Title
Field study of a desktop-based task conditioning system

Authors
Akimoto, T.
Bauman, Fred
Arens, Edward A
et al.

Publication Date
1996-12-01

Peer reviewed

日本建築学会計画系論文集　第490号，35-46，1996年12月
J. Archit. Plann. Environ. Eng., AIJ, No. 490, 35-46, Dec., 1996

FIELD STUDY OF A DESKTOP-BASED TASK CONDITIONING SYSTEM

デスクトップ型タスク空調システムに関する実測研究

Takashi AKIMOTO, Fred S. BAUMAN**, Charles C. BENTON*** and Edward A. ARENS*****

秋元孝之, *Fred S. BAUMAN, Charles C. BENTON, Edward A. ARENS*

Field tests were performed in an office to (1) investigate the desktop task conditioning system (DTC) performance in situations when demand for the local control capabilities may be increased; and (2) compare DTC performance to that of a conventional overhead system under similar high heat load conditions.

When the wall thermostat temperature was maintained at 26°C to 27.5°C, DTC was able to maintain average temperatures in the workstations to be 1 to 2°C lower than the thermostat temperature. Under increased activity levels, DTC could be adjusted to maintain similar comfort conditions, although each subject had different responses to the same environment.

keyword: task/ambient conditioning system, localized thermal distribution, thermal comfort
タスク／アンビエント空調システム、局所熱分布、熱的快適性

1. INTRODUCTION

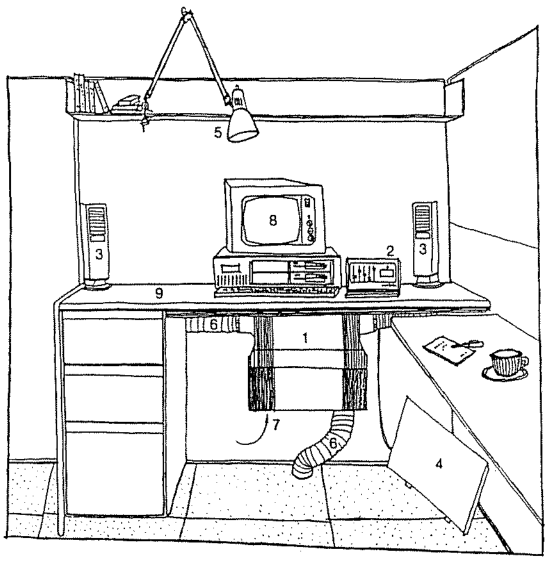
The field study was performed in a demonstration office set up by a California utility company. Previous field measurements have been made in an earlier configuration of this office in which occupant-controlled desktop task conditioning systems (DTCs) were installed in four of the workstations, with the remaining four workstations being conventional design (no DTCs). The results of this earlier work are described in detail by Bauman and McClintock[1] and Bauman et al.[2] In late 1993 and early 1994, the California utility company remodeled the demonstration office to allow four more DTCs to be installed, so that all eight workstations now have DTCs. In addition, they renovated the air distribution system serving the office to allow greater flexibility in our tests. The reconfigured air distribution system contains three variable air volume (VAV) terminal boxes that control the air flow into the office through three separate supply lines. In the previous demonstration office, two air distribution systems, one serving the DTC units and one serving conventional overhead diffusers, operated simultaneously. With this configuration, the overhead system dominated the overall airflow in the office (the overhead supply air volume was typically four to six times that of the DTC system), making it difficult to extract meaningful conclusions about the DTC performance. However with the renovated HVAC system in place, there was much greater control over the thermal conditions in the demonstration office. In this paper, we describe a series of four one-day field tests that were performed in the office during October and November 1994. The field tests took advantage of the renovated HVAC system serving the office (Bauman and Akimoto[3]). The major objectives of this work were to: (1) investigate the desktop (DTC) system performance in situations when demand for the local control capabilities may be increased (e.g., when room temperatures are near the upper boundary of the comfort zone (ASHRAE[4]), or under increased activity levels); and (2) compare the desktop (DTC) system performance to that of the conventional overhead system under similar high heat

* Senior Engineer, Shimizu Corporation, Tokyo, M. Sc.　清水建設(株)設備本部　工修
** Research Specialist, Center for Environmental Design Research, University of California, Berkeley, P.E.
*** Assoc. Prof., Center for Environmental Design Research, University of California, Berkeley
**** Prof., Center for Environmental Design Research, University of California, Berkeley, Ph.D.

load conditions.

2. DESKTOP TASK CONDITIONING SYSTEM

A sketch of a typical DTC installation is shown in Figure 1. The DTC is a desk-mounted unit supplying conditioned air at desktop level. It uses a self-powered mixing box that is hung in the back or corner of the knee space of the desk, and connected by flexible duct to two supply nozzles on the top of the desk. The supply vents may be rotated 360° in the horizontal plane and contain outlet vanes that are adjustable ±30° in the vertical plane. The mixing box uses a small variable-speed fan to pull supply air from a zero or very low pressure plenum either under the floor (as indicated) or from flexible ducts in the office partitions supplied from the ceiling (this is the duct configuration used in the demonstration office). A second fan pulls air from the knee space through a mechanical prefilter. Both supply air and recirculated room air are drawn through an electrostatic air filter. The relative fractions of supply air and recirculated air are controlled by dampers on each of these two lines. The main supply line damper is never allowed to close completely, thus ensuring the delivery of fresh ventilation air at all times. The unit has a desktop control panel containing adjustable sliders controlling the speed of the air emerging from the vents, its temperature (produced adjusting the ratio of supply to recirculated air), the temperature of a 200 W radiant heating panel located in the knee space, the dimming of the occupant's task light, and a white noise generator in the unit that issues a rushing sound through the supply vents. The control panel also contains a motion-detector-based occupancy sensor that shuts the unit off when the workstation has been unoccupied for a few minutes. The control panel is connected to a microprocessor-based programmable controller contained inside the main DTC unit located under the desk. The controller receives the incoming setpoint information from the control panel and provides the necessary output signals to control the operation of all DTC components. The controller utilizes an RS-485 communication link allowing multiple controllers to be networked together and to be connected to a central system controller. This communication capability was used to set up a DTC monitoring network in the demonstration office. Each DTC unit is capable of providing approximately 20-70 l/s (72-252 m^3/h) of air. Even when its internal fans are turned off, the system is designed to deliver 20 l/s (72 m^3/h) to satisfy minimum ventilation requirements. In a laboratory at UC Berkeley (UCB), the maximum outlet velocity measured at the face of the 58 x 100 mm supply vent varied between 2 and 7.5 m/s over the same range of airflows described above. In operation, 13°C is provided by a variable air volume HVAC system at the terminal box or underfloor plenum, with desk-level outlet temperatures in the range of 18°C.



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

Figure 1 Desktop task conditioning system (DTC)

UCB and Lawrence Berkeley Laboratory have been studying DTC performance for the past five years. Laboratory experiments have been completed in UCB's Controlled Environment Chamber to investigate the thermal and ventilation performance of DTCs. Results indicate that the DTCs are capable of controlling over a wide range of thermal conditions, allowing office workers the opportunity to fine-tune the local workstation environment to their individual comfort preferences (Arens et al.[5]), Bauman et al.[6]), Bauman et al.[2])). Under optimal operating conditions, the DTCs were able to provide true task ventilation (i.e., increased ventilation at the location of the occupant), with significantly lower ages of air at the breathing level in the workstation compared to that of the air leaving the room through the return grille (Faulkner et al.[7])). Computer modeling studies of DTC energy use have concluded that DTC installations may use more or less energy compared to a conventional air distribution system depending primarily on operating strategies (Heinemeier et al.[8]), Seem and Braun[9]), Bauman et al.[10])). Recently, a draft document has been developed to present and discuss engineering and application guidelines and recommendations that encourage the intelligent design, installation, and operation of task/ambient conditioning (TAC) systems in commercial buildings (Bauman and Arens[11])).

3. EXPERIMENTAL METHODS

The demonstration office is located on the first floor of a two-story office building in San Ramon, California. Figure 2 shows the floor plan of the demonstration office. The 149 m^2 office space has been subdivided into a 111 m^2 main office, the subject of all field tests, and two side offices at the northwest corner of the space. The main office accommodates two very similar workstation clusters, each containing four workstations. An occupant-controlled desktop task conditioning system (DTC) was installed in each of the eight workstations (DTC1-DTC8). The workstations are divided by 1.65-m high partitions. The cluster design provides a central access area that proved to be convenient for installing the DTC air supply duct and the workstation monitoring networks. This central core was extended to the ceiling, forming a hollow column through which the air supply duct was run down from the ceiling to serve the four DTC units in each workstation cluster. Entrance to the main office is from a central corridor adjacent to the south wall. The larger 23 m^2 side office contains one employee and the smaller 14 m^2 side office serves as the home base for the data acquisition system. A conference room located to the south of the main office space is not a part of this study.

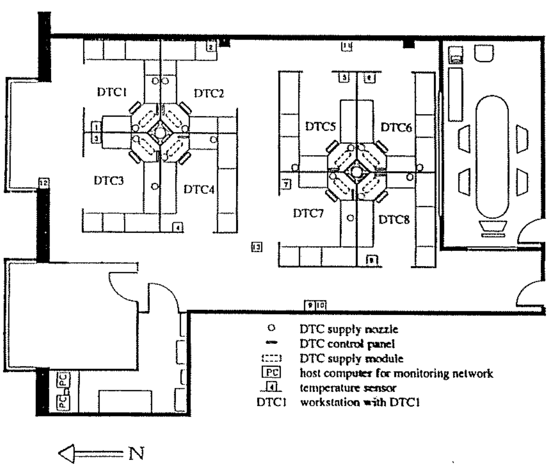


Figure 2 Demonstration office floor plan

In the renovated HVAC system, conditioned air is provided to the office through three supply lines which split off from the large incoming trunk line from the rooftop air handling unit. Airflow through each supply line is controlled by a variable air volume (VAV) terminal box. These three supply lines are described as follows. (1) One serves only the eight DTC units. A flow switch allows the VAV box to completely close off this line when a second conventional overhead supply line is in use. (2) A second VAV box controls air supplied to six overhead diffusers, serving as a conventional base case configuration. This line is completely closed off at the VAV box when the DTC supply line is in use. (3) A smaller, continuously operating VAV box serves an overhead perimeter system (with reheat) for conditioning of the area adjacent to the exterior windows. The VAV box on the DTC line is designed to maintain less than 2.54 mmAq static pressure, according to DTC installation guidelines. Under design conditions, even with its fan turned off, each DTC will provide approximately 20 l/s (72 m^3/h) of supply air to satisfy minimum ventilation requirements to the local workstation. Airflow control by the VAV box of the ceiling-based air distribution system is tied to the operational room thermostat, located on the west wall. The air distribution system utilizes a ceiling plenum return with one centrally located return grille and two perimeter return grilles in the main office area and two return grilles in the side offices. The ceiling plenum is open and connected above the main and side offices, as well as above parts of the adjacent office spaces in the building.

Using the communication link between DTC controllers, we set up a monitoring network to measure DTC and office thermal performance. Within each DTC unit, the controller allows the status of several control parameters and two temperature sensors to be monitored. These include (1) discharge air temperature setpoint, (2) radiant panel setpoint, (3) fan speed setpoint, (4) task light setpoint, (5) occupancy sensor status, (6) discharge air temperature, and (7) workstation air temperature. To monitor selected HVAC and room air conditions, we utilized the analog and digital input capabilities of three additional controllers that were connected to the network.

3.1 Thermal Comfort Measurements

Once the monitoring network had been configured and checked for accuracy, a series of one-day field tests were performed to investigate occupant response and thermal comfort for different air distribution system configurations and operating conditions.

Each field test involved seven subjects, except Test 4 which had only three. During each test, an inhouse portable measurement system (Benton and Brager[12]) was used to assess thermal comfort conditions within each workstation and for each participant. A total of four tests were completed as outlined below.

1. Test 1. Desktop supply system (30 Sept. 1994) Using only the DTC units to provide all significant supply air to the office, the office was controlled to be near the upper boundary of the comfort zone and occupied by seven participants.
2. Test 2. Overhead supply system (4 Oct. 1994) Using only the conventional overhead distribution system to provide all significant supply air to the office, the office was controlled to be near the upper

seven participants.

3. Test 3. Desktop supply system (8 Nov. 1994) Using only the DTC units to provide all significant supply air to the office, the office was controlled to be near the upper boundary of the comfort zone and occupied by seven participants. This test was a repeat of Test 1.
4. Test 4. Desktop supply system with three different activity levels for subjects (11 Nov. 1994) Using only the DTC units to provide all significant supply air to the office, the office was controlled to be near the upper boundary of the comfort zone and occupied by three participants. The subjects were instructed to do the step exercise following the special exercise protocol for Test 4 to obtain particular metabolic rates.

During all the tests, heat loads were increased (32 - 38 W/m^2) to maintain the average room air temperature at 26 - 27.5°C, near the upper boundary of the comfort zone. We used electrical heaters for the heat loads in addition to printers originally set in the office space. Detailed energy measurements of the DTC units on a component basis were performed in the previous study (Bauman and McClintock[1)]). According to that, the minimum power consumption of the DTC is about 5 W/unit, when the occupancy sensor is off (DTC 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. The DTC fan uses 70 W/unit of real power at its maximum setting. The amount of power required by the DTC task light is basically dependent on the fixture, however, in the office, almost all the task lights consume about 50 W of real power at their maximum setting. The DTC radiant panel consumes by far the most energy of any DTC component, using about 200 W/unit of real power, at its maximum setting. Average total supply air volume was approximately 190 l/s (684 m^3/h) during all the tests. Task/ambient conditioning (TAC) systems can be designed to have separate task and ambient conditioning systems, or the task supply diffusers can be used to provide both types of conditioning. This would be most common with floor-based diffusers. In this field experiment, we wanted to completely turn off the overhead system when we were using the DTCs to provide improved control of the experimental conditions in the room. In other words, we didn't want to have to "fight" the cooling effect of the overhead system while trying to raise the ambient temperature to test the occupants use of the DTCs.

Results from these four tests have been analyzed within the context of existing thermal comfort standards. This process includes the calculation of standard comfort indices, comparison of acquired data to similar data from a ten building sample of Bay Area office buildings, and comparison to existing ASHRAE and ISO standards (ASHRAE[4)], ISO[13),14)]).

Portable measurement methods were used to assess the thermal comfort of subjects occupying the office. A second-generation physical measurement system was developed in 1991 and used for the current study. The system design was based on an earlier version that had been developed and used for a field study of thermal comfort in 10 San Francisco Bay area office buildings (Schiller et al.[15)], Benton et al.[16)]). Figure 3 shows a sketch of the measurement cart. The new thermal measurement cart takes advantage of recent technological developments in data acquisition hardware and transducers by packaging these in a frame smaller and more maneuverable than the original cart design. The new cart, like its predecessor, collects a complete set of detailed measurements characterizing the local thermal environment using an automated approach. We collected data for air temperature, relative humidity, air velocity, globe temperature, and radiant asymmetry to satisfy the requirements of ASHRAE Standard 55-1992 (ASHRAE[4)]) and ISO Standard 7726 (ISO[14)]). The portable measurement system also included a laptop-based subjective survey that was administered to the subjects before each workstation visit. The survey asks questions relating to current thermal sensation, current satisfaction with the environment, recently used methods to make changes to the local thermal environment (e.g. turn on fan, turn on heater), current emotions, current clothing, and recent activity levels.

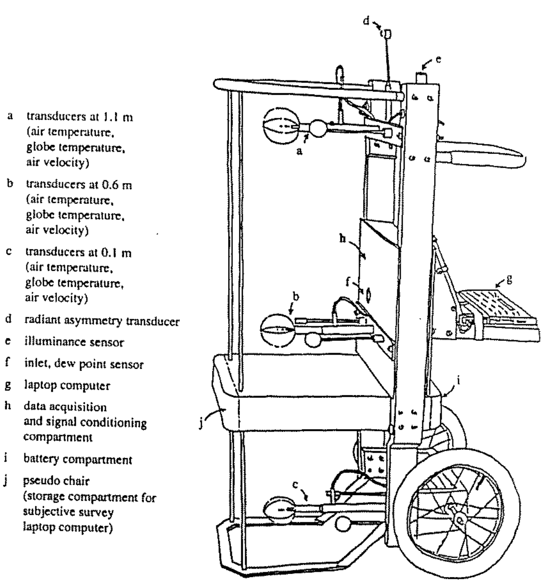


Figure 3 Sketch of measurement cart

3.2 Metabolic Rate Measurement for Test 4

In real office spaces, the occupants are usually involved in various levels of activity, including sitting quietly, standing and talking, frequently walking around, and even a short-term exertion (e.g., going up or down several flights of stairs). The increase in activity results in increased physiological effort, metabolic heat, and perspiration, all of which may affect people's sensation of comfort. It is important to investigate the relationship between specific metabolic rates, frequently be seen in the office, and reactions of the occupants under that conditions. We therefore decided to test the human subjects at three different activity levels, representative of typical office work. The design of the exercise protocol has been described by Arens et al.[17] and involves the subject getting up from his/her seat at regular intervals, and stepping up and down a specific number of times on a nearby 0.2-m step. The subject then returns to his/her seat. The three different activity levels that the subjects simulated using this approach are defined as follows: (1) 12 steps / 10 minutes (≈1.2 met); (2) 20 steps / 5 minutes (≈1.6 met); and (3) 40 steps one-time, representing a short-term exertion of approximately 4-5 met. In order to determine metabolic rate accurately, physiological measurement were made of selected subjects in an exercise physiology laboratory on UCB campus. During these tests, an oxygen consumption measurement apparatus was used to measure (through indirect calorimetry) the metabolic rate for each subject as they repeated the same sequence of activities to be used in the subsequent field study . A total of eleven subjects (six male and five female) were tested in the exercise physiology laboratory. Subjects arrived one hour before the test and spent this time sitting quietly to reach their sedentary metabolic rate. At the beginning of the test period, each subject was monitored while sitting for the first 20 minutes to estimate his/her sedentary metabolic rate. All subjects then repeated two sets of the 12-step exercise over the next 20 minutes, followed by 20 more minutes of sitting quietly. Finally seven subjects repeated two sets of the 20-step exercise over the next 10 minutes followed by 20 minutes of sitting quietly. The other four subjects performed one 40-step exercise followed by 30 minutes of sitting quietly.

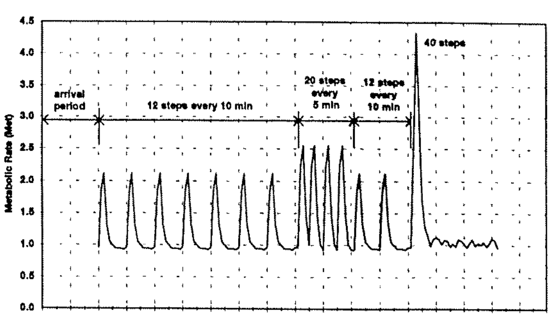


Figure 4 Metabolic rate for exercise protocol

Figure 4 displays a timeline of the exercise protocol used in Test 4 in terms of the average metabolic rate for each activity level that was quantified from the above tests. In Figure 4, these results are repeated for each step-cycle during the course of the experiment to show the approximate metabolic rate versus time. In the above exercise protocol, the choice of a 90-minute duration for the first activity period at 1.2 met was made to ensure that the subjects would reached equilibrium with their thermal environment. This was based in part on the results of Berglund[18] who found that the responses of subjects under similar test conditions typically reached quasi-steady values at or before 60 minutes of exposure. The subsequent activity periods were significantly shorter (20 minutes or less) and were intended to test the response of subjects to realistic short-term variations in their activity levels. Results from these later periods were not intended to represent steady-state responses.

3.3 Field Measurement Protocol

A pool of five utility company employees and five graduate students from UCB were originally selected to participate in the demonstration office comfort study, including six females and four males. Since the 8-workstation office was only partially occupied by 3-4 utility company employees on any given day, it was decided to have graduate students occupy the vacant workstations and participate in the study on the test days. In this way, we were able to have seven subjects participate in each of Tests 1, 2, and 3 (one workstation was used as a printer station). Test 4 occurred after the utility company had vacated the office completely, and we therefore used only three available students for this test.

In the early morning on the day of a test, several electric heaters were positioned throughout the office and turned on to raise the average temperature in the space. By mid-morning, the average room temperature was close to 26°C and some of the heaters were turned off to allow the temperature to stabilize at this elevated level. During all four tests, heat loads averaged 32 - 38 W/m^2 in combination with an average total air supply volume (either through the DTC or overhead system) of about 190 l/s (684 m^3/h) to maintain the average room air temperature at 26 - 27.5°C, near the upper boundary of the comfort zone. The collection of subjective and physical data through visits to the subjects in their workstations began after 11 am and continued until the end of the day (around 5 pm). Twenty-three online visits were made during both Tests 1 and 2; during Test 3, 19 online visits were made. Each visit lasted approximately 10 minutes for the combined subjective and physical measurements.

The field measurement protocol of Tests 1, 2, and 3 closely followed that developed in our previous thermal comfort field work. While a physical measurement is collected at a particular workstation, the field worker looks for potentially available subjects to take the subjective survey. Having found the next subject, the field worker enters the subject's identification number into the laptop computer and places it on the subject's desk. While the subject takes the online survey, the field worker retrieves the cart from the previous workstation and moves it to the vicinity of the subject taking the survey. When the survey is completed, the field worker removes both the laptop computer from the subjects' desk and the subjects' chair from in front of the desk. The cart is then placed in the location and orientation of the subjects' chair and the measurement period is initiated by flipping a switch on the cart. During the next five minutes, the cart collects physical data at the workstation.

4. RESULTS

In this section we present and discuss the measurement results of the four field tests, including: (1) thermal comfort assessment from the portable survey and measurement cart, and (2) DTC performance from the installed monitoring network. The first three tests were conducted to compare the performance of the desktop (DTC) supply system (Tests 1 and 3) with that of the overhead supply system (Test 2) under warm conditions. Test 4 studied the occupant use patterns and response to the desktop system under three different activity levels representative of a range of typical office work.

4.1 Room Temperature Control

During all four tests, the intention of environmental control was to maintain the same elevated average room air temperature in the office, as measured at a typical wall thermostat location. Figure 5 shows a comparison of wall thermostat (T-TS) and workstation (T-WS) temperatures from Tests 1, 2, and 3. The figure shows that the wall thermostat temperature was generally maintained in the range of 26 - 27.5°C over the duration of the tests, and this temperature agreed to within 1°C for all three tests. Each data point in Figure 5 represents measurements from a single workstation visit. The figure indicates that the workstation temperatures for the desktop supply system (Tests 1 and 3) averaged 1 - 2°C lower than the wall thermostat temperature, and those for the overhead supply system (Test 2) averaged less than 1°C lower than the wall thermostat temperature. This finding clearly demonstrates the local cooling capability of the individually-controlled DTC units in comparison to a conventional air distribution system having no local air supply within the workstations.

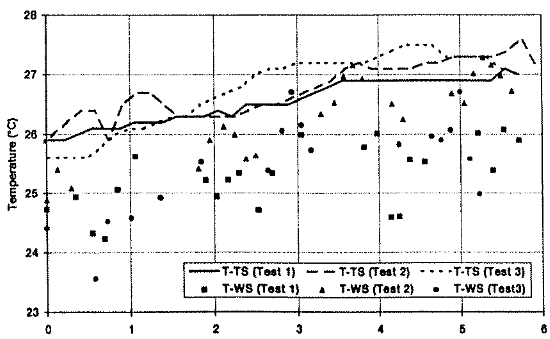


Figure 5 Comparison of thermostat (T-TS) and workstation (T-WS) temperatures: Tests 1 - Desktop Supply; Test 2 - Overhead Supply; and Test 3 - Desktop Supply

4.2 Thermal Comfort

Each data set from the four tests as measured by the portable measurement cart and online survey includes, for each workstation visit, values for each of the major physical comfort parameters, variables characterizing the subject's assessment of the thermal environment, and calculated values for the major thermal comfort indices. To complete the data sets, we calculated the standard comfort indices (PMV, PMV*, DISC, TSENS, ET*, SET*, and HSI) for each workstation visit using the Fobelets and Gagge[19)] two-node comfort model. The model accounts for the combined effects of air temperature, air velocity, mean radiant temperature, relative humidity, clothing level, and activity level. The measured and calculated values from all studies are summarized in Tables 1 - 2. Table 1 shows a comparison of Test 1 (Desktop supply system), Test 2 (Overhead supply system), Test 3 (Desktop supply system), and Test 4 (Desktop supply system with three different activity levels for subjects), to the average results from ASHRAE RP-462, a field study of ten office buildings in the San Francisco Bay Area (Schiller et al.[15)]). Since we found a significant seasonal variation in conditions through the ASHRAE study and the first two demonstration office tests occurred during what could be a swing season, Table 1 includes both the winter and summer data from RP-462.

Our physical measurement results indicated that the air temperatures maintained in the space were approximately near the upper boundary of the summer comfort zone as we intended. As shown in Table 1, workstation air temperatures measured by the portable cart averaged 25.3°C, 26.3°C, 25.5°C, and 25.9°C for Tests 1, 2, 3, and 4, respectively. These values were 2-3.5°C higher than the winter and summer averages from the ASHRAE RP-462 field study. In all test, average room air temperatures measured by the thermostat sensor on the west wall were maintained at 26 - 27.5°C. The relatively higher air temperature of Test 2 was produced by the overhead supply system configuration. Average air velocities were slightly higher than the summer averages measured in the previous ten-building field study (0.14, 0.11, 0.12, and 0.18). The effect of the DTC diffusers on local air motion is demonstrated by the results of Tests 1,3,and 4, which have slightly higher average velocities and significantly higher maximum velocities compared to Test 2 (overhead system). Radiant effects in the demonstration office were insignificant. Dewpoint temperatures were all within the limits specified by the ASHRAE 55-92 comfort standard. The average clothing insulation values reported by the study participants for Tests 1 and 3 were in the normal range, for Test 2 was slightly lower, and for Test 4 was higher compared to the others. The results for effective temperature (ET*) and operative temperature (both indices that combine other physical parameters into a "temperature" index) were 2 - 3°C higher than the summer average calculated for the ASHRAE RP-462 field study, primarily due to the higher air temperature.

Table 2 shows a comparison of overall average values of landmark variables of subjective response and comfort. Results are presented for the Tests 1, 2, and 3. The ASHRAE thermal sensation vote (ASH) 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 votes were 0.40 and 0.75 for Tests 1 and 3, representing results that were slightly higher than the neutral point. However, for Test 2, the average thermal sensation was 1.27, much higher than the neutral point, reflecting the higher air temperatures at workstations. The McIntyre thermal preference scale (MC) 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 2, average results from thermal preference vote found a greater preference to be cooler for Test 2 (0.87) in comparison with that for Tests 1 and 3 (0.52 and 0.58). The calculated comfort indices of SET* (Standard Effective Temperature), DISC (Discomfort), and PMV (Predicted Mean Vote) for Test 2 were also relatively higher than Tests 1 and 3. The general comfort scale is a six-point scale ranging from very uncomfortable (1) to very comfortable (6). Average results were 4.30 and 4.47 for Tests 1 and 3. However, the Test 2 subjects voted 3.48, a significant drop in general comfort compared to the others. The ventilative comfort is a six-point scale in which the subjects describe their ventilative environment as being stuffy (1) to breezy (6). The Tests 1 and 3 subjects, as expected, had a higher average ventilative comfort rating than the Test 2 subjects did because of the DTC diffusers. Also included in Table 2 are average air velocities at each of three measurement heights (0.1, 0.6, and 1.1 m). While all velocity results were very similar between each height for Test 2, the average velocities was noticeably higher at the 0.6 m height for Tests 1 and 3 (0.15 m/s). This demonstrates that the desk-mounted DTC supply nozzles have a significant impact on air movement at heights near the desk level.

TABLE 1
Distribution of Physical Data: Comparison of Test 1 - Desktop Supply, Test 2 - Overhead Supply, Test 3 - Desktop Supply, and Test 4 - Desktop Supply / Three Activity Level to ASHRAE RP-462 Measurements

Building	Test 1	Test 2	Test 3	Test 4	Winter	Summer
Test Date	30 Sep. 1994	4 Oct. 1994	8 Nov. 1994	11 Nov. 1994	ASHRAE RP-462	
Sample Size	23	23	19	15	1308	1034
Clothing (clo)						
mean	0.51	0.47	0.54	0.77	0.58	0.52
std.dev.	0.06	0.06	0.13	0.36	0.14	0.12
minimum	0.39	0.35	0.39	0.53	0.24	0.16
maximum	0.59	0.55	0.82	1.44	1.14	1.44
Air Temperature (°C) (mean of 3 heights)						
mean	25.3	26.3	25.5	25.9	22.8	23.3
std.dev.	0.6	0.7	0.8	0.6	1.2	1.3
minimum	24.2	24.9	23.6	24.6	17.5	20.7
maximum	26.1	27.3	26.7	26.6	29.8	29.5
Vapor Pressure (torr)						
mean	11.3	11.3	9.2	7.9	7.8	12.9
std.dev.	0.4	0.1	0.3	0.3	1.7	1.3
minimum	10.6	11.1	8.6	7.3	4.6	8.6
maximum	12.1	11.5	9.7	8.2	11.8	17.7
Dew Point Temperature (°C)						
mean	13.1	13.1	10.0	7.7	7.3	15.1
std.dev.	0.5	0.1	0.5	0.6	3.3	1.6
minimum	12.1	12.8	8.9	6.6	0.0	9.0
maximum	14.1	13.3	10.8	8.2	13.7	20.2
Air Velocity (m/s) (mean of 3 heights)						
mean	0.14	0.11	0.12	0.18	0.06	0.10
std.dev.	0.07	0.02	0.04	0.11	0.05	0.09
minimum	0.10	0.10	0.10	0.10	0.00	0.00
maximum	0.34	0.15	0.24	0.45	0.56	1.24
Operative Temperature (°C) (mean of 3 heights)						
mean	25.4	26.4	25.6	26.0	22.9	23.5
std.dev.	0.6	0.7	0.9	0.6	1.2	1.2
minimum	24.3	24.9	23.6	24.6	17.8	20.3
maximum	26.3	27.3	26.9	26.8	28.5	29.5
ET* (°C) (mean of 3 heights)						
mean	25.3	26.2	25.3	25.2	22.5	23.5
std.dev.	0.6	0.7	0.8	0.9	1.1	1.3
minimum	24.3	24.8	23.5	23.9	17.4	20.2
maximum	26.1	27.1	26.7	26.2	28.3	29.0

TABLE 2
Landmark Variables of Subject Response and Comfort Averages for Tests 1 - Desktop Supply; Test 2 - Overhead Supply; and Test 3 - Desktop Supply

	Test 1	Test 2	Test 3
Thermal Sensation (ASH)	0.40	1.27	0.75
Thermal Preference (MC)	0.52	0.87	0.58
General Comfort	4.30	3.48	4.47
Ventilative Comfort	3.35	2.52	3.21
Lighting Comfort	4.35	4.13	3.79
Estimated Temperature (°C)	23.81	26.88	24.86
Metabolic Rate (met)	1.1	1.1	1.1
Clothing Level (clo)	0.51	0.47	0.54
Effective Temperature* (°C)	25.3	26.2	25.3
DISC	0.22	0.40	0.27
SET* (°C)	24.4	25.2	24.6
PMV	0.24	0.45	0.30
Velocity at 1.1 m (m/s)	0.15 (0.35)	0.08 (0.32)	0.09 (0.42)
Velocity at 0.6 m (m/s)	0.15 (0.29)	0.08 (0.26)	0.15 (0.32)
Velocity at 0.1 m (m/s)	0.07 (0.23)	0.09 (0.23)	0.07 (0.22)

Turbulent Intensity is shown in ( )

Averaging the subjective votes together, as in the tables described above, can tend to mask some of the underlying patterns inherent in the data. Figure 6 compares occupant assessment of thermal comfort on the ASHRAE thermal sensation (ASH) and the McIntyre thermal preference (MC) scales. Results are shown for Tests 1, 2, and 3. As described above, convention holds that the middle three categories of the thermal sensation scale (-1.5 < ASH < +1.5) are considered thermally acceptable, and, according to ASHRAE Standard 55-92 (ASHRAE[4)]), 80% of the building occupants should fall within this range. Figure 6 shows that about 80% of the Tests 1 and 3 subjects meet this criteria. On the other hand, 39% (9 out of 23) of the Test 2 subjects votes fell outside of the central "thermally acceptable" categories. Also shown in Figure 6 are the results from the McIntyre scale, which illustrates comfort on the basis of thermal preference. During Tests 1 and 3, 48% (11 out of 23) and 42% (8 out of 19) of the subjects preferred to have no change in their thermal environment. In Test 2, however, the distribution of thermal preference votes has changed considerably. Despite 61% (14 out of 23) of the subjects voting to be thermally acceptable on the thermal sensation scale, only 13% (3 out of 23) of the subjects voted for no change on the McIntyre scale. Almost as many subjects, 87% (20 out of 23), preferred to be cooler. It is considered that personal control is an inexact process. There is some tradeoff between maintaining absolute preferred thermal conditions, and having to spend too much time adjusting the DTC. On the other hand, this demonstrates that people who have access to personal control are more tolerant of variations in their local environment. Despite the fact that more than 50% of the subjects desired to be cooler (based on McIntyre scale), at least 80% of them indicated that the environment was acceptable (based on ASHRAE Thermal Sensation scale).

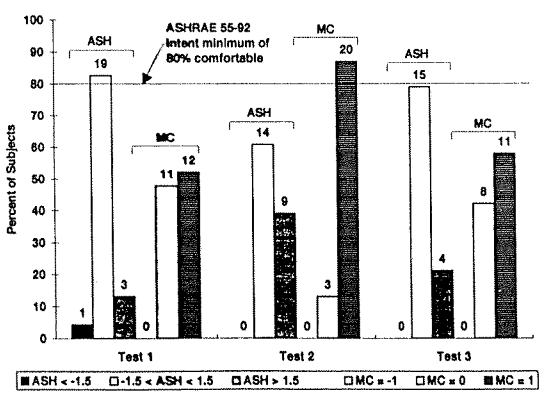


Figure 6 Comfort votes on ASHRAE Thermal Sensation (ASH) and McIntyre (MC) Scales:Tests 1 - Desktop Supply; Test 2 - Overhead Supply; and Test 3 - Desktop Supply

4.3 DTC Performance

Average discharge air temperature monitored at each DTC unit were 18.6°C (SD 0.2), 19.1°C (SD 0.5), and 18.7°C (SD 0.2) for Tests 1, 3, and 4 respectively. The low standard deviation shows that subjects did not change the discharge air temperature setpoint often during tests periods. However, subjects used different settings of fan speed for Tests 1, 3, and 4. Figures 7, 8, and 9 present the comparison of the thermostat on the west wall and the workstation temperatures, and the fan setpoint for Test 4. In Figures 7 and 9, the fan setpoints are turned up according to the gradual increase of temperatures and the metabolic rate change. In figure 8, however, the fan setpoint is only adjusted to 38% at the first moment of the test, and is maintained until the end of the day despite the gradual increase of temperatures and the metabolic change. The results show that office workers tended to increase the fan speed setpoint with increasing metabolic rate during this test. However, as would be expected, each office worker had his/her own individual response to the thermal environment. None of the subjects in Test 4 did anything beyond putting the setpoint of discharge air temperature at the coolest setting (0%). We believe this is the position in which the

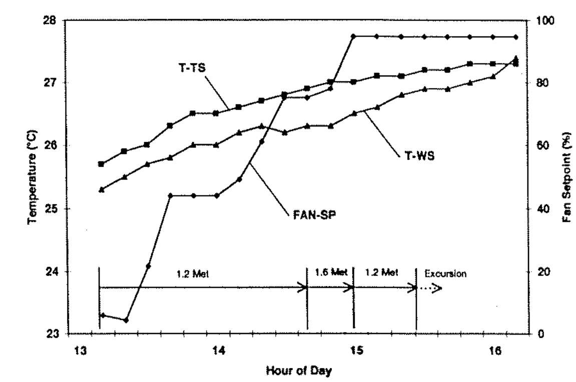


Figure 7 Comparison of Thermostat (T-TS), Workstation (T-WS) temperatures and fan setpoint for Test 4 (Subject ID #6)

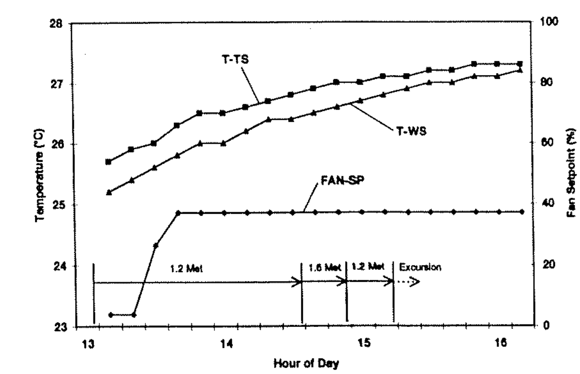


Figure 8 Comparison of Thermostat (T-TS), Workstation (T-WS) temperatures and fan setpoint for Test 4 (Subject ID #7)

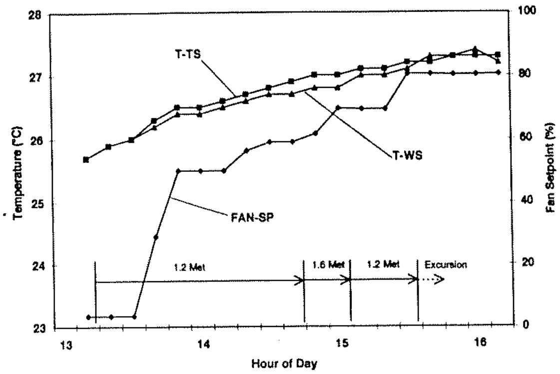


Figure 9 Comparison of Thermostat (T-TS), Workstation (T-WS) temperatures and fan setpoint for Test 4 (Subject ID #10)

setpoint control usually remains during most of the time. The temperature setpoint control on the DTC is not very effective, and as a result it is rarely used.

5. CONCLUSIONS

A series of four one-day field tests were performed in the office to (1) investigate the desktop (DTC) system performance in situations when demand for the local control capabilities may be increased (e.g., when room temperatures are near the upper boundary of the comfort zone, or under increased activity levels); and (2) compare the desktop (DTC) system performance to that of a conventional overhead system under similar high heat load conditions. When the wall thermostat temperature was maintained at 26°C to 27.5°C, the desktop system, with its local air supply and individual control, was able to maintain average temperatures in the workstations to be 1 to 2°C lower than the thermostat temperature. These conditions were considered to be comfortable by 80% of the subjects according to the ASHRAE thermal sensation scale, although 55% of the subjects preferred to be cooler according to the McIntyre thermal preference scale. In comparison, under the same elevated wall thermostat temperatures, the overhead system maintained the average workstation temperatures to be only 0 to 1°C lower. These conditions were considered comfortable by only 61% of the subjects, and 87% of the subjects preferred to be cooler. Under increased activity levels, the desktop system could be adjusted (primarily by increasing the fan speed) to maintain similar comfort conditions, although each subject had different responses to the same environment.

ACKNOWLEDGMENTS

This project would not have been possible without the cooperation and assistance provided by Steve Blanc of Pacific Gas & Electric Company (PG&E), San Ramon, CA. This research was also partially supported by the California Institute for Energy Efficiency (CIEE), a research unit of the University of California. Publication of research results does not imply CIEE endorsement of or agreement with these findings, nor that of any CIEE sponsor. We would also like to acknowledge the assistance on the monitoring system provided by John David Heinzmann and Rob Reed of Endecon, San Ramon, CA.

REFERENCES

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

2) Bauman, F.S., H. Zhang, E.A. Arens, and C.C. Benton. "Localized comfort control with a desktop task conditioning system: laboratory and field measurements." *ASHRAE Transactions*, Vol. 99, Pt. 2, pp. 733-749, 1993.

3) Bauman, F.S., and T. Akimoto. "Field Study of a Desktop-Based Task Conditioning System in PG&E's Advanced Office Systems Testbed." Final Report to CIEE (California Institute of Energy Efficiency), Center for Environmental Design Research, University of California, Berkeley, 1996.

4) ASHRAE. *ANSI/ASHRAE Standard 55-1992*, "Thermal environmental conditions for human occupancy." Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1992.

5) Arens, E., F. Bauman, L. Johnston, and H. Zhang. "Testing of localized ventilation systems in a new controlled environment chamber." *Indoor Air*, No. 3, pp. 263-281, 1991.

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

7) Faulkner, D., W. Fisk, and D. Sullivan. "Indoor air flow and pollutant removal in a room with desktop ventilation." *ASHRAE Transactions*, Vol. 99, Pt. 2, 1993.

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

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

10) Bauman, F., E. Arens, M. Fountain, C. Huizenga, K. Miura, T. Xu, T. Akimoto, H. Zhang, D. Faulkner, W. Fisk, and T. Borgers. "Localized Thermal Distribution for Office Buildings; Final Report - Phase III." Center for Environmental Design Research, University of California, Berkeley, July, 115 pp, 1994.

11) Bauman, F., and E. Arens. "Task/Ambient Conditioning Systems: Engineering and Application Guidelines." Center for Environmental Design Research, University of California, Berkeley, In Press.

12) Benton, C.C., and G.S. Brager. "Sunset Building: Final Report -- A Study of Occupant Thermal Comfort in Support of PG&E's Advanced Customer Technology Test (ACT2) for Maximum Energy Efficiency." Center for Environmental Design Research, University of California, Berkeley, June 8, 76 pp, 1994.

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

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

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

16) Benton, C., F.Bauman, and M. Fountain. "A field measurement system for the study of thermal comfort." *ASHRAE Transactions*, Vol.96, Pt. 1, 1990.

17) Arens, E., F. Bauman, A. Baughman, M. Fountain, A. Kwok, K. Miura, T. Xu, and H. Zhang. "Comfort and Health Considerations: Air Movement and Humidity Constraints: Final Report - Phase I." Center for Environmental Design Research, University of California, Berkeley, August 1993.

18) Berglund, L. "Comfort criteria in a low humidity environment." Final Report to EPRI, Palo Alto, CA, 1989.

19) Fobelets, A.P.R. and A.P. Gagge. "Rationalization of the effective temperature ET*, as a measure of the enthalpy of the human indoor environment." *ASHRAE Transactions*, Vol. 94, Pt. 1, pp. 12-31, 1988.

和文要約

１．はじめに

実測試験は、米国カリフォルニアのエネルギー供給会社の先端技術テスト用の事務室で行われた。事務室内には８つのワークステーションがあり、各々に居住者による任意の制御が可能なデスクトップ型タスク空調システム（desktop task conditioning system：以下、ＤＴＣと称す）を設置した。本報では、１９９４年9月～１１月に実施した計４回の実測テストの結果について報告する。本研究の目的は、局所空調が望まれる状況下（室温が快適域の上限に近い場合、また居住者の代謝量が高い場合）におけるＤＴＣの性能の調査、および熱負荷が大きい場合のＤＴＣと従来型の天井吹出型空調システムとの性能比較を行うことである。

２．デスクトップ型タスク空調システム（ＤＴＣ）

ＤＴＣは、机設置型の空調ユニットであり、机下に設けられたミキシング・ボックスと机上に置かれた２つの給気ノズルにより構成されている。ミキシング・ボックスは室内の空気と一次空気を混合するためのものであり、ミキシング・ボックスと給気ノズルはフレキシブル・ダクトでつながれている。机上にはデスクトップ型コントロール・パネルがあり、これを調節することによって、二次空気の吹出速度、温度、在席者の足下用の放射暖房パネル、タスク照明、およびホワイト・ノイズの音量の出力を制御することが可能である。また、このコントロール・パネルは動作感知型の居住者センサーを内蔵しており、居住者が机を離れてしばらくすると、自動的にＤＴＣの機能を停止することができる。

３．実験方法

実測の対象となった事務室の主要部分（１１１m^2）には、２つのワークステーション群があり、それぞれ4つのワークステーションにより構成されている。ＤＴＣは全てのワークステーションに設置された。このワークステーションは、高さ1.６５ｍのパーティションで仕切られ、ワークステーション群の中央部分には、ＤＴＣへの給気用ダクトを内蔵した柱型が設置してある。事務室内への空調給気系統は3種類あり、それぞれＶＡＶにより制御することができる。３種類のラインは以下の通りである。（1）８つのＤＴＣユニットだけに給気する系統。従来型天井給気系統が使用される場合は完全に閉鎖される。（２）従来型天井給気系統。６つの天井吹出口へ給気する。ＤＴＣ給気系統が使用される場合は完全に閉鎖される。（３）ペリメータ環境制御用給気系統。他系統の使用状況に関わらず常時運転する。再熱機能付である。

ＤＴＣの運転状況と事務室内の温熱環境を計測するために、各ＤＴＣ間のデータ通信機能を利用したモニター・ネットワークを構築した。これを用いてＤＴＣの吹出空気温度、放射パネルの出力、ファン・スピードの出力、タスク照明の出力、居住者センサの状態（ｏｎ／ｏｆｆ）、ワークステーションの温度、給気系統、その他の室内空気環境に関するデータを収集した。

実験条件別の被験者の反応と熱的快適性を調査するために実測試験テストを計４回行った。

各試験の実験条件は、以下の通りである。

１．テスト１　デスクトップ給気システム（１９９４年９月３０日）
ＤＴＣ給気系統を使用。室温は快適域の上限程度に制御。被験者７名。

２．テスト２　天井給気システム（１９９４年１０月４日）
従来型天井給気系統を使用。室温は快適域の上限程度に制御。被験者７名。

３．テスト３　デスクトップ給気システム（１９９４年１１月８日）
テスト１と同一条件。被験者７名。

４．テスト４　デスクトップ給気システム（代謝量を３段階に変化させた）（１９９４年１１月１１日）
ＤＴＣ給気系統を使用。被験者に対して特定のステップ運動を課した。

すべてのテストにおいて、室温を快適域の上限である２６～２７．５℃に保つために、オフィス内のプリンタの他、電気ヒータを用いて熱負荷を増加した（３２～３８W／m^2）。室温、相対湿度、気流速、グローブ温度、不均一放射のデータはポータブル計測システム（カリフォルニア大学バークレー校で開発された実測用カート）を用いて実測した。また、ラップトップ・コンピュータにより、被験者に対し温熱感覚、環境に対する満足感、

クロ値、代謝量等の質問を行った。

４．実験結果

壁面に設置したサーモスタットの温度が２６℃～２７．５℃になるように制御した場合、サーモスタット温度と比較して、ＤＴＣはワークステーションの温度を約１～２℃低く維持することができた（テスト１、テスト３）。これに対し天井吹出システムは、サーモスタット温度との差が平均して１℃以下であった。これはＤＴＣに局所冷却能力があることを示している。

ポータブル計測システムで実測したワークステーションの平均温度はテスト１、２、３、４でそれぞれ２５．３℃、２６．３℃、２５．５℃、２５．９℃であった。これらは、ＡＳＨＲＡＥ　ＲＰ－４６２（サンフランシスコ湾岸地区のオフィスビルにおける実測調査）の結果と比較して２～３．５℃高い値であった。テスト２のワークステーションの温度が相対的に高いのは、吹出方式の違いによるものである。平均気流速はそれぞれ０．１４ｍ／ｓ、０．１１ｍ／ｓ、０．１２ｍ／ｓ、０．１８ｍ／ｓであり、ＤＴＣの局所気流により、テスト１、３、４における平均気流速と最大気流速が高くなった。新有効温度（ＥＴ*）と作用温度（ＯＴ）は、設定室温が高かったため、ＡＳＨＲＡＥ　ＲＰ－４６２の実測調査における夏期のデータと比較して２～３℃高くなっていた。

温冷感申告（－３：寒い、＋３：暑い）の－１．５から＋１．５の範囲は一般的に「熱的に許容できる」とされている。また、ＡＳＨＲＡＥ　５５－９２では、建物の居住者の８０％がこの範囲に収まるようにするように推奨している。テスト１、３の被験者の温冷感申告結果はほぼこの基準を満たした（約８０％）が、テスト２の被験者の温冷感申告結果はその６１％しか「熱的に許容できる」範囲に入らなかった。ＭｃＩｎｔｙｒｅによる尺度（－１：より暖かくしたい、０：変化なしで良い、＋１：より涼しくしたい）については、テスト１、３でそれぞれ４８％、４２％の被験者が「変化なしで良い」と申告した。これに対して、テスト２では、６１％の被験者が「熱的に許容できる」範囲に申告しているにも関らず、１３％の被験者のみしか「変化なしで良い」と申告しなかった。すなわち約８７％の被験者が「より涼しくしたい」と申告した。

テスト４において、室温およびステップ運動を行い代謝量が徐々に増加するのに伴って、二人の被験者はＤＴＣのファン・スピードの設定値を上げた。しかし、別の被験者は、室温および代謝量の増加に関らず、実測開始直後にファン・スピードを３８％の出力にした後は、その設定値を変えなかった。ステップ運動を課せられた被験者は、ＤＴＣのファン・スピードの設定値を上げることにより、熱的快適感を得ることができたが、予測された通りその際の被験者のＤＴＣへの入力は個人により異なることがわかった。

５．結論

局所空調が望まれやすい状況下におけるデスクトップ型タスク空調システムの性能の調査、および熱負荷が大きい場合のＤＴＣと従来型の天井吹出し型空調システムの性能比較をするために実測を行った。

壁面に設置したサーモスタットの温度が２６℃～２７．５℃となるように制御した場合、サーモスタット温度と比較して、ＤＴＣはワークステーションの温度を約１～２℃低く維持することができた。このときの被験者の温冷感申告結果から、被験者の８０％が「熱的に許容できる」状態であったと考えられる。しかし、被験者の５５％は、ＭｃＩｎｔｙｒｅによる尺度について「より涼しくしたい」と申告した。これに対して、天井吹出システムはワークステーションの温度を０～１℃しか低くできなかった。この場合は、温冷感申告結果から、被験者の６１％のみが「熱的に許容できる」状態であったと考えられ、被験者の８７％は、ＭｃＩｎｔｙｒｅによる尺度については「より涼しくしたい」と申告した。

また、ステップ運動を課せられた被験者は、快適状態を維持するためにＤＴＣを調整したが、ＤＴＣへの入力は個人により異なった。

(1996年２月８日原稿受理，1996年７月20日採用決定)