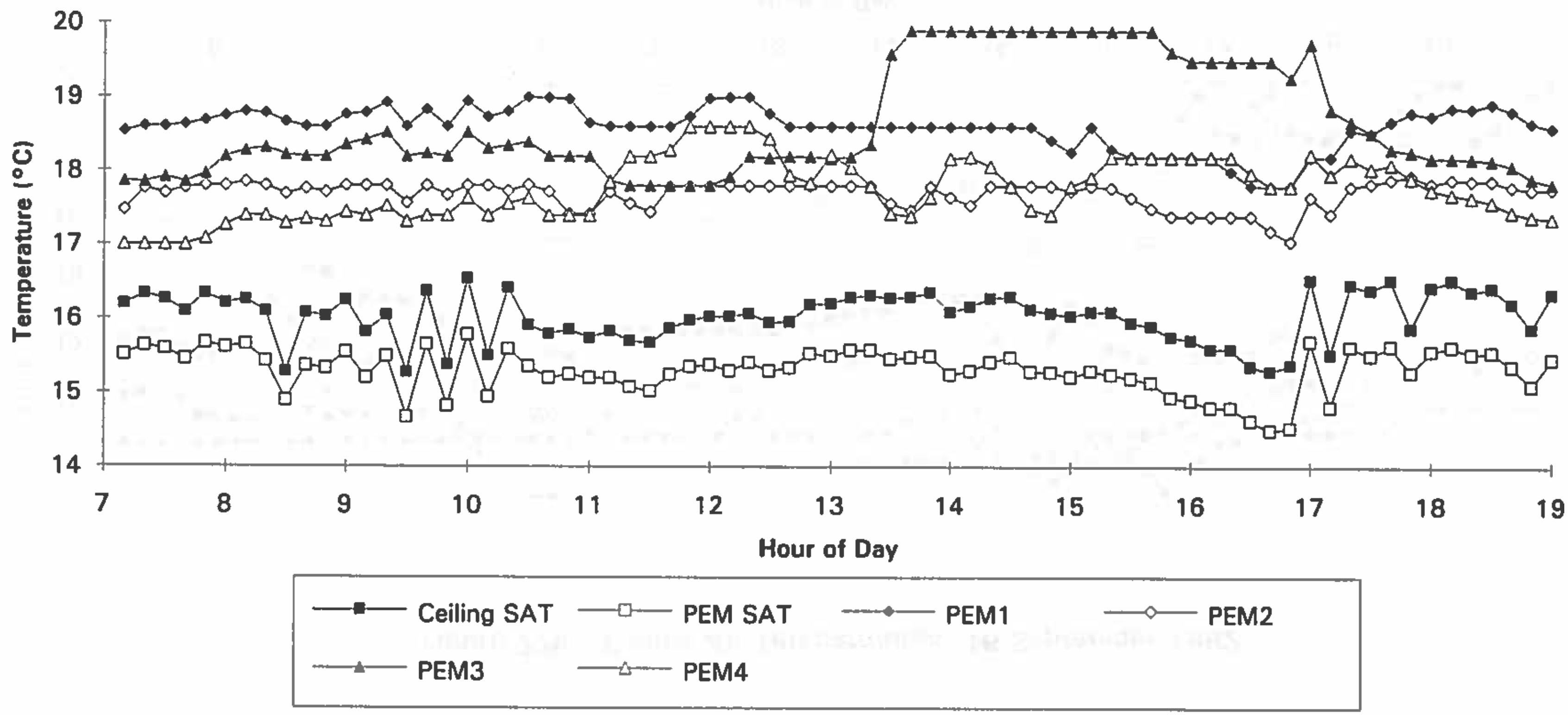


Figure 27a. Supply Air Temperatures: 30 April 1992



PEM controls. A similar pattern of increased PEM supply temperature corresponding to PEM fan operation is also shown for PEM4 during the afternoon in Figure 27a, and for PEM2 during the afternoon in Figure 27b. On average, PEM supply temperatures range from 2°C to nearly 4°C higher than the PEM SAT (measured upstream in the overhead duct), demonstrating the magnitude of the temperature rise through the long supply ducts serving the PEMs.

CONCLUSIONS

The Advanced Office Systems Testbed Project has successfully developed a facility in which advanced office technologies can be installed, tested, and demonstrated in a realistic office space. State-of-the-art data acquisition systems have been installed, providing detailed measurements of the performance of these advanced office systems, as well as a means for evaluating the suitability of the applied measurement and analysis methods. The measurement protocols and data acquisition systems are capable of collecting a large amount of data addressing energy use, thermal performance, environmental control, occupant use patterns, and thermal comfort. The manageable size of the AOST office has permitted project personnel to experience and learn from all aspects of developing and operating an office monitoring system. The lessons learned from the project have provided guidance for modifying the AOST office facility to improve its capabilities in future planned experiments, and for preparing for future scaled-up field studies of office technology.

The first advanced office system to be installed and tested in the AOST office was the Personal Environmental Module (PEM), manufactured by Johnson Controls. The PEM represents one example of an emerging technology known as task conditioning, or localized thermal distribution (LTD). Based on the results of this project and our other ongoing research, some general recommendations to improve the performance of localized thermal distribution systems are presented in Appendix H.

By utilizing a network communication capability provided by the PEMs, we were able to directly monitor the occupant use patterns and performance characteristics of individually-controlled PEM units. With the assistance of Johnson Controls, who had previously developed a PEM monitoring network at their headquarters building in Milwaukee, WI, we adapted their hardware and software to the configuration of the AOST office. The monitoring network software allows data to be collected and displayed on attractive color-graphic screens, to visually demonstrate the PEM performance characteristics to visitors of PG&E's AOST facility.

In addition to the issues described above, several important lessons have been learned through our work on the AOST Project. These are described briefly below.

1. The PEM monitoring network provides a good example of what an increasing number of environmental control technologies may look like in the future. Advances in microcomputer and communication technologies allow distributed (as opposed to centralized) intelligent control networks to be utilized to manage an increasing number of complex building environmental control and system integration issues. The effective performance of future

AOST office are maintained within the ASHRAE-specified comfort zone. There is little need to fine-tune the environment, except under extreme conditions (e.g., returning to work after playing basketball during lunch). In the future, tests could be defined to investigate the use of the PEM controls in situations when the demand for local control may be increased (e.g., raise room thermostat setpoint, disconnect primary (cool) air supply to PEMs, etc.).

5. The adaptation of the original PEM monitoring network to the AOST office, while certainly benefiting from the earlier developmental work and technical assistance by Johnson Controls, proved to be troublesome and time-consuming. As described previously, a lack of documentation and familiarity with the assembler code used to access the DR-9100 network has made it more difficult to solve several timing and computer-dependent problems. In future installations of this kind, it is recommended that alternate software approaches be investigated, in an effort to make the system operation more robust and understandable.

6. Due to the small number (ten) of AOST office workers participating in the study, the measurement database is not large enough to establish statistically significant PEM performance results. In addition, there are no reliable methods available to directly measure worker productivity in the AOST office. To date, the analysis of measurement results from the testbed has focused on identifying what effects can be measured in an office environment with PEMs, providing guidance for a scaled-up field study of PEM performance if funding and a suitable test site can be identified.

   On the other hand, the AOST office represents a unique facility for carefully defined studies of advanced office technology. Although smaller than a typical office building, the AOST office is considerably larger than a single-room controlled environment chamber, such as the one at UC Berkeley. It therefore falls somewhere in-between a rigidly controlled laboratory setting and an uncontrolled but larger and more realistic office space. Field studies in office buildings are always limited by any number of the following factors, including limited time to complete the study, limited access, limited data acquisition capabilities, potential for uncooperative building occupants (both individuals and company-wide), and usually no control over the HVAC operation of the building. The AOST office provides a practical alternative to field studies of this type due to its detailed data acquisition systems, cooperative tenant (PG&E), potential to improve the integration of the advanced (PEM) system with the central HVAC system, and the possibility of having some control over the thermal and occupancy conditions within the AOST office during future tests.

FUTURE DIRECTIONS

Described briefly below are our recommendations and suggestions for future work related to the AOST Project.

1. It is highly recommended that the existing overhead air distribution system and PEM installation be modified to allow improved system integration and operation. The most effective approach in this regard would be to (1) isolate to the extent possible the operation

Other tests in which the PEM units are temporarily modified or disabled (e.g., disconnect primary (cool) air supply to PEMs) can provide more data on occupant use patterns.

3. Although the PEM monitoring network is fully functional, development of additional capabilities could improve its effectiveness, particularly as a visual tool to demonstrate the office performance to visitors. New Smalltalk graphic display screens that could be developed include: (1) PEM control panels showing the relative position of the control levers, (2) plan view of the ceiling air distribution ducts, showing the location and current status of sensors monitoring HVAC performance, and (3) an automated software-driven demonstration tool that steps through a series of screens to show the full range of display options provided by Smalltalk. Additional development work could respond to suggestions from users of the system to improve the overall performance of Smalltalk.

4. It is recommended that future measurement plans, both in the AOST office and other field test sites, include some amount of ventilation efficiency testing. These measurements are typically carried out using tracer gas techniques and can provide valuable multipoint data to demonstrate the task ventilation performance characteristics of the PEM units in comparison to the surrounding office space. Tracer gas tests in the AOST office could help determine the effectiveness of different ventilation system designs and operating strategies.

5. An important objective of the AOST project is to develop and test the monitoring methods that could be applied to future scaled-up field studies of PEM performance in selected buildings. We know from the experiences of the AOST project that the overall effectiveness of any future field study will be greatly enhanced by specifying plans for the office configuration and selecting the study participants as soon as possible. Studies of occupant response and satisfaction, thermal comfort, and productivity (if a suitable measure can be identified) will benefit from this early planning by allowing baseline measurements to be taken of the study participants before they occupy the new or renovated office. Baseline measurements will be more meaningful if they can be taken well in advance of the move into the office. If possible, it is advisable to select two distinct groups of subjects to participate in the study: (1) a group who will eventually occupy workstations having PEM units, and (2) a control group of equal number who will occupy conventional workstations in the new/renovated office. Analysis and comparison of measurement data from these two groups will provide the best opportunity to extract significant PEM performance results.

ACKNOWLEDGMENTS

This project would not have been possible without the significant contributions from several colleagues, associates, and organizations. We would like to thank Peter Brothers and Steve Drollinger at Johnson Controls, Milwaukee, WI, for providing the opportunity for us to obtain technical assistance to set up the monitoring network. In particular, Linda Endres deserves praise for guiding the development of the Smalltalk code. Don Perkovich, formerly an undergraduate physics student researcher, provided assistance in setting up and installing the network hardware and software. Chuck Rohrer, a consultant with Technisoft, Milwaukee, WI, served as the primary

Heinemeier, K.E., G.S. Brager, C.C. Benton, F.S. Bauman, and E.A. Arens. 1991. "Task/ambient conditioning systems in open-plan offices: assessment of a new technology." Center for Environmental Design Research, University of California, Berkeley, September.

ISO. 1984. *International Standard 7730*, "Moderate thermal environments -- determination of the PMV and PPD indices and specification of the conditions for thermal comfort." Geneva: International Standards Organization.

ISO. 1985. *International Standard 7726*, "Thermal environments --instruments and methods for measuring physical quantities." Geneva: International Standards Organization.

Johnson Controls. 1988. "DR-9100 -- Digital Room Terminal Unit Controller -- Technical Bulletin." Issue Date 08-88.

Johnson Controls. 1990. "DR-910X Configuration Manual." MN-9100-4102, Issue Date 6-90.

Kammerud, R. 1991. "Office 2000 testbed: measurement and analysis plan." Internal PG&E document. December 9.

Kroner, W. J.A. Stark-Martin, and T. Willemain. 1992. "Using advanced office technology to increase productivity: the impact of environmentally responsive workstations (ERWs) on productivity and worker attitude." The Center for Architectural Research, Rensselaer, Troy, NY.

Schiller, G., E. Arens, F. Bauman, C. Benton, M. Fountain, and T. Doherty. 1988. "A Field Study of Thermal Environments and Comfort in Office Buildings." *ASHRAE Transactions*, Vol. 94, Pt. 2.

Seem, J.E., and J.E. Braun. 1992. "The impact of personal environmental control on building energy use." *ASHRAE Transactions*, Vol. 90, Pt. 1.

APPENDIX A

AOST Monitoring Network Configuration

ADVANCED OFFICE SYSTEMS TESTBED MONITORING NETWORK CONFIGURATION
Center For Environmental Design Research, UC Berkeley

DR-9100			Variable		Sensor					Power	
Label	Item Label	Item Addr.	Description	Label	Name	Location	Output	Eng. Units	Range	Input	Source
WS	AI1	J4/2	Air Temperature - Workstation 1	T-WS1	JC RS-9100	39 in.	0-10 V	°C	0-40	15 VDC	DR-9100
WS	AI2	J4/3	Air Temperature - Workstation 2	T-WS2	JC RS-9100	39 in.	0-10 V	°C	0-40	15 VDC	DR-9100
WS	AI3	J9/2	Air Temperature - Workstation 3	T-WS3	JC RS-9100	38 in.	0-10 V	°C	0-40	15 VDC	DR-9100
WS	AI4	J9/3	Air Temperature - Workstation 4	T-WS4	JC RS-9100	40 in.	0-10 V	°C	0-40	15 VDC	DR-9100
WS	DI1	J1/1	Occupancy - Workstation 1	OCC-WS1	Unenco PIR-1000	39 in.		-	0,1	24 VDC	211 power pack
WS	DI2	J1/2	Occupancy - Workstation 2	OCC-WS2	Unenco PIR-1000	39 in.		-	0,1	24 VDC	211 power pack
WS	AI5	J6/3	Occupancy - Workstation 3	OCC-WS3	Unenco PIR-1000	38 in.		-	0,1	24 VDC	211 power pack
WS	DI5	J3/1	Occupancy - Workstation 4	OCC-WS4	Unenco PIR-1000	40 in.		-	0,1	24 VDC	211 power pack
ROOM	AI1	J4/2	Thermostat Temperature	T-TS	JC RS-9100-8108	60 in.	0-10 V	°C	0-40	15 VDC	DR-9100
ROOM	AI2	J4/3	Thermostat Temperature Setpoint	TSP-TS	JC RS-9100-8108	60 in.	0-10 V	°C	0-40	15 VDC	DR-9100
ROOM	AI3	J9/2	Near-Ceiling Air Temperature	T-CEIL	JC RS-9100	101 in.	0-10 V	°C	0-40	15 VDC	DR-9100
ROOM	AI4	J9/3	Average Room Air Temperature	T-RM	JC RS-9100	60 in.	0-10 V	°C	0-40	15 VDC	DR-9100
ROOM	AI5	J6/3	Average Room Relative Humidity	RH-RM	JC HE-6300	60 in.	0-10 V	%	0-100	15 VDC	DR-9100
HVAC	AI1	J4/2	Supply Air Temperature 1 (Room)	SAT-1	JC TS-9100	duct	0-10 V	°C	0-40	15 VDC	DR-9100
HVAC	AI2	J4/3	Supply Air Temperature 2 (PEM)	SAT-2	JC TS-9100	duct	0-10 V	°C	0-40	15 VDC	DR-9100

DR-9100			Variable		Sensor					Power	
Label	Item Label	Item Addr.	Description	Label	Name	Location	Output	Eng. Units	Range	Input	Source
PEM2	AI6	J6/2	Task Light Setpoint - PEM2	LITE-P2	existing in PEM	control panel	0-8 V	%	0-100		DR-9100
PEM2	DI2	J1/2	Occupancy - PEM2	OCC-P2	existing in PEM	control panel		-	0,1		DR-9100
PEM3	AI1	J4/2	Air Temperature - PEM3	T-P3	JC RS-9100	36 in.	0-10 V	°C	0-40	15 VDC	DR-9100
PEM3	AI2	J4/3	Discharge Temp. Setpt. - PEM3	TSP-P3	existing in PEM	control panel		%	0-100		DR-9100
PEM3	AI3	J9/2	Fan Speed Setpoint - PEM3	FAN-P3	existing in PEM	control panel	4.5-7 V	%	0-100		DR-9100
PEM3	AI4	J9/3	Radiant Panel Setpoint - PEM3	RAD-P3	existing in PEM	control panel	0-10 V	%	0-100		DR-9100
PEM3	AI5	J6/3	Discharge Temperature - PEM3	SAT-P3	existing in PEM	flex duct		°C	0-40		DR-9100
PEM3	AI6	J6/2	Task Light Setpoint - PEM3	LITE-P3	existing in PEM	control panel	0-8 V	%	0-100		DR-9100
PEM3	DI2	J1/2	Occupancy - PEM3	OCC-P3	existing in PEM	control panel		-	0,1		DR-9100
PEM4	AI1	J4/2	Air Temperature - PEM4	T-P4	JC RS-9100	33 in.	0-10 V	°C	0-40	15 VDC	DR-9100
PEM4	AI2	J4/3	Discharge Temp. Setpt. - PEM4	TSP-P4	existing in PEM	control panel		%	0-100		DR-9100
PEM4	AI3	J9/2	Fan Speed Setpoint - PEM4	FAN-P4	existing in PEM	control panel	4.5-7 V	%	0-100		DR-9100
PEM4	AI4	J9/3	Radiant Panel Setpoint - PEM4	RAD-P4	existing in PEM	control panel	0-10 V	%	0-100		DR-9100
PEM4	AI5	J6/3	Discharge Temperature - PEM4	SAT-P4	existing in PEM	flex duct		°C	0-40		DR-9100
PEM4	AI6	J6/2	Task Light Setpoint - PEM4	LITE-P4	existing in PEM	control panel	0-8 V	%	0-100		DR-9100
PEM4	DI2	J1/2	Occupancy - PEM4	OCC-P4	existing in PEM	control panel		-	0,1		DR-9100

APPENDIX B

Smalltalk Basic Instructions
and
General Information

BASIC INSTRUCTIONS

instruct.doc

Basic Instructions for the use of the Menus, and the Facility Map and Trend Data displays for the Advances Office Systems Testbed Project.

QUICK AND DIRTY STARTUP AND EXIT

To Enter Smalltalk:

- First you must get to the directory that houses the smalltalk program - to do this, type in:
  CD \STV286 <enter> (<enter> is the enter key)
- To start up the smalltalk program, type in:
  V /D:100 <enter> (note the space between V /)
  This starts the program leaving some of the computer's memory open for use by the basic and assembly code to gather data.

  Note: To use the mouse in smalltalk, "clicking" the right button will bring up menus and "clicking" the left button will "pick" (select) whatever the cursor on the screen is pointing to.

- In the main screen (anywhere in the pink screen except in the window labeled TRANSCRIPT at the top) "click right" to bring up the main menu.
- Move the cursor (the arrow on the screen) to highlight (in yellow) FACILITY MAP in the menu and "click left" to pick it.
- A ghost image of a rectangle will appear with the cursor as the upper left corner - position the corner where you want it and "click left" to fix it in position (the upper left corner of the screen is best.)
- The cursor will now be the lower right corner of the ghost rectangle - position the corner where you want it and "click left" to fix the size of the Facility Map on the screen (the larger the ghost rectangle the better - it makes things easier to read.)
- There will be a delay (the screen will show a blank white window) while the image of the Facility Map is being drawn.

To Display Data on the Facility Map Underlay:

- In the Facility Map window (the blue screen with a floor plan) "click right" to bring up the main Facility Map menu.
- To choose to display any of the choices in the main Facility Map menu - move the cursor to highlight your choice and "click left" to choose it.
- Either a sub-menu will appear with some more choices, or a purple window will appear asking for an entry to be typed in, or data will be displayed on the screen.

  for example:

  Highlight and "click left" on PEM PERAMETERS

POP-UP MENU OVERVIEW

MAIN MENU

Turn Timer On/Off

"Picking" (with the mouse cursor) turns on/off the timer. This timer polls the PEMs for data (using the Turbo Basic code "off2000.exe") at a specified interval. The data is written to the data files in the data directory (see "Select Data to Analyze" below).

Turning ON displays a window asking for a time interval (in seconds) to collect data. "On" will be written in the Transcript window and the PEMs will be polled for data at the specified interval until the timer is turned off.

Turning OFF the timer, turns off the polling and data will no longer be collected. "Off" will be written in the Transcript window. (The Transcript window is the small window in the upper left corner of the screen that is titled SMALLTALK/V TRANSCRIPT.)

Manual AHU Reset

"Picking" displays a series of windows asking for desired set points for the AHUs (Air Handling Units.)

Facility Map

"Picking" allows the placement of a Facility Map underlay on the computer screen.

To place the Map on the screen: Position the upper left corner of the ghost image somewhere on the screen and click to lock it in place - drag the lower right corner of the ghost image until the desired size is obtained and click to lock it in place.

Exit Demo

Exits to the main Smalltalk menu.

FACILITY MAP MAIN MENU

Select Data to Analyze

"Picking" displays a sub menu:

Enter "new" to evaluate data

"New" comes up in the window as the default, so just hitting the <enter> key will load the most recently created (single time period) block of data into the facility map. The data can then be viewed using menu items described below.

Enter date (mm/dd/yy) to evaluate data

Typing in: a date (in the format above but without the parentheses) and the <enter> key, will load the data collected for that day. You will then be prompted for a specific time that data was collected during that day.

Set Point Temp

"Picking" displays the relative position (0 - 100%) of the set point temperature control lever located on the control panel for the PEMs in the four PEM cubicles during the time of the data being displayed.

Discharge Temp

"Picking" displays the air discharge temperature for the PEMs in the four PEM cubicles during the time of the data being displayed.

Fan

"Picking" displays a sub-menu:

Air Flow Set Point

"Picking" displays the relative position (0 - 100%) of the fan speed set point control lever located on the control panel for the PEMs in the four PEM cubicles during the time of the data being displayed.

Radiant Panel

"Picking" displays a sub-menu:

Radiant Panel Set Point

"Picking" displays the relative position (0 - 100%) of the radiant panel set point control lever located on the control panel for the PEMs in the four PEM cubicles during the time of the data being displayed.

Task Lighting

"Picking" displays a sub-menu:

Task Lighting Set Point

"Picking" displays the relative position (0 - 100%) of the task lighting set point control lever located on the control panel for the PEMs in the four PEM cubicles during the time of the data being displayed.

HVAC Parameters

"Picking" displays a sub-menu:

Supply Volumes

Picking" displays the HVAC supply volume to the room ceiling diffusers and to the PEMs during the time of the data being displayed.

Supply Temps

"Picking" displays the HVAC supply temperature to the room ceiling diffusers and to the PEMs during the time of the data being displayed.

Supply RH

"Picking" displays the HVAC supply relative humidity during the time of the data being displayed.

Return Temps

"Picking" displays the HVAC return temperature (plenum temperature) during the time of the data being displayed.

NumWksta - is defined as the number of cubicles that are serviced by the AHUs and will have data collected from AHU#1 attributed to them - in the Advanced Office Systems Testbed control chamber this is 4.

NumAhus - is defined as the number of AHU's that will have data attributed to them - in the Advanced Office Systems Testbed control chamber this is 3.

To change these global variables:

- Use the class hierarchy browser to get into the Representation Applications method (scroll the upper left pane of the window down until this method appears, highlight this option and click twice to display sub-methods)

- Get into the Facility Map method (highlight this option in the upper left pane and click to display its instance methods in the upper right pane of the window)

- Get into the initVariables instance method (scroll the upper right pane down until this method appears, highlight it and click on it to display the code of this method in the bottom pane of the window)

- Type in the new values for the global variables and save the changes (to save: with the cursor in the bottom pane of the window, click right on the mouse to pull up the menu - highlight the option SAVE and click left on it)

- Also be sure to save the image after making changes (click right somewhere in the pink screen to bring up the main menu - highlight and click on EXIT DEMO - then highlight and click on SAVE IMAGE in the nest menu the pops up)

CHANGING CUBICLE ATTRIBUTES:

Each cubicle will have data assigned to it (for example:

```
aCubicle := Cubicle new.
aCubicle addrCUBE: 1.
aCubicle name: 'Gail Brager'
        age: '31'
        gender: 'Female'
        activity: '3.0'
        color: 12
        height: (17/8)
        width:  (17/8)
        xCoord: (23/4)
        yCoord: (3/2).
Cubicles add: aCubicle. )
```

APPENDIX C

Background Survey

UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

COLLEGE OF ENVIRONMENTAL DESIGN
DEPARTMENT OF ARCHITECTURE

BERKELEY, CALIFORNIA 94720

A STUDY OF INDOOR CLIMATE AND COMFORT

Office 2000 Demonstration Project

As part of PG&E's Office 2000 Demonstration project, the Building Science Group in the Dept. of Architecture is investigating how building occupants respond to the thermal environments in your building. The results will serve the larger agenda of PG&E's investigation of buildings' energy efficiency and environmental quality, while also furthering our understanding of your working conditions before and after you move into the Office 2000 Demonstration Office. The project involves collecting physical measurements along with occupants' subjective ratings of the thermal conditions in their workspace.

As a participant, you will initially be asked to fill out a background information form requiring approximately 20 minutes to complete. This form addresses basic demographic data as well as your overall impressions of and satisfaction with a range of attributes of the workplace. It is important that these forms are completed and returned before our field study begins.

The remainder of the survey consists of approximately 5 visits to your workstation by a project member over the course of 2-3 days. At each visit you will be asked to answer a short (2-8 minutes) series of questions addressing your immediate comfort, clothing and activity levels. The questions are administered on a laptop personal computer. We will then ask you to step away from your desk for 5 minutes while an instrumented cart is placed in your normal working position to gather data on the physical environment.

It is important that we have an opportunity to visit you 5 times during the 2-3 day measurement period. However, our objective is to be as unobtrusive as possible. If the researcher approaches you at an inconvenient time, please let him or her know when would be a more convenient time during that day.

Please be assured that your identity will remain anonymous and your responses will be kept confidential. All data will be associated with an ID number only.

The success of this project hinges on the role of volunteers. Volunteers in past projects have found the experience educational as well as enjoyable. We are sincerely grateful for your interest and cooperation.

Office Description

We would like to know your general impressions of your office work area, as influenced by room temperature, humidity, air movement and illumination. Next to each word, please write the number from the scale below which best reflects HOW OFTEN YOUR WORK AREA SEEMS THAT WAY.

5 always
4 often
3 sometimes
2 rarely
1 never

_____ adjustable	_____ air-conditioned	_____ airless
_____ airy	_____ blinding	_____ bright
_____ chilly	_____ close	_____ cold
_____ comfortable	_____ controllable	_____ cool
_____ cozy	_____ damp	_____ dark
_____ dim	_____ drafty	_____ dry
_____ dusty	_____ flickering	_____ fresh
_____ gloomy	_____ heated	_____ hot
_____ humid	_____ illuminated	_____ inadjustable
_____ misty	_____ over-heated	_____ shadowy
_____ shiny	_____ smoky	_____ snug
_____ stale	_____ stifling	_____ stuffy
_____ sunny	_____ uncomfortable	_____ uncontrollable
_____ under-heated	_____ unventilated	_____ ventilated
_____ warm	_____ well-lit	_____ window-less

In terms of comfort, how acceptable is your office work area overall? (check one below)

6 ☐ **very acceptable**
5 ☐ **moderately acceptable**
4 ☐ **slightly acceptable**
3 ☐ **slightly unacceptable**
2 ☐ **moderately unacceptable**
1 ☐ **very unacceptable**

Do you have any additional comments about the comfort of your office work area?

____

____

____

Personal Comfort

Now that you've told us how frequently you experience different attributes of your work area environment, and indicated your level of satisfaction with a number of characteristics, we are interested in your perception of the quality of specific aspects of the thermal and luminous environments. Please complete each of the following statements by checking the box that best expresses your personal feelings or preferences.

1. On average, I perceive my work area to be: (check one)

   6 ☐ very comfortable
   5 ☐ moderately comfortable
   4 ☐ slightly comfortable
   3 ☐ slightly uncomfortable
   2 ☐ moderately uncomfortable
   1 ☐ very uncomfortable

2. On average, I perceive the TEMPERATURE of my work area to be: (disregarding the effects of air movement, lighting and humidity)

   6 ☐ very warm
   5 ☐ moderately warm
   4 ☐ slightly warm
   3 ☐ slightly cool
   2 ☐ moderately cool
   1 ☐ very cool

3. On average, I perceive the AIR MOVEMENT of my work area to be: (disregarding the effects of temperature, lighting and humidity)

   6 ☐ very drafty
   5 ☐ moderately drafty
   4 ☐ slightly drafty
   3 ☐ slightly stuffy
   2 ☐ moderately stuffy
   1 ☐ very stuffy

4. On average, I perceive the LIGHTING of my work area to be: (disregarding the effects of temperature, air movement and humidity)

   6 ☐ very bright
   5 ☐ moderately bright
   4 ☐ slightly bright
   3 ☐ slightly dim
   2 ☐ moderately dim
   1 ☐ very dim

5. On average, I perceive the HUMIDITY of my work area to be: (disregarding the effects of temperature, air movement, and lighting)?

   6 ☐ very humid
   5 ☐ moderately humid
   4 ☐ slightly humid
   3 ☐ slightly dry
   2 ☐ moderately dry
   1 ☐ very dry

››

Please note: All survey responses will remain confidential.
Only statistical summaries of this, and most other questions, will be provided.

››

Job Satisfaction

The questions below ask about different characteristics of your job. Please indicate how SATISFYING YOUR JOB IS with respect to each characteristic by circling the number that reflects how you feel.

6 very satisfied
5 moderately satisfied
4 slightly satisfied
3 slightly dissatisfied
2 moderately dissatisfied
1 very dissatisfied

(circle one number for each item)

How generally satisfied are you with:

1. Your job overall?	1	2	3	4	5	6
2. Your company's policies?	1	2	3	4	5	6
3. The degree of access to other people you work with?	1	2	3	4	5	6
4. The opportunity to develop your skills?	1	2	3	4	5	6
5. Your job security?	1	2	3	4	5	6
6. Your relations with your co-workers?	1	2	3	4	5	6
7. Your relations with your supervisors?	1	2	3	4	5	6
8. Your pay?	1	2	3	4	5	6
9. Your chances for advancement?	1	2	3	4	5	6
10. Your level of responsibility?	1	2	3	4	5	6
11. Your independence or autonomy?	1	2	3	4	5	6
12. The degree of recognition for good work?	1	2	3	4	5	6
13. Your interest in the work itself?	1	2	3	4	5	6
14. The quality of equipment you work with?	1	2	3	4	5	6
15. The time pressures of your job?	1	2	3	4	5	6

Your Characteristic Emotions

A number of words which people have used to describe their characteristic emotions are given below. Please read each word and rate HOW OFTEN YOU FEEL THAT WAY using the scale below. In each case simply write the number in the blank which best reflects how often you feel that way.

5 very often
4 often
3 sometimes
2 rarely
1 never

_____ Frustrated

_____ Uncomfortable

_____ Happy

_____ Energetic

_____ Sad

_____ Fatigued

_____ Comfortable

_____ Burdened

_____ Relaxed

_____ Restless

Summary Comments

Please list any additional comments you have about the comfort of your office work area.

Thank you very much for your help.

APPENDIX D

Online Subjective Survey

ONLINE SUBJECTIVE SURVEY SCREENS

ASHRAE THERMAL COMFORT PROJECT SURVEY

In this survey you will be shown a series of screens which will ask you to rate your level of thermal comfort and satisfaction, and identify your levels of activity and types of clothing.

Each question will require you to respond by:

1) entering a numerical value or
2) pressing the YES or NO key or
3) moving the cursor (   ) to the most appropriate position.

Use the arrow keys at any time to position the cursor to change your response.

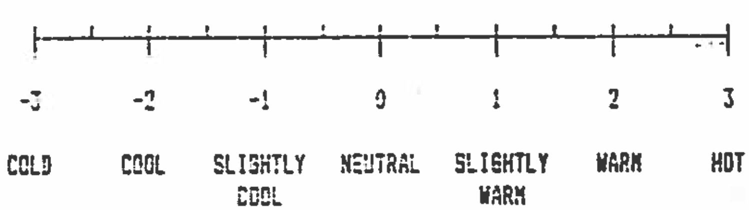
Press the ENTER key to continue to the next screen.

Press ENTER to continue ...

Place the cursor at the location that describes how you feel at this moment.

Enter a number to position the cursor roughly on the scale then use - and - keys to fine tune its position.

Enter a number between -3 and 3 now:



When the cursor is positioned press the ENTER key to proceed to the next question.

3. How comfortable is your office work area RIGHT NOW in terms of air flow (enter one of the following numbers) ?

6 = very drafty
5 = moderately drafty
4 = slightly drafty
3 = slightly stuffy
2 = moderately stuffy
1 = very stuffy

4. How comfortable is your office work area RIGHT NOW in terms of lighting (enter one of the following numbers) ?

6 = very bright
5 = moderately bright
4 = slightly bright
3 = slightly dim
2 = moderately dim
1 = very dim

press ENTER to continue ...

To indicate how you feel RIGHT NOW, enter the appropriate number from the scale below beside each word in the list. You may use the - and - keys to move through the words for corrections.

6 = very appropriate for describing my mood
5 = moderately appropriate for describing my mood
4 = slightly appropriate for describing my mood
3 = slightly inappropriate for describing my mood
2 = moderately inappropriate for describing my mood
1 = very inappropriate for describing my mood

Frustrated	Relaxed
Comfortable	Sad
Happy	Energetic
Fatigued	Burdened
Uncomfortable	Restless

press ENTER to continue to the next screen

Within the last 15 MINUTES ....

Have you been 1. SITTING most of the time,
2. WALKING around most of the time
3. Both SITTING and WALKING around ? (PRESS 1, 2, or 3) ?

Have you eaten a SNACK or MEAL (YES/NO) ?

Have you drunk anything a. Hot (YES/NO) ?
b. Cold (YES/NO) ?
c. Caffeinated (YES/NO) ?

Have you smoked a cigarette (YES/NO) ?

Press ENTER to continue ...

CURRENT CLOTHING CHECKLIST

For each item of clothing which you are wearing RIGHT NOW enter one of the numbers from the scale below to indicate its relative weight. You may skip all items which are correct.

0 Not Wearing the item AT THIS TIME
1 Light weight
2 Medium weight
3 Heavy Weight

UNDERLAYER:
0 top: 1= sleeveless
2= Tshirt
3= long underwear

0 bottom: 1= briefs
3= long underwear

MIDLAYER:
0 short sleeve shirt
0 long sleeve shirt
0 Pants
0 Shorts

OUTERLAYERS:
0 Sweater
0 Vest
0 Jacket

FOOTWEAR:
0 Socks
0 Shoes: 1= sandals
2= shoes or sneakers
3= boots

Press ENTER to continue ...

ARE YOU REALLY DONE WITH THE CLOTHING SCREEN (YES/NO) ?

THANK YOU

for your time in responding to this survey.

Please notify a project worker that you are finished.

OK ?

APPENDIX E

Complete Baseline Data Spreadsheet
16, 17 October 1991

THERMAL COMFORT ASSESSMENT

Baseline Survey DATA - Advanced Office Systems Testbed (AOST) Baseline - 16,17 October 1991

Building Science Group - Center for Environmental Design Research - UC Berkeley

SITE VISIT SPECIFICS | **PHYSICAL DATA**

Bldg. Code	MEA No.	Julian Date	Cart PSHR	Visit Code	Subject	Gender (1M) (2F)	Time	Air TEMP 1.1m degC	Air TEMP 0.6m degC	Air TEMP 0.1m degC	Est. TEMP degC	Globe TEMP 1.1m degC	Globe TEMP 0.6m degC	Globe TEMP 0.1m degC	DEW POINT 0.6m degC	PRT DELTA 1.1m degC	ILLUM Illumn. 1.1m lux	VELOC Ave 1.1m m/s	VELOC Ave 0.6m m/s	VELOC Ave 0.1m m/s	VELOC Brst Ave 1.1m m/s
CO	NO	Date	PSHR	VST	SUB	GEN	TIME	TAH	TAM	TAL	Etmp	TGH	TGM	TGL	TD	PRTD	LUX	VELH	VELM	VELL	UBARH
O	1	289	2	1	3	1	944	22.6	22.4	22.1	23.9	22.7	22.3	22.1	11.2	-0.2	1101	0.14	0.12	0.17	0.16
O	2	289	2	1	7	2	959	21.8	21.6	21.3		21.9	21.6	21.3	11.2	0.1	721	0.08	0.08	0.06	0.08
O	3	289	2	1	1	1	1007	22.7	22.4	22.1	21.1	22.9	22.5	22.3	11.3	0.7	924	0.05	0.09	0.07	0.06
O	4	289	2	1	2	1	1018	22.6	22.7	22.4	20.0	22.6	22.7	22.4	10.9	-0.5	776	0.17	0.16	0.08	0.10
O	5	289	2	1	4	2	1027	23.0	22.7	22.4	22.2	23.2	22.8	22.5	11.3	0.6	780	0.06	0.06	0.06	0.11
O	6	289	2	1	6	1	1043	22.1	21.7	21.4	21.1	22.3	21.9	21.5	8.8	0.3	783	0.08	0.08	0.14	0.04
O	7	289	2	1	5	2	1055	20.3	20.5	20.7		20.9	20.8	20.9	8.6	-0.3	631	0.30	0.23	0.15	0.23
O	8	289	2	2	3	1	1125	22.8	22.6	22.5	23.9	23.0	22.6	22.4	11.2	-0.5	1093	0.16	0.14	0.15	0.16
O	9	289	2	2	1	1	1132	23.1	22.9	22.6	22.2	23.3	23.0	22.7	11.3	0.7	983	0.04	0.06	0.05	0.04
O	10	289	2	2	2	1	1140	22.5	22.6	22.5	20.0	22.6	22.7	22.5	10.7	-0.6	807	0.15	0.14	0.05	0.11
O	11	289	2	2	4	2	1155	22.6	22.7	22.4	21.1	22.9	22.9	22.5	10.6	-0.7	903	0.10	0.09	0.16	0.04
O	12	289	4	2	7	2	1354	22.1	21.9	21.5		22.3	21.8	21.5	10.0	-0.1	588	0.05	0.08	0.05	0.06
O	13	289	4	2	5	2	1410	21.3	21.4	21.5		21.7	21.6	21.7	9.0	-0.9	652	0.21	0.15	0.17	0.24
O	14	289	4	2	6	1	1418	22.3	21.9	21.7	23.9	22.6	22.1	21.8	9.2	-0.2	756	0.05	0.04	0.12	0.05
O	15	289	4	3	2	1	1444	22.4	22.8	22.2	20.0	22.4	23.0	22.2	9.8	-1.0	731	0.15	0.20	0.05	0.11
O	16	289	4	3	1	1	1500	23.0	22.8	22.5	23.3	23.2	22.9	22.6	10.4	-0.2	1047	0.06	0.09	0.04	0.04
O	17	289	4	3	4	2	1538	22.6	22.5	22.3	20.0	22.8	22.5	22.3	10.5	-0.6	825	0.06	0.07	0.08	0.02
O	18	289	4	3	3	1	1555	23.5	23.4	23.0	23.9	23.6	23.4	23.1	10.9	-0.5	1104	0.15	0.13	0.11	0.19
O	19	289	4	3	5	2	1618	22.8	22.8	22.8		23.1	22.9	22.8	10.5	-0.9	670	0.18	0.16	0.15	0.26
O	20	289	4	3	6	1	1626	23.2	23.1	22.9	23.9	23.6	23.2	23.0	10.3	-0.2	775	0.06	0.07	0.09	0.05
O	21	289	4	4	1	1	1637	23.4	23.3	23.1	21.1	23.6	23.4	23.1	10.9	-0.3	1042	0.08	0.11	0.05	0.08
O	22	290	5	3	7	2	935	21.6	21.3	21.0		21.8	21.3	21.1	10.9	-0.1	701	0.07	0.10	0.05	0.07
O	23	290	5	4	3	1	944	21.7	21.5	21.3		22.0	21.6	21.4	11.2	0.1	1077	0.16	0.12	0.07	0.14
O	24	290	5	4	2	1	955	23.2	23.1	22.2		23.2	23.3	22.2	11.8	-0.6	806	0.07	0.07	0.04	0.06

						COMFORT QUESTIONS					**AFFECT QUESTIONS**								
VELOC Brst Ave 0.6m m/s	VELOC Brst Ave 0.1m m/s	VELOC Brst TI 1.1m	VELOC Brst TI 0.6m	VELOC Brst TI 0.1m	MAIN BATTERY VDC	ASH Scale (-3,3) cold hot	McINT Scale (-1,1) cooler warmer	GEN COMF (1,6) uncomf. comf.	VENT COMF (1,6) stuffy drafty	LIGHT COMF (1,6) dim bright	Frustrated	Comfortable	Happy	Fatigued	Uncomfortable	Relaxed	Sad	Energetic	Burdenec
UBARM	UBARL	TIH	TIM	TIL	BAT	ASH	MC	COMF	VENT	LIGHT									
0.10	0.17	0.08	0.49	0.31	11.9	1	1	3	4	4	4	4	3	2	2	4	1	3	5
0.09	0.07	0.26	0.60	1.69	11.9	-0.4	0	6	4	5	1	1	1	1	1	1	1	1	1
0.11	0.08	0.65	0.61	1.53	11.9	-0.5	0	5	4	4	2	5	5	2	2	4	1	5	2
0.14	0.10	0.27	0.37	0.42	11.9	0	0	6	4	4	1	5	5	2	2	4	1	4	1
0.13	0.12	0.22	0.34	0.58	11.9	2	1	5	4	4	1	5	1	6	2	3	6	2	5
0.05	0.09	0.69	1.33	0.53	11.8	-1	0	5	4	3	2	5	4	1	1	4	1	4	2
0.21	0.14	0.34	0.32	0.33	11.8	0	0	6	4	5	1	6	6	1	1	6	1	6	1
0.15	0.12	0.36	0.54	0.47	11.7	0	0	4	4	4	1	5	4	2	2	4	1	3	5
0.04	0.05	1.49	2.38	3.03	11.7	0.5	1	4	3	4	2	4	4	2	3	4	1	4	3
0.11	0.05	0.54	0.53	1.77	11.8	0	0	6	4	4	1	5	5	2	1	4	1	4	2
0.11	0.16	2.77	0.30	0.18	11.8	0	0	6	4	6	1	5	2	5	1	3	5	4	2
0.06	0.04	0.16	0.31	0.59	11.6	-0.5	0	5	4	5	1	1	1	1	1	1	1	1	1
0.21	0.15	0.47	0.13	0.33	11.6	0	0	6	4	5	1	6	6	1	1	6	1	6	1
0.08	0.13	1.01	1.02	0.23	11.6	0	0	5	4	3	2	5	4	2	2	5	2	4	2
0.22	0.05	0.23	0.21	1.00	11.5	0	0	6	4	4	1	5	5	1	1	4	1	4	1
0.05	0.04	0.50	0.18	0.30	11.6	1	1	3	3	4	3	4	4	2	2	4	1	4	2
0.06	0.11	0.86	0.28	0.23	11.5	-1	-1	4	4	4	2	4	3	2	4	5	5	5	2
0.10	0.09	0.40	0.19	0.31	11.4	-1	0	5	4	4	2	5	4	4	2	2	1	3	4
0.24	0.13	0.86	0.49	0.22	11.5	0	0	6	3	5	1	6	6	1	1	6	1	5	1
0.05	0.04	1.12	0.50	0.91	11.4	0	0	5	5	3	2	1	4	3	2	5	2	4	2
0.08	0.05	0.28	0.26	2.91	11.4	0	0	6	3	4	2	5	5	2	2	5	1	4	2
0.12	0.04	0.21	0.10	0.48	12.3														
0.13	0.13	0.12	0.28	0.41	12.3														
0.12	0.04	0.26	0.32	0.17	12.2														

d

Restless	COPING MECHANISMS: Opened/Closed window	Opened/Closed door to outside	Opened/Closed door to inside	Adjusted thermostat	Adjusted Drapes/Blinds	Space heater on/off	Local fan on/off	Adjust clothes	Hot or cold drink	Took a break	Talked to others	Talked to staff	Ignored	ACTIVITY FLAGS: MET (MET(estimated))	FOOD (Eat food)	DHOT (Hot drink)	DCLD (Cold Drink)	DCAF (Caffeine)	CIG (Smoke)
2	9	9	9	9	9	9	9	0	0	2	0	0	2	1.2	0	1	0	1	0
1	9	9	9	9	9	9	9	0	0	0	0	0	0	1	0	1	0	1	0
3	9	9	9	9	9	9	9	0	0	3	0	0	1	1	0	0	0	0	0
2	9	9	9	9	9	9	9	0	0	0	0	0	1	1.2	1	1	0	1	0
2	9	9	9	9	0	9	9	0	0	2	0	0	2	1.2	0	0	0	0	0
1	0	0	0	0	9	9	9	0	1	0	0	0	1	1	1	1	0	1	0
1	9	9	0	9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
5	9	9	9	9	9	9	9	0	0	2	0	0	2	1.4	0	0	0	1	0
2	9	9	9	9	9	9	9	0	2	1	0	0	1	1	0	0	0	0	0
2	9	9	9	9	9	9	9	0	0	0	0	0	0	1	0	0	0	0	0
4	9	9	9	9	0	9	9	0	3	3	0	0	0	1.2	1	1	0	1	0
1	9	9	9	9	9	9	9	0	0	0	0	0	1	1.2	0	0	0	0	0
1	9	9	0	9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
1	0	0	0	0	9	9	9	0	0	0	0	0	0	1	0	0	0	0	0
2	9	9	9	9	9	9	9	0	0	0	0	0	0	1	0	0	0	0	0
3	9	9	9	9	9	9	9	2	1	2	0	0	2	1	0	0	0	0	0
2	9	9	9	9	0	9	9	0	0	2	0	0	2	1.2	1	0	0	0	0
4	9	9	9	9	9	9	9	0	0	2	0	0	0	1	1	0	0	1	0
1	9	9	0	9	0	0	0	0	1	1	0	0	0	1.2	0	0	1	0	0
1	0	0	0	0	9	9	9	0	0	0	0	0	0	1	0	0	0	0	0
2	9	9	9	9	9	9	9	2	0	0	0	0	1	1	0	0	0	0	0

CLOTHING

QUESTIONS(header for women's clothing only)

SURVEY COMPLETION TIMES(seconds)

Underlayer			Footware			Midlayer						Outerlayers							
top	bottom	slip	socks	pantyhose	shoes	ss shirt	ls shirt	dress	skirt	pants	shorts	sweater	vest	jacket		Comfort	Affect	Activity	Clothing
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CLO				
CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9	CL10	CL11	CL12	CL13	CL14	CL15					
0	1	0	2	2	0	0	0	0	1	2	0	0	0	0	0.55	32	73	22	97
1	1	1	0	1	1	0	0	2	0	0	0	0	0	0	0.55	76	85	50	136
0	1	0	1	1	0	0	0	0	1	2	0	0	0	0	0.5	31	67	35	81
0	1	0	2	2	0	0	0	0	2	2	0	0	0	0	0.57	19	36	25	98
1	1	2	1	1	2	0	0	3	0	0	0	0	0	0	0.84	53	88	24	91
2	1	0	1	2	0	0	0	0	0	2	0	0	0	0	0.57	67	124	30	168
0	1	0	1	0	2	1	0	0	0	2	0	1	0	0	0.57	75	62	15	166
0	1	0	2	2	0	0	0	0	1	2	0	0	0	0	0.55	19	45	76	14
0	1	0	1	1	0	0	0	0	1	2	0	0	0	0	0.5	22	39	22	35
0	1	0	2	2	0	0	0	0	2	2	0	0	0	0	0.57	12	39	11	6
1	1	2	3	1	2	0	0	3	0	0	0	0	0	0	0.92	27	65	20	56
1	1	1	0	1	1	0	0	2	0	0	0	0	0	0	0.55	34	22	22	17
0	1	0	1	0	2	1	0	0	0	2	0	1	0	0	0.57	26	36	15	27
2	1	0	1	2	0	0	0	0	0	2	0	0	0	0	0.57	28	51	27	69
0	1	0	2	2	0	0	0	0	2	2	0	0	0	0	0.57	13	31	10	21
0	1	0	1	1	0	0	0	0	1	2	0	0	0	0	0.5	37	110	20	20
1	1	2	3	1	2	0	0	3	0	0	0	0	0	0	0.92	25	95	54	57
0	1	0	2	2	0	0	0	0	1	2	0	0	0	0	0.55	64	66	23	156
0	1	0	1	0	2	1	0	0	0	2	0	1	0	0	0.57	27	34	21	9
2	1	0	1	2	0	0	0	0	0	2	0	0	0	0	0.57	15	38	17	82
0	1	0	1	1	0	0	0	0	1	2	0	0	0	0	0.5	53	27	10	15

COMFORT MODEL

INPUT AND OUTPUT VARIABLES

TOTAL	TAAV	TRAV	PAAV	VELAV	TCR	TSK	PWET	ET*	SET*	DISC	TSENS	PMV	PMV*	HSI
224	22.37	22.36	9.96	0.14	36.83	33.29	6.00	22.35	22.11	-0.04	-0.04	-0.27	-0.28	8.46
347	21.57	21.63	9.96	0.10	36.81	32.21	6.00	21.61	20.86	0.00	-0.21	-0.29	-0.29	2.97
214	22.40	22.73	10.03	0.10	36.82	32.50	6.00	22.57	21.48	0.00	-0.16	-0.21	-0.22	4.74
178	22.57	22.56	9.77	0.11	36.83	33.50	6.25	22.54	22.46	-0.02	-0.02	-0.24	-0.25	8.88
256	22.70	22.98	10.03	0.12	36.84	33.95	13.60	22.80	24.90	0.32	0.24	0.27	0.36	19.48
389	21.73	22.07	8.48	0.10	36.80	30.67	6.00	21.84	17.58	0.00	-0.59	-0.80	-0.92	-3.60
318	20.50	21.41	8.37	0.19	36.81	31.65	6.00	20.93	19.69	0.00	-0.33	-0.48	-0.53	0.50
154	22.63	22.71	9.96	0.14	36.85	33.57	10.15	22.63	22.88	-0.01	-0.01	-0.12	-0.15	14.70
118	22.87	23.13	10.03	0.10	36.82	32.73	6.00	22.99	21.92	0.00	-0.13	-0.15	-0.17	5.77
68	22.53	22.67	9.64	0.10	36.82	32.78	6.00	22.57	22.01	0.00	-0.12	-0.15	-0.15	5.86
168	22.57	22.96	9.57	0.10	36.84	34.03	15.11	22.67	25.38	0.43	0.33	0.36	0.48	21.33
95	21.83	21.90	9.20	0.10	36.83	32.93	6.00	21.83	21.58	-0.07	-0.07	-0.31	-0.33	7.47
104	21.40	22.07	8.60	0.20	36.81	31.96	6.00	21.68	20.39	0.00	-0.26	-0.37	-0.43	2.62
175	21.97	22.36	8.71	0.10	36.81	30.80	6.00	22.11	17.91	0.00	-0.55	-0.74	-0.86	-2.69
75	22.47	22.61	9.07	0.13	36.82	32.73	6.00	22.48	21.92	0.00	-0.13	-0.16	-0.17	5.78
187	22.77	23.03	9.45	0.10	36.82	32.65	6.00	22.86	21.78	0.00	-0.14	-0.17	-0.20	5.48
231	22.47	22.60	9.51	0.10	36.84	33.99	14.46	22.44	25.17	0.38	0.29	0.32	0.43	20.42
309	23.30	23.44	9.77	0.13	36.82	33.13	6.00	23.33	22.63	0.00	-0.07	-0.07	-0.08	7.37
91	22.80	23.14	9.51	0.21	36.83	33.58	7.25	22.91	22.84	-0.01	-0.01	-0.15	-0.18	10.84
152	23.07	23.46	9.38	0.10	36.82	33.15	6.00	23.23	22.68	0.00	-0.07	-0.07	-0.08	7.26
105	23.27	23.46	9.77	0.10	36.82	32.91	6.00	23.32	22.26	0.00	-0.10	-0.11	-0.14	6.53
	21.30	21.50	9.77	0.10	36.83	31.95	6.00	21.41	19.99	-0.19	-0.19	-0.45	-0.49	4.89
	21.50	21.86	9.96	0.13	36.82	31.95	6.00	21.71	20.13	-0.22	-0.22	-0.40	-0.43	3.76
	22.83	22.97	10.37	0.10	36.83	33.25	6.00	22.90	22.06	-0.04	-0.04	-0.27	-0.30	8.19

APPENDIX F

Complete Test 1 Data Spreadsheet
30 April - 1 May 1992

THERMAL COMFORT ASSESSMENT

Survey DATA - Advanced Office Systems Testbed (AOST) Test #1 - 30 April, 1 May 1992

Building Science Group - Center for Environmental Design Research - UC Berkeley

SITE VISIT SPECIFICS								PHYSICAL DATA														
Bldg. Code	MEA No.	Julian Date	Cart PSHR	Visit Code	Subject	Gender (1M) (2F)	Time	Air TEMP 1.1m degC	Air TEMP 0.6m degC	Air TEMP 0.1m degC	Est. TEMP degC	Globe TEMP 1.1m degC	Globe TEMP 0.6m degC	Globe TEMP 0.1m degC	DEW POINT 0.6m degC	PRT DELTA 1.1m degC	ILLUM illumn. 1.1m lux	VELOC Ave 1.1m m/s	VELOC Ave 0.6m m/s	VELOC Ave 0.1m m/s	VELOC Brst Ave 1.1m m/s
CO	NO	Date	PSHR	VST	SUB	GEN	TIME	TAH	TAM	TAL	Etmp	TGH	TGM	TGL	TD	PRTD	LUX	VELH	VELM	VELL	UBARH
O	1	121	4	1	6	1	852	22.8	22.6	22.4	20.0	23.0	22.6	22.5	10.4	-0.2	1293	0.08	0.09	0.10	0.07
O	2	121	4	1	3	1	901	22.8	22.7	22.5	22.2	22.9	22.6	22.5	10.5	0.0	516	0.10	0.07	0.09	0.05
O	3	121	4	1	4	2	912	22.8	22.6	22.5	25.6	23.0	22.7	22.6	10.5	0.2	1248	0.13	0.10	0.07	0.08
O	4	121	4	1	8	1	919	22.5	22.5	22.3	20.6	22.7	22.6	22.3	10.6	-0.7	400	0.12	0.09	0.08	0.13
O	5	121	4	1	1	1	934	22.7	22.3	22.4	21.1	22.8	22.5	22.4	10.6	-0.3	644	0.16	0.08	0.07	0.07
O	6	121	4	1	7	2	1003	23.4	23.2	22.8		23.5	23.2	22.9	10.6	-0.1	1275	0.07	0.06	0.05	0.10
O	7	121	4	1	9	2	1013	23.1	23.0	22.9	15.6	23.2	23.0	22.9	10.5	-0.2	1271	0.14	0.06	0.07	0.14
O	8	121	4	2	3	1	1117	23.1	23.1	23.0	23.9	23.5	23.2	23.0	10.1	-0.7	530	0.12	0.30	0.10	0.17
O	9	121	4	2	4	2	1131	23.1	23.0	22.8	21.7	23.3	23.0	22.9	10.2	-0.2	1275	0.13	0.12	0.10	0.13
O	10	121	4	2	7	2	1149	23.3	23.2	23.0		23.6	23.4	23.1	10.3	-0.3	1271	0.09	0.12	0.06	0.11
O	11	121	4	2	6	1	1156	23.4	23.2	22.9	20.0	23.6	23.4	23.0	10.3	-0.3	1269	0.09	0.11	0.09	0.07
O	12	121	4	2	8	1	1204	22.9	22.9	22.7	20.0	23.1	23.0	22.7	10.4	-0.8	392	0.10	0.13	0.07	0.20
O	13	121	4	2	9	2	1345	23.3	23.3	23.0	21.1	23.5	23.4	23.1	10.2	-0.4	1293	0.10	0.07	0.05	0.10
O	14	121	4	1	2	1	1352	22.9	23.6	23.0	20.0	23.2	23.6	22.9	10.3	-0.5	506	0.28	0.08	0.07	0.32
O	15	121	4	3	8	1	1404	22.6	22.7	22.5	22.2	22.8	22.8	22.4	10.3	-0.3	393	0.11	0.07	0.08	0.12
O	16	121	4	2	1	1	1412	23.1	22.7	22.6	22.2	23.2	22.6	22.6	10.3	-0.4	680	0.25	0.32	0.11	0.23
O	17	121	4	3	4	2	1419	23.2	23.0	22.8	24.4	23.3	23.1	22.8	10.2	-0.5	1242	0.14	0.08	0.06	0.13
O	18	121	4	3	6	1	1426	23.3	23.1	22.9	21.1	23.5	23.3	23.0	10.3	-0.6	1279	0.08	0.11	0.09	0.08
O	19	121	4	2	2	1	1454	23.1	23.5	22.9	20.0	23.2	23.5	22.9	10.1	-0.7	475	0.32	0.08	0.10	0.28
O	20	121	4	3	9	2	1503	23.4	23.4	23.0	18.3	23.5	23.4	23.1	10.1	-0.5	1316	0.11	0.08	0.06	0.05
O	21	121	4	3	7	2	1522	23.4	23.4	23.0		23.7	23.5	23.1	10.2	-0.5	1250	0.06	0.12	0.05	0.08
O	22	121	4	3	3	1	1534	23.4	23.3	23.1	23.3	23.6	23.2	23.2	10.2	-0.6	585	0.11	0.16	0.08	0.20
O	23	121	4	3	1	1	1548	23.2	22.9	22.8	21.1	23.2	22.8	22.7	10.1	-0.5	680	0.29	0.19	0.06	0.23
O	24	122	3	4	6	1	955	23.1	22.7	22.2	25.6	23.2	22.8	22.3	9.9	0.3	1312	0.08	0.06	0.05	0.06

VELOC Brst Ave 0.6m m/s	VELOC Brst Ave 0.1m m/s	VELOC Brst TI 1.1m	VELOC Brst TI 0.6m	VELOC Brst TI 0.1m	MAIN BATTERY VDC	COMFORT QUESTIONS: ASH Scale (-3,3) cold / hot	McINT Scale (-1,1) cooler / warmer	GEN COMF (1,6) uncomf. / comf.	VENT COMF (1,6) stuffy / drafty	LIGHT COMF (1,6) dim / bright	AFFECT QUESTIONS: Frustrated	Comfortable	Happy	Fatigued	Uncomfortable	Relaxed	Sad	Energetic	Burdened
UBARM	UBARL	TIH	TIM	TIL	BAT	ASH	MC	COMF	VENT	LIGHT									
0.12	0.12	0.29	0.14	0.12	12.3	0	0	5	4	4	2	5	4	1	2	5	2	4	2
0.05	0.06	1.62	1.96	1.58	12.2	-1	0	5	4	4	2	6	4	2	2	4	1	3	4
0.09	0.05	0.22	0.26	1.40	12.2	1	1	3	3	3	4	4	2	5	4	3	5	3	4
0.08	0.07	0.50	0.45	0.19	12.1	-0.3	0	6	4	2	4	3	3	3	3	3	1	5	5
0.12	0.09	0.69	0.41	0.50	12.1	0.5	0	5	4	4	4	5	3	4	2	5	1	4	4
0.09	0.06	0.23	0.17	1.02	12.2	0	0	5	3	5	5	5	5	1	1	5	1	6	3
0.04	0.06	0.40	0.93	0.66	12.1	-0.1	-1	4	2	5	2	4	5	5	5	5	1	5	1
0.29	0.06	0.24	0.67	0.37	12.0	1	0	4	4	4	4	4	4	4	2	3	2	2	2
0.10	0.11	0.11	0.14	0.31	12.1	-0.8	0	5	4	4	3	5	4	2	2	5	4	5	4
0.09	0.07	0.14	0.24	0.91	12.0	0	0	6	4	5	1	6	4	1	1	6	1	5	1
0.15	0.11	0.76	0.29	0.13	11.9	3	0	5	4	4	2	5	4	2	2	5	1	4	2
0.11	0.07	0.26	0.16	1.49	11.9	-0.4	0	6	4	3	3	5	5	2	1	5	1	5	4
0.05	0.05	0.33	1.27	1.43	11.8	2.5	1	2	2	6	1	4	5	5	3	4	1	4	2
0.05	0.08	0.96	1.54	0.63	11.8	0	0	6	4	5	1	6	5	2	1	5	1	4	2
0.08	0.06	0.16	0.38	0.16	11.8	0.1	0	6	3	2	1	5	6	2	1	4	1	6	5
0.24	0.07	0.58	0.24	0.32	11.8	1	1	3	5	4	4	4	3	4	3	4	2	5	4
0.10	0.04	0.13	0.32	1.84	11.8	0.3	1	5	3	5	3	5	3	4	3	4	4	4	5
0.06	0.14	0.33	1.12	0.11	11.7	3	0	5	4	4	1	5	4	2	1	4	1	4	2
0.10	0.08	0.75	0.23	1.22	11.7	0	0	6	4	5	1	6	5	2	2	5	1	5	2
0.07	0.05	0.63	0.64	0.83	11.7	0	0	6	2	4	1	6	6	5	5	5	1	6	1
0.10	0.04	0.22	0.20	0.81	11.7	0	0	5	4	5	1	5	5	1	2	3	1	5	1
0.14	0.06	0.19	0.31	0.26	11.6	-1	0	5	4	4	2	5	5	2	2	4	2	4	4
0.20	0.06	0.82	0.83	0.41	11.6	0	0	6	4	5	3	5	4	3	3	4	1	4	3
0.07	0.03	0.37	0.16	0.18	12.4	3	0	5	4	4	2	5	3	2	1	5	1	4	2

d

Restless	COPING MECHANISMS: Opened/Closed window	Opened/Closed door to outside	Opened/Closed door to inside	Adjusted thermostat	Adjusted Drapes/Blinds	Space heater on/off	Local fan on/off	Adjust clothes	Hot or cold drink	Took a break	Talked to others	Talked to staff	Ignored	ACTIVITY FLAGS: MET(estimated) MET	Eat food FOOD	Hot drink DHOT	Cold Drink DCLD	Caffeine DCAF	Smoke CIG
2	9	9	9	9	9	9	9	0	0	0	0	0	0	1	1	1	0	0	0
4	9	9	9	0	9	0	0	0	0	0	0	0	2	1.2	0	1	0	1	0
5	9	9	9	9	9	9	9	0	1	1	0	0	2	1.2	0	1	0	1	0
5	9	9	9	0	9	0	0	0	0	0	0	0	1	1.2	0	0	0	0	0
2	9	9	9	0	9	0	0	0	0	0	0	0	1	1	0	0	0	0	0
1	9	9	9	9	9	9	9	0	0	0	0	0	1	1.4	0	0	0	0	0
3	9	9	9	9	9	9	9	0	1	2	0	0	2	1.2	0	0	1	0	0
3	9	9	9	0	9	0	3	0	0	0	1	0	0	1.2	0	1	0	1	0
4	9	9	9	9	9	9	9	0	0	0	0	0	0	1.2	0	0	1	1	0
1	9	9	9	9	9	9	9	0	0	0	0	0	1	1	0	0	0	0	0
2	9	9	9	9	9	9	9	0	0	0	0	0	0	1	0	0	0	0	0
3	9	9	9	0	9	0	0	0	0	0	0	0	1	1.2	0	0	0	0	0
2	9	9	9	9	9	9	9	2	2	4	0	0	2	1.4	0	1	1	0	0
2	9	9	9	0	9	0	0	0	0	0	0	0	0	1.4	0	0	1	0	0
4	9	9	9	0	9	0	0	0	0	0	0	0	1	1.2	1	0	1	0	0
2	9	9	9	0	9	0	4	0	2	0	0	0	0	1	0	0	1	0	0
4	9	9	9	9	9	9	9	0	0	0	0	0	0	1	0	0	0	0	0
2	9	9	9	9	9	9	9	0	0	0	0	0	0	1	0	0	0	0	0
2	9	9	9	0	9	0	0	0	0	0	0	0	0	1	0	1	0	1	0
1	9	9	9	9	9	9	9	0	2	3	0	0	4	1.2	1	0	1	0	0
2	9	9	9	9	9	9	9	0	0	0	0	0	4	1.2	0	0	0	0	0
4	9	9	9	0	9	0	0	0	0	2	0	0	0	1	0	0	0	0	0
3	9	9	9	0	9	0	0	0	2	1	0	0	1	1	0	0	1	0	0
1	9	9	9	9	9	9	9	0	0	0	0	0	0	1	1	1	0	1	0

CLOTHING

QUESTIONS(header for women's clothing only)

SURVEY COMPLETION TIMES(seconds)

Underlayer			Footware			Midlayer						Outerlayers							
top	bottom	slip	socks	pantyhose	shoes	ss shirt	ls shirt	dress	skirt	pants	shorts	sweater	vest	jacket		Comfort	Affect	Activity	Clothing
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CLO				
CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9	CL10	CL11	CL12	CL13	CL14	CL15					
2	1	0	1	0	0	0	0	0	1	2	0	0	0	0	0.36	49	72	117	150
2	1	0	0	2	0	0	0	0	2	2	0	0	0	0	0.43	30	41	23	130
1	1	2	0	1	2	0	0	2	0	0	0	0	0	0	0.62	45	71	23	89
0	1	0	1	1	0	0	0	0	1	2	0	0	0	0	0.5	36	78	15	81
0	1	0	1	1	0	0	0	0	1	2	0	0	0	0	0.5	29	66	14	80
1	1	1	0	1	1	0	0	1	0	0	0	0	0	1	0.49	63	77	28	42
1	1	1	0	1	1	0	0	0	2	0	0	2	0	0	0.52	57	63	22	100
2	1	0	0	2	0	0	0	0	2	2	0	0	0	0	0.43	21	21	14	6
1	1	2	0	1	2	0	0	2	0	0	0	0	0	0	0.62	31	71	30	17
1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0.35	26	43	15	21
2	1	1	1	0	0	0	0	0	1	2	0	0	0	0	0.48	18	34	29	39
0	1	0	1	1	0	0	0	0	1	2	0	0	0	0	0.5	39	105	13	54
1	1	1	0	1	2	0	0	0	2	0	0	2	0	0	0.54	27	52	30	71
0	1	0	2	2	0	0	0	0	2	2	0	0	0	0	0.57	19	36	24	82
0	1	0	1	1	0	0	0	0	1	2	0	0	0	0	0.5	53	85	19	18
0	1	1	0	1	0	0	0	0	1	2	0	0	0	0	0.43	23	41	18	30
1	1	2	0	1	2	0	0	2	0	0	0	0	0	0	0.62	29	51	22	9
2	1	0	1	0	0	0	0	0	1	2	0	0	0	0	0.36	19	34	14	57
0	1	0	2	2	0	0	0	0	2	2	0	0	0	0	0.57	14	25	19	15
1	1	1	0	1	2	0	0	0	2	0	0	2	0	0	0.54	31	45	22	18
1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0.35	22	36	17	9
2	1	0	0	2	0	0	0	0	2	2	0	0	0	0	0.43	25	26	17	6
0	1	1	0	1	0	0	0	0	1	2	0	0	0	0	0.43	13	35	15	30
2	1	0	1	0	0	0	0	0	1	2	0	0	0	0	0.36	124	37	30	103

COMFORT MODEL

INPUT AND OUTPUT VARIABLES

TOTAL	TAAV	TRAV	PAAV	VELAV	TCR	TSK	PWET	ET*	SET*	DISC	TSENS	PMV	PMV*	HSI
388	22.60	22.80	9.45	0.10	36.81	31.95	6.00	22.66	20.45	0.00	-0.26	-0.35	-0.40	2.72
224	22.67	22.66	9.51	0.10	36.83	32.75	6.00	22.61	21.33	-0.09	-0.09	-0.33	-0.38	7.23
228	22.63	22.90	9.51	0.10	36.83	33.62	7.88	22.71	23.05	-0.01	-0.01	-0.11	-0.12	11.11
210	22.43	22.64	9.57	0.10	36.83	33.08	6.00	22.50	21.83	-0.06	-0.06	-0.29	-0.32	7.86
189	22.47	22.66	9.57	0.10	36.82	32.47	6.00	22.54	21.44	0.00	-0.17	-0.22	-0.24	4.68
210	23.13	23.27	9.57	0.10	36.85	33.55	9.70	23.09	22.76	-0.01	-0.01	-0.13	-0.21	13.68
242	23.00	23.07	9.51	0.10	36.83	33.50	6.25	22.97	22.48	-0.02	-0.02	-0.24	-0.27	8.81
62	23.07	23.46	9.26	0.17	36.83	33.13	6.00	23.19	21.93	-0.05	-0.05	-0.28	-0.35	8.36
149	22.97	23.17	9.32	0.11	36.83	33.68	8.59	22.97	23.31	0.00	0.00	-0.05	-0.07	12.21
105	23.17	23.56	9.38	0.10	36.82	32.26	6.00	23.32	21.09	0.00	-0.20	-0.26	-0.32	4.33
120	23.17	23.50	9.38	0.11	36.82	32.80	6.00	23.29	22.08	0.00	-0.12	-0.14	-0.17	6.21
211	22.83	23.05	9.45	0.13	36.83	33.35	6.00	22.89	22.22	-0.03	-0.03	-0.26	-0.30	8.52
180	23.20	23.47	9.32	0.10	36.85	33.69	11.13	23.18	23.31	0.00	0.00	-0.03	-0.10	15.69
161	23.17	23.31	9.38	0.15	36.85	33.73	11.71	23.09	23.51	0.01	0.02	0.01	-0.04	17.06
175	22.60	22.73	9.38	0.10	36.83	33.16	6.00	22.61	21.94	-0.05	-0.05	-0.28	-0.32	8.01
112	22.80	22.80	9.38	0.18	36.81	32.01	6.00	22.73	20.56	0.00	-0.25	-0.33	-0.41	3.45
111	23.00	23.13	9.32	0.10	36.82	33.23	6.00	23.01	22.81	0.00	-0.06	-0.05	-0.06	7.50
124	23.10	23.43	9.38	0.10	36.82	32.25	6.00	23.21	21.06	0.00	-0.21	-0.26	-0.33	4.23
73	23.17	23.24	9.26	0.15	36.82	33.00	6.00	23.13	22.42	0.00	-0.09	-0.10	-0.13	7.04
116	23.27	23.40	9.26	0.10	36.83	33.60	7.41	23.23	22.91	-0.01	-0.01	-0.14	-0.18	10.45
84	23.27	23.60	9.32	0.10	36.83	32.76	6.00	23.36	21.39	-0.09	-0.09	-0.32	-0.41	7.41
74	23.27	23.41	9.32	0.13	36.82	32.58	6.00	23.27	21.68	0.00	-0.15	-0.18	-0.23	5.53
93	22.97	22.81	9.26	0.16	36.81	32.17	6.00	22.80	20.87	0.00	-0.22	-0.29	-0.36	3.99
294	22.67	22.86	9.14	0.10	36.81	31.97	6.00	22.70	20.50	0.00	-0.26	-0.34	-0.40	2.89

APPENDIX G

Complete Test 2 Data Spreadsheet
16, 17 September 1992

THERMAL COMFORT ASSESSMENT

Survey Data - Advanced Office Systems Tested (AOST) Test #2 - 16,17 Sept., 1992

Building Science Group - Center for Environmental Design Research - UC Berkeley

SITE VISIT SPECIFICS | **PHYSICAL DATA**

BLDG. CODE	MEA. NO.	JULIAN DATE	CART PSHR	VISIT CODE	SUBJ	GEND (1M) (2F)	TIME	AIR TEMP 1.1m degC	AIR TEMP 0.6m degC	AIR TEMP 0.1m degC	EST. TEMP degC	GLOB TEMP 1.1m degC	GLOB TEMP 0.6m degC	GLOB TEMP 0.1m degC	DEW POINT 0.6m degC	PRT DELTA 1.1m degC	ILLUM illumn. 1.1m lux	VELOC AVE. 1.1m m/s	VELOC AVE. 0.6m m/s	VELOC AVE. 0.1m m/s	VELOC Brst Ave 1.1m m/s	VELOC Brst Ave 0.6m m/s	VELOC Brst Ave 0.1m m/s
CO	NO	DATE	PSHR	VST	SUB	GEN	TIME	TAH	TAM	TAL	EImp	TGH	TGM	TGL	TD	PRTD	LUX	VELH	VELM	VELL	UBARH	UBARM	UBARL
T	1	260	3	1	9	2	923	22.72	22.46	22.41	25.60	22.74	22.37	22.30	10.85	0.03	1345	0.14	0.10	0.13	0.15	0.15	0.09
T	2	260	3	1	6	1	934	22.42	22.26	22.09	20.00	22.61	22.30	22.17	11.27	-0.09	1388	0.07	0.07	0.07	0.09	0.10	0.06
T	3	260	3	1	1	1	941	22.30	22.24	21.96	20.60	22.41	22.23	21.98	11.34	-0.38	883	0.09	0.07	0.07	0.10	0.05	0.11
T	4	260	3	1	3	1	1007	22.67	22.62	22.18	23.90	22.92	22.90	22.32	11.56	-0.59	1216	0.09	0.12	0.06	0.16	0.13	0.06
T	5	260	3	1	2	1	1016	23.14	22.98	22.53	18.30	23.20	23.15	22.53	11.66	-0.60	975	0.19	0.08	0.07	0.22	0.10	0.09
T	6	260	3	1	4	2	1027	22.91	22.69	22.51	17.80	23.03	22.79	22.58	11.54	-0.08	1406	0.12	0.09	0.09	0.07	0.09	0.08
T	7	260	3	1	10	1	1123	22.94	22.87	22.50	20.60	23.03	22.92	22.51	11.57	-0.15	627	0.09	0.07	0.06	0.11	0.04	0.05
T	8	260	9	2	6	1	1135	23.04	22.93	22.61	20.00	23.23	23.04	22.70	11.33	-0.29	1255	0.08	0.11	0.06	0.13	0.09	0.06
T	9	260	9	1	7	2	1206	23.19	23.02	22.68		23.39	23.18	22.84	11.23	-0.07	1316	0.07	0.07	0.07	0.06	0.05	0.05
T	10	260	4	2	2	1	1341	22.89	23.86	23.37	21.10	23.26	23.94	23.31	11.49	-0.67	922	0.83	0.08	0.06	0.80	0.06	0.07
T	11	260	4	2	4	2	1401	23.55	23.38	23.18	18.90	23.68	23.54	23.26	10.84	-0.25	1358	0.07	0.10	0.07	0.11	0.10	0.07
T	12	260	4	2	7	2	1413	23.57	23.39	23.10		23.75	23.62	23.20	10.59	-0.62	1348	0.08	0.08	0.07	0.09	0.08	0.07
T	13	260	4	2	1	1	1432	23.03	23.13	22.65	21.70	23.10	23.24	22.75	10.71	-0.55	855	0.14	0.06	0.08	0.14	0.08	0.08
T	14	260	4	3	6	1	1508	23.26	23.22	22.91	20.00	23.46	23.39	23.01	10.64	-0.38	1283	0.09	0.09	0.06	0.08	0.10	0.06
T	15	260	4	2	10	1	1550	22.89	22.83	22.60	20.60	23.05	23.01	22.61	10.55	-0.25	548	0.13	0.06	0.10	0.14	0.10	0.10
T	16	260	4	2	3	1	1558	23.45	23.21	22.85	25.60	23.60	23.43	22.96	10.63	-0.73	1442	0.12	0.12	0.06	0.12	0.11	0.08
T	17	260	4	3	10	1	1637	22.69	22.69	22.56	20.60	22.89	22.88	22.59	10.52	-0.23	604	0.11	0.08	0.07	0.09	0.13	0.06
T	18	261	4	4	10	1	927	22.50	22.34	22.54	20.60	22.78	22.52	22.71	10.72	-0.45	659	0.20	0.11	0.07	0.19	0.16	0.10
T	19	261	4	3	4	2	936	22.69	22.58	22.46	20.00	22.90	22.66	22.54	10.76	-0.09	1263	0.10	0.09	0.05	0.10	0.07	0.07
T	20	261	4	3	9	2	946	22.81	22.73	22.66	22.20	22.86	22.73	22.57	10.96	0.03	1380	0.19	0.12	0.16	0.21	0.11	0.21

VELOC Brst Tl 1.1m TIH	VELOC Brst Tl 0.6m TIM	VELOC Brst Tl 0.1m TIL	MAIN BATTERY VDC BAT	COMFORT QUESTIONS ASH Scale (-3,3) cold hot ASH	McINI Scale (-1,1) coole warm MC	GEN COMI (1,6) uncor comf. COMI	VENT COMI (1,6) stuffy drafty VENT	LIGHT COMF (1,6) dim bright LIGHT	AFFECT QUESTIONS Frustrated	Comfortable	Happy	Fatigued	Uncomfortable	Relaxed	Sad	Energetic	Burdened	Restless	COPING MECHANISMS Opened/Closed window	Opened/Closed door to outside	Opened/Closed door to in	Adjusted thermostat	Adjusted Drap	Space
0.20	0.20	0.26	12.29	1	1	4	3	6	2	5	5	3	4	5	1	5	4	4	9	9	9	9	9	9
0.19	0.11	0.29	12.28	0	0	5	4	5	2	5	4	1	1	5	1	3	2	2	9	9	9	9	9	9
0.33	0.37	0.17	12.27	-1	-1	5	4	4	4	4	4	2	2	4	1	4	2	3	9	9	9	0	9	0
0.23	0.13	0.36	12.32	0	0	5	4	4	4	4	4	5	2	4	1	1	5	4	9	9	9	0	9	0
0.15	0.21	0.19	12.23	-0.3	0	5	4	4	1	5	5	2	1	5	1	5	1	2	9	9	9	0	9	0
0.32	0.28	0.23	12.22	-2.5	-1	2	5	4	5	1	3	2	5	1	4	5	4	6	9	9	9	9	9	9
0.12	0.57	0.10	12.17	0	-1	5	4	4	1	4	4	2	3	5	1	4	2	2	9	9	9	0	9	0
0.12	0.21	0.37	12.15	0	0	5	4	5	1	5	3	2	1	5	1	4	2	1	9	9	9	9	9	9
0.39	0.27	0.15	12.12	-1	0	5	4	5	2	5	4	1	1	4	1	5	2	3	9	9	9	9	9	9
0.41	0.31	0.23	12.01	1	1	5	5	5	1	5	5	1	1	5	1	6	1	2	9	9	9	0	9	0
0.10	0.15	0.36	12.06	-1	0	5	4	3	4	3	3	3	3	3	4	4	5	3	9	9	9	9	9	9
0.19	0.35	0.93	11.97	-0.6	0	5	4	5	2	5	4	2	1	4	1	6	1	2	9	9	9	9	9	9
0.36	0.07	0.26	12.01	0.8	0	5	4	4	4	4	3	3	3	4	2	4	2	3	9	9	9	0	9	0
0.25	0.17	0.31	11.90	0	0	5	4	5	1	5	4	2	1	5	1	3	2	1	9	9	9	9	9	9
0.18	0.14	0.42	11.84	0	-1	5	4	5	1	4	4	2	2	5	1	5	2	1	9	9	9	0	9	0
0.17	0.17	0.68	11.83	1	1	4	3	4	4	3	2	4	4	2	3	2	5	5	9	9	9	0	9	0
0.20	0.14	0.18	11.85	0	-1	4	4	4	1	5	5	1	4	5	1	4	3	2	9	9	9	0	9	0
0.18	0.16	0.47	12.31	0	-1	5	4	5	2	4	4	2	3	4	1	4	2	2	9	9	9	0	9	3
0.20	0.15	1.54	12.31	1	1	5	4	3	2	5	4	2	3	4	4	5	4	2	9	9	9	9	9	9
0.19	0.28	0.15	12.29	1	1	3	2	6	2	4	6	1	4	5	1	6	4	2	9	9	9	9	9	9

ACTIVITY
FLAGS

CLOTHING
QUESTIONS(header for women's clothing only)

side
t
pes/Blinds
heater on/off

Local fan on/off	Adjust clothes	Hot or cold drink	Took a break	Talked to others	Talked to staff	Ignored	MET(estimated) MET	Eat food FOOD	Hot drink DHOT	Cold Drink DCLD	Caffeine DCAF	Smoke CIG	Underlayer: top 1 CL1	Underlayer: bottom 2 CL2	Underlayer: slip 3 CL3	Footware: socks 4 CL4	Footware: pantyhose 5 CL5	Footware: shoes 6 CL6	Midlayer: ss shirt 7 CL7	Midlayer: ls shirt 8 CL8	Midlayer: dress 9 CL9
9	0	0	0	0	0	1	1.2	0	0	0	0	0	1	1	1	0	0	2	0	0	1
9	0	1	0	0	0	0	1.2	1	1	0	1	0	2	1	0	1	0	0	0	0	0
0	0	0	1	0	0	1	1.2	0	0	0	0	0	0	2	0	2	2	0	0	0	0
0	0	0	0	0	0	0	1.2	0	0	1	0	0	0	1	1	0	2	0	0	0	0
0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	2	0	3	0	0	0	0
9	0	0	0	0	0	1	1.2	0.	0	1	1	0	1	1	1	0	1	2	1	0	0
0	0	0	2	0	0	2	1.2	0	0	0	0	0	0	1	1	0	2	0	0	0	0
9	0	0	0	0	0	0	1	0	0	0	0	0	2	1	0	1	0	0	0	0	0
9	0	0	0	0	0	1	1.2	0	0	0	0	0	1	1	2	0	1	2	0	0	1
4	0	2	0	0	0	0	1.2	1	1	1	0	0	0	1	2	0	3	0	0	0	0
9	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	2	1	0	0
9	0	0	0	0	0	1	1	1	0	0	0	0	1	1	2	0	1	2	0	0	1
0	2	0	0	0	0	1	1	0	0	0	0	0	0	2	0	2	2	0	0	0	0
9	0	0	0	0	0	0	1	0	0	0	0	0	2	1	0	1	0	0	0	0	0
0	0	3	1	0	0	1	1.2	0	0	1	1	0	0	1	1	0	2	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	2	0	0	0	0
0	0	0	0	0	0	0	1.2	0	0	0	0	0	0	1	1	0	2	0	0	0	0
0	0	3	0	0	0	2	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0
9	0	0	0	0	0	1	1.2	0	0	0	0	0	1	1	2	0	2	2	0	0	2
9	0	0	0	0	0	1	1.2	0	0	0	0	0	1	1	1	0	0	2	0	0	0

skirt 10 CL10	pants 11 CL11	shorts 12 CL12	Outerlayers sweater 13 CL13	vest 14 CL14	jacket 15 CL15	CLO	SURVEY COMPLETION TIMES(sec.) Comfort	Affect	Activity	Clothing	TOTAL	COMFORT MODEL INPUT AND OUTPUT VARIABLES TAAV	TRAV	PAAV	VELAV	TCR	TSK	PWET	ET*	SET*	DISC
0	0	0	0	0	0	0.36	26	71	18	80	195	22.53	22.40	9.74	0.13	36.83	32.22	6.00	22.43	20.50	-0.16
1	2	0	0	0	0	0.36	41	57	29	143	270	22.26	22.46	10.01	0.10	36.83	32.18	6.00	22.35	20.42	-0.16
2	2	0	0	0	0	0.69	24	49	18	58	149	22.17	22.25	10.06	0.10	36.83	33.64	8.26	22.21	23.14	-0.01
1	2	0	0	0	0	0.46	19	34	24	66	143	22.49	22.95	10.21	0.12	36.83	33.01	6.00	22.73	21.71	-0.06
2	2	0	0	0	0	0.55	18	31	19	54	122	22.88	23.05	10.27	0.13	36.82	32.93	6.00	22.96	22.26	0.00
2	0	0	0	2	0	0.62	28	86	31	122	267	22.70	22.90	10.19	0.10	36.83	33.64	8.19	22.79	23.13	-0.01
1	2	0	0	0	0	0.46	46	222	29	132	429	22.77	22.87	10.21	0.10	36.83	33.07	6.00	22.81	21.79	-0.06
1	2	0	0	0	0	0.36	15	33	15	17	80	22.86	23.12	10.05	0.10	36.81	32.13	6.00	22.98	20.80	0.00
0	0	0	0	0	0	0.42	26	77	17	44	164	22.96	23.32	9.98	0.10	36.83	33.03	6.00	23.11	21.76	-0.06
2	2	0	0	0	0	0.55	23	22	14	7	66	23.37	23.75	10.16	0.31	36.83	33.51	6.38	23.51	22.51	-0.02
2	0	0	0	2	0	0.62	24	47	26	10	107	23.37	23.61	9.73	0.10	36.82	33.51	6.00	23.45	23.26	0.00
0	0	0	0	0	0	0.42	19	45	14	8	86	23.35	23.69	9.57	0.10	36.82	32.65	6.00	23.47	21.82	0.00
2	2	0	0	0	0	0.69	28	37	14	48	127	22.94	23.12	9.64	0.10	36.82	33.53	6.00	23.00	23.30	0.00
1	2	0	0	0	0	0.36	16	29	15	21	81	23.13	23.45	9.60	0.10	36.82	32.27	6.00	23.25	21.10	0.00
1	2	0	0	0	0	0.46	41	110	19	119	289	22.77	23.02	9.54	0.11	36.83	33.08	6.00	22.85	21.84	-0.06
1	2	0	0	0	0	0.46	24	45	15	6	90	23.17	23.49	9.59	0.10	36.82	32.72	6.00	23.29	21.93	0.00
1	2	0	0	0	0	0.46	19	39	15	24	97	22.65	22.93	9.52	0.10	36.83	33.01	6.00	22.75	21.73	-0.06
1	2	0	0	0	0	0.43	30	91	21	67	209	22.46	22.94	9.65	0.15	36.81	32.17	6.00	22.69	20.88	0.00
0	0	0	0	0	0	0.63	38	96	19	53	206	22.58	22.82	9.68	0.10	36.83	33.63	8.00	22.66	23.09	-0.01
1	0	0	1	0	0	0.4	24	71	15	59	169	22.73	22.71	9.81	0.17	36.83	32.62	6.00	22.68	21.13	-0.11

TSENS	PMV	PMV*	HSI
-0.16	-0.39	-0.46	6.18
-0.16	-0.40	-0.46	5.90
-0.01	-0.09	-0.06	11.64
-0.06	-0.30	-0.33	7.85
-0.10	-0.11	-0.11	6.58
-0.01	-0.09	-0.09	11.55
-0.06	-0.29	-0.33	7.86
-0.23	-0.29	-0.34	3.54
-0.06	-0.29	-0.35	7.82
-0.02	-0.22	-0.30	9.85
-0.03	-0.01	-0.01	8.33
-0.14	-0.17	-0.21	5.73
-0.03	0.00	0.01	8.39
-0.20	-0.26	-0.32	4.30
-0.06	-0.29	-0.34	7.95
-0.13	-0.15	-0.19	5.89
-0.06	-0.30	-0.35	7.76
-0.22	-0.29	-0.34	3.79
-0.01	-0.10	-0.11	11.28
-0.11	-0.34	-0.40	7.29

APPENDIX H

Recommendations to Improve Localized Thermal Distribution System Performance

Recommendations to Improve Localized Thermal Distribution System Performance

Based on our research work on localized thermal distribution (LTD), or task conditioning, systems during the past five years and the results of this study, the following general recommendations can be made regarding improving the performance of LTD systems.

1. Careful attention should be paid to integrating the design and operation of the LTD system with the overall HVAC system design and operation.
2. Individual units should be controlled by nearby building occupants to adjust their local thermal environments to satisfy their personal comfort preferences. At a minimum, occupants should have control over a suitably wide range of supply directions and velocities. We currently recommend that individually-controllable units supply up to a maximum of at least 1 m/s at the work location and possibly up to 1.5 to 2 m/s depending on future research findings.
3. An occupancy sensor should be associated with each occupant-controlled unit to respond to the presence/absence of the nearby office worker and to turn the unit on/off accordingly, provided minimum ventilation rates are maintained within the space. This will minimize the load from local fans and other components.
4. Units containing variable speed fans will have the best performance in response to occupant control and are recommended. Efficient fan motors should be incorporated into these designs.
5. Unit controls should be accessible and easy to use by the office worker. For example, controls located on the desktop are preferred over those at floor level. Inconvenient controls will not be used, defeating their main purpose.
6. Supply outlets should be designed to perform in a manner that responds quickly and effectively to occupant control. While diffusers with high induction ratios (e.g., swirl diffusers) reduce the risk of draft discomfort, jet diffusers may be preferred in circumstances where a broader range of control is desired. In addition, the location of the supply outlet in relation to the user may affect acceptability. More data on occupant satisfaction and use patterns with different systems are needed, and will presumably be obtained as experience with these systems grows.
7. The potential advantages of providing environmental control features beyond the basic supply direction and velocity (e.g., the Johnson Controls Personal Environmental Module) must be evaluated in relation to the added complexity, cost, and energy use of such a system. Additional performance data are needed to resolve this issue.
8. When possible, use an underfloor air distribution system due to advantages in reduced ductwork, reduced static pressures (distribution losses), reconfigurability, and convenient distribution of building services.
9. In retrofit applications where floor-based systems are not possible, supply units must be able to accommodate connection to an existing overhead air distribution system.
10. The widespread use of repeatable patterns of partitions and furniture in open plan offices presents an opportunity to develop LTD designs that are well-integrated into the office furnishings. Just as a floor-based LTD systems are easily adaptable to different configurations, a desk- or partition-based system that is compatible with an underfloor air distribution system by being "plugged into" specially-designed access floor panels could

relaxed in less critical building zones, while occupied areas can be well conditioned by the local supply units.

22. Cost analyses should consider all aspects of LTD systems over the lifetime of the building, including first costs, maintenance and operating costs, adaptability costs, and potential cost savings associated with improved thermal comfort, ventilation efficiency, and worker productivity.