VENTILATION EFFICIENCIES OF TASK/AMBIENT CONDITIONING SYSTEMS WITH DESK-MOUNTED AIR SUPPLIES

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ABSTRACT

In laboratory experiments, we investigated the ability of two task/ambient conditioning systems with air supplied from desk-mounted air outlets to efficiently ventilate the breathing zone of heated manikins seated at desks. In most experiments, the task conditioning systems provided 100% outside air while a conventional ventilation system provided additional space cooling but no outside air. Air change effectiveness (i.e., exhaust air age divided by age of air at the manikin's face) was measured. Tracer gases simulated the release of pollutants from nearby occupants and from the floor covering, and the associated pollutant removal efficiencies (i.e., exhaust air concentrations divided by concentrations at manikin's face) were also measured. High values of air change effectiveness (~ 1.3 to 1.9) and high values of pollutant removal efficiency (~ 1.2 to 1.6) were measured when these task conditioning systems supplied 100% outdoor air at a flow rate of 7 to 10 L s^{-1} per occupant.

INTRODUCTION

Task/ambient conditioning (TAC) is a method for providing occupants with control of a local supply of air so that they can adjust their individual thermal environment. Controlled variables can be the supply-air temperature, flow rate, direction and the ratio of room air to main air handling system supply air. TAC systems may provide all or part of the conditioned air to the occupied space. TAC systems have the potential to improve ventilation at the occupant's breathing zone because they can provide supply air (which is generally less polluted than room air) preferentially toward the breathing zone [1, 2, 3]. In addition, prior research has shown increased thermal comfort while using TAC systems [4, 5].

The objectives of this research were to determine ventilation efficiencies obtained through the use of two desk-mounted TAC systems operating in conjunction with a conventional (ceiling supply and return) heating ventilation and air conditioning (HVAC) system. In this paper, to characterize the improvement in ventilation at the breathing zone we use two “ventilation efficiency” parameters (see [6] for more details). The first is the air change effectiveness (ACE), defined as the age of air that would occur throughout the room if the air was perfectly mixed, divided by the average age of air where occupants breathe. Because the average age of air exiting the room is identical to the age of air that would occur throughout the room if the indoor air were perfectly mixed, the ACE is also the exhaust-air age divided by the average age of air where occupants breathe. A short-circuiting flow pattern decreases the exhaust-air age and causes ACE to be less than unity. Perfect mixing results in an ACE of unity. Preferentially ventilating the breathing zone with outside air will cause the ACE to be greater than unity.

The second ventilation efficiency parameter is the pollutant removal efficiency (PRE). We define the PRE as the time-average concentration of pollutants in the exhaust air divided by the time-average concentration where occupants breathe. The PRE is a function of the locations of pollutant sources, the indoor airflow pattern and the nature of the pollutant emission process, e.g., emitted with or without momentum. In many configurations, values of PRE may be correlated to the values of ACE.

TASK/AMBIENT CONDITIONING SYSTEMS

The first TAC system evaluated is the Personal Environmental Module (PEM). A mixing box with a fan, located underneath the desk, draws air from a dedicated air-handling unit (AHU) via a flexible duct connected directly to AHU supply ducts or to an under-floor supply air plenum. Normally (but not in our experiments) another stream of air enters the mixing box from beneath the desk. After passing through the mixing box, the mixture of AHU supply air and room air exits two air supply outlets located at the back corners of the desk. The air supply outlets on top of the desk can be rotated 360° in the horizontal direction and contain movable vanes which can be rotated ± 30° in the vertical direction. The PEM has a control panel from which the air flow rate, percent of room air that is mixed in the mixing box with air from the main AHU, and other parameters can be changed.

The second TAC system is the Climadesk. A panel attached to the underside of a conventional desk is connected by a flexible duct to a portable fan-filter unit placed next to the desk. The fan-filter unit is supplied with air from the AHU or draws air from outdoors. Supply air exits two adjustable outlets underneath and close to the underside of the worksurface. These outlets are located close to a seated worker's knees and direct air horizontally above the seated worker's thighs and towards the torso. In the horizontal plane, the angle of air supply from these outlets is manually adjustable. There is an additional, non-adjustable outlet at the front edge of the desk, which directs air almost vertically upwards, but slightly away from a seated occupant. A proportion of the total airflow (0-100%) can be directed to this third outlet, as desired by the occupant.

RESEARCH METHODS

All experiments were performed in a controlled environment chamber (CEC) with a 5.5 m by 5.5 m floor and 2.5 m high ceiling. The CEC resembles a modern office space. Figure 1 shows the floor plan of the workstations in the chamber. During experiments, two identical TAC systems were operated with heated manikins seated in workstations 2 (WS2) and WS3, while a conventional HVAC system supplied air through a perforated diffuser located in the ceiling. All measurements were performed at steady state conditions. Air was exhausted from the chamber through a ducted ceiling-level return grill.

EXPERIMENTAL CONDITIONS

Each workstation with the TAC system and manikin were configured identically for each test. PEM air supply outlets were either pointed toward the occupant or parallel to the side walls of the workstation. The Climadesk supplied air either horizontally under the desk, vertically upward from the front edge of the desk or approximately equally from both the horizontal and vertical directions. Except as noted in Table 1, all of the outside air was supplied through either the PEM or Climadesk nominally at 10 L/s-occupant and 19 °C. The room temperature was controlled at ~25 °C. The manikins were seated upright with their faces located about 15 cm back from the edges of the desks, except during four tests with the manikins leaning slightly forward with their faces in the vertical air supply jets exiting the Climadesks.

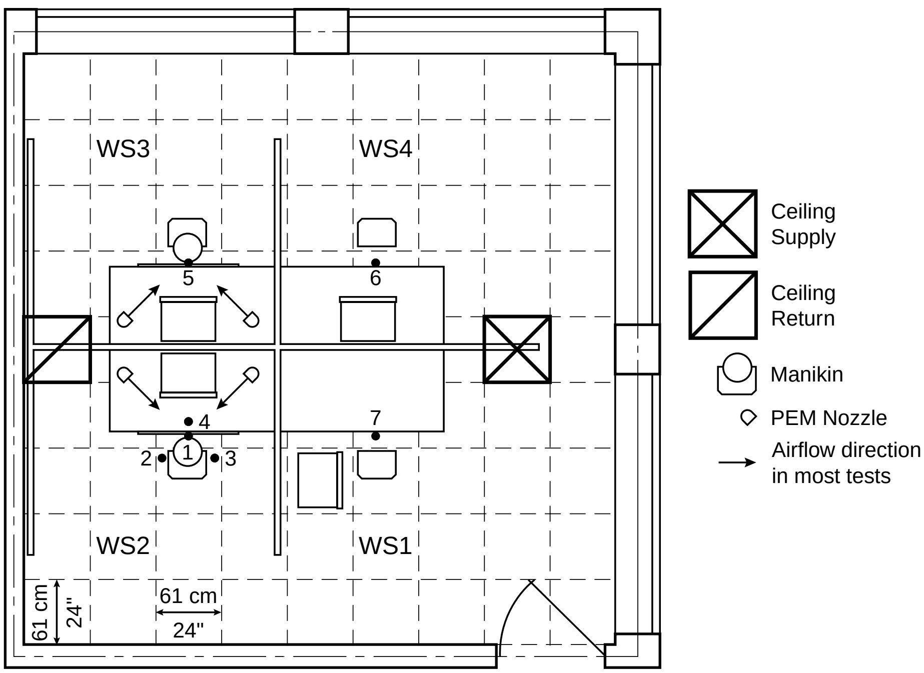

Figure 1. Plan view of CEC with workstations denoted WS1, WS2, WS3 and WS4. All sample points were 1.1 m above the floor. Points 1 and 5 are 3 cm below the tip of the nose; points 2 and 3 are immediately above each shoulder; point 4 is 15 cm in front of the nose; points 6 and 7 are at the edge of the desk.

MEASUREMENT METHODS

ACE was measured using a tracer-gas stepup procedure. After steady state test conditions were established, sulfur hexafluoride (SF_6) tracer gas was injected at a steady rate into the supply or outside air duct. Concentrations were measured every four minutes at locations shown in Figure 1. Ages of air (τ) were determined from the SF_6 tracer data via the equation

$$\tau = \frac{1}{C(t_{end})} \int_0^{t_{end}} [C(t_{end}) - C(t)]dt \qquad (1)$$

where C(t) is the tracer-gas concentration at the point in question, $C(t_{end})$ is the steady-state concentration at the end of the stepup, and t is the time elapsed since the start of tracer-gas injection. The ACE is defined as the ratio, τ_{return} / τ_{bl}, where τ_{return} is the age of the return/exhaust air and τ_{bl} is the average age of air at the breathing level in WS2 and WS3.

Table 1. Experimental conditions and results.

				From each TAC			Ceiling Air Supply per (TAC unit)		ACE	PRE	
TEST	TAC[1]	Air Supply Direction	Manikin Position[2]	%OA[3]	Flow (L/s)	Temp (C)	%OA[3]	Flow (L/s)		Floor Source	Body Source
130	C	Vertical	Upright	100	7	19.1	0	36	1.03	0.88	1.04
132	C	Vert/Horiz	Upright	100	7	19.6	0	35	1.06	1.00	1.28
145	C	Vert/Horiz	Upright	100	7	18.4	0	31	1.15	1.14	1.47
131	C	Horizontal	Upright	100	7	20.2	0	35	1.37	1.15	1.35
140	C	Horizontal	Upright	100	7	25.8	0	33	1.33	1.17	1.31
141	C	Vertical	Lean	100	7	19.4	0	31	1.73	1.55	1.44
142	C	Vertical	Lean	100	7	19.1	0	31	1.83	1.49	1.52
143	C	Vertical	Lean	100	3	24.4	12	31	1.75	1.38	1.52
144	C	Vertical	Lean	100	3	26.1	12	31	1.94	1.35	1.58
135	P	Parallel	Upright	21	37	19.2	0	17	NA	0.92	1.11
136	P	Parallel	Upright	19	38	19.1	0	30	NA	0.93	1.08
137	P	Parallel	Upright	20	38	19.3	0	31	1.04	0.98	1.09
133	P	Toward	Upright	100	10	19.7	0	33	1.63	1.25	1.54
139	P	Toward	Upright	100	9	19.6	0	34	1.42	1.20	1.46
134	P	Toward	Upright	100	10	19.5	0	34	NA	1.20	1.43
138	P	Toward	Upright	15	15	19.0	20	34	1.17	1.00	1.07

1. C: Climadesk; P: PEM
2. Upright: Manikin seated upright about 15 cm from edge of desk.
Lean: Nose of manikin in vertical jet from Climadesk.
3. %OA: Percent Outside Air

For the measurements of PRE, three different perfluorocarbon tracer-gases were used to simulate sources of indoor-generated pollutants. Passive emitters of the first tracer was placed on the floor in each of the four workstations simulating emissions from the floor covering. Passive emitters of the second and third tracer gases were placed on the manikins in WS2 and WS3, respectively. The PRE for the “Floor” and “Body” pollutants were calculated from the equations:

$$PRE_{Floor} = \frac{C_{Floor}^{Return}}{\frac{1}{2}\left(C_{Floor}^{BL2} + C_{Floor}^{BL3}\right)} \quad PRE_{Body} = \frac{1}{2}\left(\frac{C_{Body2}^{Return}}{C_{Body2}^{BL3}} + \frac{C_{Body3}^{Return}}{C_{Body3}^{BL2}}\right) \qquad (2)$$

where the superscript denotes the measurement location (Return duct, Breathing Level in either WS2 or WS3) and the subscript denotes the location of the pollutant source (floor, manikin in WS2 or WS3). The values of PRE_{Body} indicate the efficiency of the ventilation process in controlling exposures to pollutants from the occupants in the adjoining workstation.

RESULTS

The highest values of ACE and PRE were measured, with either of the TAC systems supplying 100% OA at approximately 7 - 10 L/s per occupant, with the air supply directed toward the manikin's face. With the PEM, the nozzles were pointed toward the manikin's face and with the Climadesk, the manikin leaned into the vertical air jet exiting the front edge of the desk. In experiments with the Climadesk (Tests 141 - 144), the high values of ACE and PRE were very localized at the mouth and nose, as measurements of ACE and PRE 15 cm in front of the nose and mouth were close to unity. High values of ACE and PRE were not measured with the manikin seated upright (i.e., with the face not located directly in the vertical supply air jet) and air supplied through the vertical outlet of the Climadesk (Test 130).

The Climadesk also produced high ACE and PRE values when the air supply was entirely horizontal (Tests 131 and 140), directed toward the manikin's torso from beneath the desk. Tests with a smoke tube suggest that some of the outside air supplied horizontally by the Climadesk was entrained in the thermal plume flowing upward along the body and carried into the region of the nose and mouth. Under these operating conditions, high values of ACE and PRE were also measured 15 cm in front of the nose and mouth.

With approximately equal amounts of air supplied vertically and horizontally from the Climadesk, the ACE and PRE values were not consistent. Results from Test 132 indicated little or no improvement in ACE or PRE, whereas results from Test 145 indicate enhanced ACE and PRE as expected. As discussed above, the improved ACE and PRE values with this configuration may be highly dependent upon the manikin position relative to the location of the vertical jet of air exiting the Climadesk.

In two tests with the Climadesk, high values of ACE and PRE were maintained when approximately half of the total outside air supply was provided by the conventional overhead ventilation system. We anticipated a decrease in performance under these operating conditions. However, these results were obtained in tests with the manikin's head located directly in the vertical air supply jet. As discussed above, under these conditions the ACE and PRE will vary considerably with small changes in the position of the head and an optimal location of the manikin's head may have counteracted the expected performance decrease.

DISCUSSION AND CONCLUSIONS

In our previous research [1] with air supplied from the PEM at much higher flow rates (19 to 94 L/s), PREs and ACEs were significantly above unity only if 100% outside air was directed toward the occupants face – a condition that is not likely to be comfortable [7]. Directing the air away from the face made conditions more comfortable but resulted in ACEs and PREs close to unity. These prior results suggest that high rates of air supply from TAC systems may vigorously mix the air within the workstation, making it difficult to preferentially ventilate the breathing zone. With the lower supply flow rates employed in this current set of experiments, ventilation efficiencies were high and thermal comfort conditions were acceptable [8].

For the Climadesk unit operating with a vertical air supply jet, a superior ventilation performance was achieved with the occupant's head located precisely within the vertical jet of air. However, our data and understanding of system performance suggest that supplying air horizontally toward the body's thermal plume is the more robust method of assuring high ventilation efficiencies.

Our findings indicate that energy savings could be realized while maintaining a typical level of IAQ at the breathing zone by allowing rates of outside air supply to be reduced. Values of ACE from 1.3 to 1.9 translate to a 23% to 47% decrease in the design ventilation rate, assuming the airflow pattern is not significantly changed. Alternatively, IAQ at the breathing zone could be improved while maintaining typical rates of outside air supply.

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