INDIVIDUAL THERMAL COMFORT CONTROL WITH DESK-MOUNTED AND FLOOR-MOUNTED TASK/AMBIENT CONDITIONING (TAC) SYSTEMS

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ABSTRACT

Three very different task/ambient conditioning (TAC) systems were investigated in a climate chamber. Two desk-mounted TACs, the "Personal Environmental Module" (PEM), intended for US offices, and the "ClimaDesk" (CDESK), intended for European offices, were compared experimentally with a floor-mounted unit, the "Task Air Module" (TAM). All three provide some individual control of cooling, while PEM and CDESK also provide individual control of heating. They were installed with floor-ducted supply air (19-25°C) in standard office cubicles in a climate chamber, and their effect on the heat loss from a 16-section heated thermal mannequin was measured at various room temperatures (19-25°C). The individual control provided by each unit, in terms of the change in room air temperature that would have affected whole-body heat loss equivalently, was PEM: 9K, CDESK: 3K, TAM: 5K. The "thermal asymmetry" caused by each unit is given as the rate of heat loss from each body section.

INTRODUCTION

Individual control of the thermal microclimate at each workplace has a number of important advantages, in comparison with conventional heating and cooling, which has to assume that all occupants have the same thermal requirements and usually leads to >20% dissatisfied. Even though individual neutral temperatures differ between occupants and occasions and are strongly affected by activity, clothing and fatigue, with sufficient individual control of the thermal microclimate it is theoretically possible to achieve the ideal, in which all building occupants are 100% comfortable all the time. The payback in terms of reduced call-out frequency alone has been shown to be very large [1]. Substantial additional payback will be achieved in the form of increased occupant satisfaction (thermal comfort), reduced frequency of SBS symptoms, and increased productivity [2]. With the inter-individual variability observed in a study of 200 Swedish office workers wearing their own clothes (SD=1.17K), individual control equivalent to changing room temperature ±2K would satisfy >90%, ±2.3K would satisfy >95%, and ±3K would satisfy 99% [3]. The present experiment was carried out to determine whether any existing task/ambient conditioning systems may be said to provide a degree of individual microclimate control approaching or exceeding these values for an office worker seated at a desk, and under what conditions of supply air flow, supply air temperature and room temperature.

METHODS

Four 2.3 x 1.9 m office cubicles with 1.7 m high partitions, with open doorways, were installed in a controlled environment chamber (CEC) in a university laboratory. The CEC has a 5.5 x 5.5 m floor area and a 2.5 m ceiling height [4]. Room temperature is controlled by means of conventional supply and return air vents in the ceiling. Standard office equipment, including a desk with a heat source simulating a PC, was installed in 3 of the cubicles, and a different TAC was installed in each of these. Each TAC was provided with the requisite amount of conditioned supply air from ducts beneath the raised access floor.

PEM: The Personal Environmental Module mixes room air from beneath the desk with a nominally 6-71 L/s supply air flow so as to achieve the required supply air temperature. The fan speed is variable and the supply air emerges from two vents 0.3 m above the desk surface, at the back corners. These vents can be rotated 360° about a vertical axis and have vanes which can direct the air flow ±30° from the horizontal. Supply air flows of 9.5-71 L/s were used in the present study. A 200 W electrically heated panel stands vertically on the floor in a position determined by the occupant. An infra-red movement sensor on the control panel, which stands on the desk surface, normally keeps the unit switched on while the workplace is occupied.

CDESK: The ClimaDesk nominally supplies 0-7 L/s of supply air to two laminar-flow vents under the desk surface, 0.6 m behind the front edge. The fan speed is variable and these vents can be rotated ±30° horizontally to either impinge on the occupant or pass close by. 0-100% of the air flow can be directed to a third laminar-flow vent at the front edge which is directed upwards 7° backwards from the vertical, i.e. slightly away from the occupant, to minimize the resultant cooling effect. Supply air flows of 3.5-7.1 L/s were used in the present study. A 200 W electrically heated panel, 0.8 x 0.6 m and capable of maintaining any required surface temperature up to 50°C, is fixed to the underside of the desk surface, i.e. horizontal and just above the occupant's thighs. An infra-red movement sensor on the panel underneath the desk normally keeps the unit switched on while the workplace is occupied.

TAM: Each Task Air Module, measuring 0.6 m by 0.6 m, can be located at any position in a raised access floor system simply by exchanging it with a solid floor panel of equal size. An adjustable-speed fan/motor assembly draws air from the sub-floor plenum and supplies it to the room through four 127-mm diameter discharge grills. Fixed individual vanes in the grills are inclined at 40° from vertical. A rotary speed control knob is recessed into one grill and each grill can be rotated 360°, allowing office workers to control both the direction and quantity of air supplied from the module. When the fan is switched on, the TAM can deliver 43-85 L/s from a zero or very low pressure floor plenum. Supply air flows of 23.6-85 L/s were used in the present study.

Thermal mannequin: A 16-section heated thermal mannequin was used to simulate a person seated at each of the desks with a TAC unit in turn. The mannequin was dressed in a tight-fitting lightweight set of clothing covering all but head and hands, with a total (clothing plus air layer) whole-body insulation value of 0.181 m^2K/W (1.17 Clo). It could be soaked with distilled water to determine the maximum rate of evaporative cooling when sweating. The mannequin simulates a female occupant with hair length just below the ears. It maintains a constant skin temperature distribution characteristic of an occupant in thermal neutrality at all times and the electrical power per unit surface area (W/m^2) that must be supplied to each section to maintain the set skin temperature at equilibrium is an accurate and reproducible estimate of an occupant's rate of heat loss from that body section in the same microclimate. An occupant's whole-body rate of heat loss is estimated as the area-weighted sum of the sectional rates of heat loss. The mannequin was always placed centrally, 0.1 m from the front edge of the desk, seated in an upright posture on a typical typist's chair, i.e. a minimally upholstered chair with a small lumbar support, whose effective insulation was equivalent to an additional 0.023 m^2K/W (0.15 Clo), with arms slightly bent and hands and forearms resting on the desk surface.

Experimental conditions: Desired room air and supply air temperatures were maintained constant by the CEC control system. A number of combinations of room air temperature and supply air temperature in the range of 19-25°C were studied. For each test condition, preliminary experiments were carried out to optimize airflow direction, fan speed, and heater setting to achieve maximum cooling and heating, respectively. Supply air flow was measured using a series of long, small-diameter, straight pipes with pitot tubes and venturi flow meters mounted beneath the floor. In some of the test conditions, the partitions between the cubicles were removed. Detailed results are given in [5].

RESULTS

Sectional and whole-body rates of heat loss from the mannequin were measured under a variety of conditions [5]. They were converted to EHT-values [6] by means of reference exposures with the same clothing and posture (Equivalent Homogeneous Temperature or EHT is defined as the temperature of a uniform space, with all surface temperatures equal to air temperature and no air movement other than the self-convection of the mannequin, in which the rate of heat loss from a given body section would be the same as was actually measured under the experimental conditions). This index reduces any combination of environmental variables into a single temperature that can be readily understood, as it is closely related to typical indoor experience. Figs. 1-3 present the sectional rates of heat loss in the form of profile diagrams of ΔEHT (the change in EHT from reference conditions [same room temperature with no TAC airflow] caused by the device in use) for the settings found to yield the highest degree of individual control of whole-body EHT, for PEM, CDESK and TAM, respectively.

DISCUSSION

All three devices provide individual control of cooling. The amount of cooling was dependent primarily on the air supply volume and direction, and to a lesser degree on the supply air temperature, the proximity of the supply device to the mannequin, and the room air temperature. The maximum amount of individual control of cooling provided by each unit, in terms of the change in room air temperature that would have affected whole-body heat loss equivalently without local air movement, was PEM: 7K, TAM: 5K, CDESK: 1K. These values were achieved with the supply air directed toward the mannequin in such a way as to maximize the convective heat loss from the mannequin. PEM provided the highest cooling rate, as it delivers a high volume of air directly onto the chest, head, and arms of the mannequin. Although TAM has a higher maximum supply volume than PEM, its air supply comes from a location further away, at floor level and to the left side of the mannequin, reducing the cooling effect on the body that can be achieved. CDESK naturally provided the smallest cooling impact, as the maximum supply volume is only 10% of that of PEM or TAM.

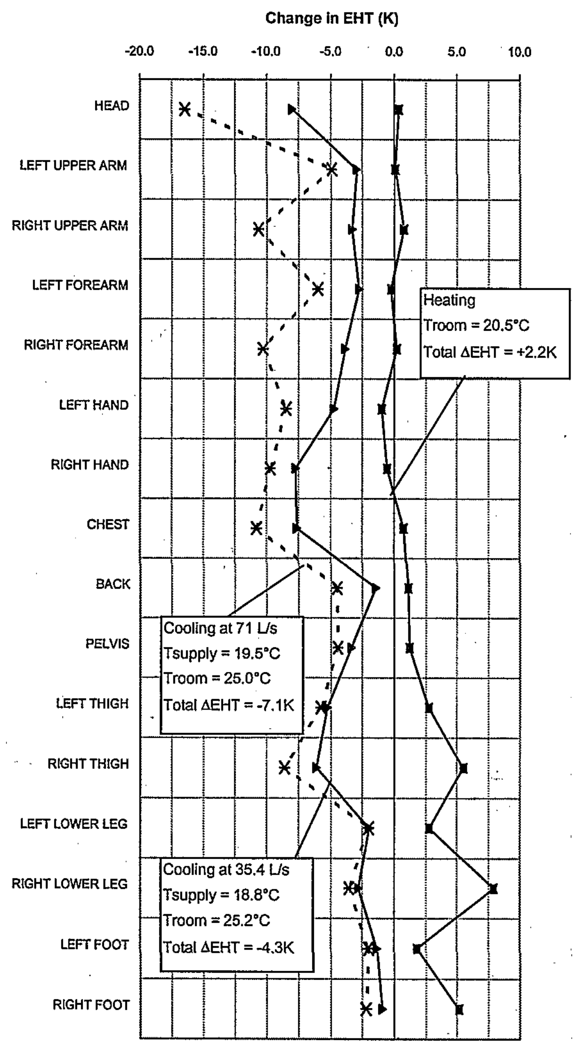

Figure 1. Mannequin profile diagram for PEM: Change in EHT from reference conditions

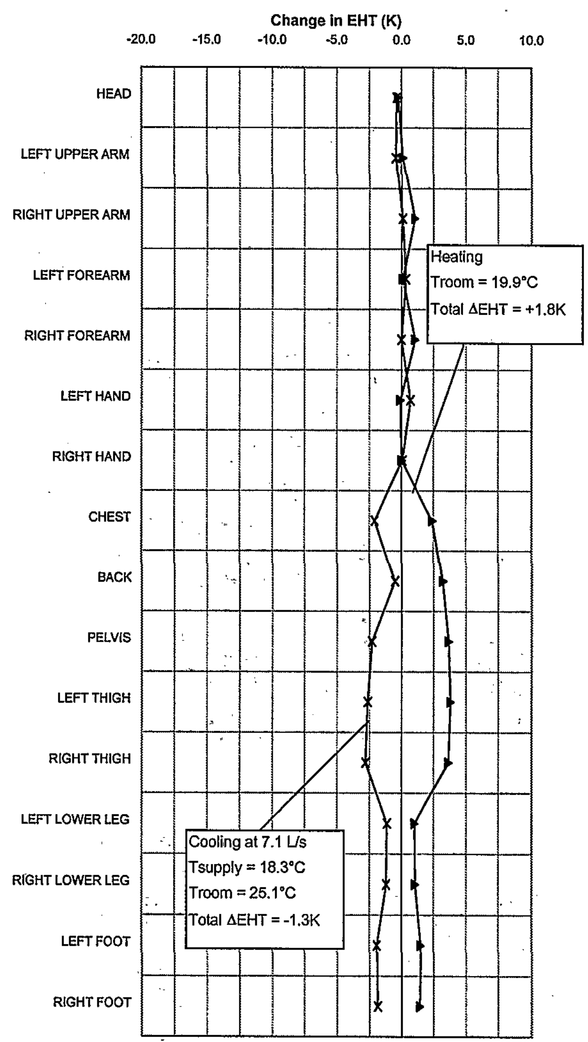

Figure 2. Mannequin profile diagram for CDESK: Change in EHT from reference conditions

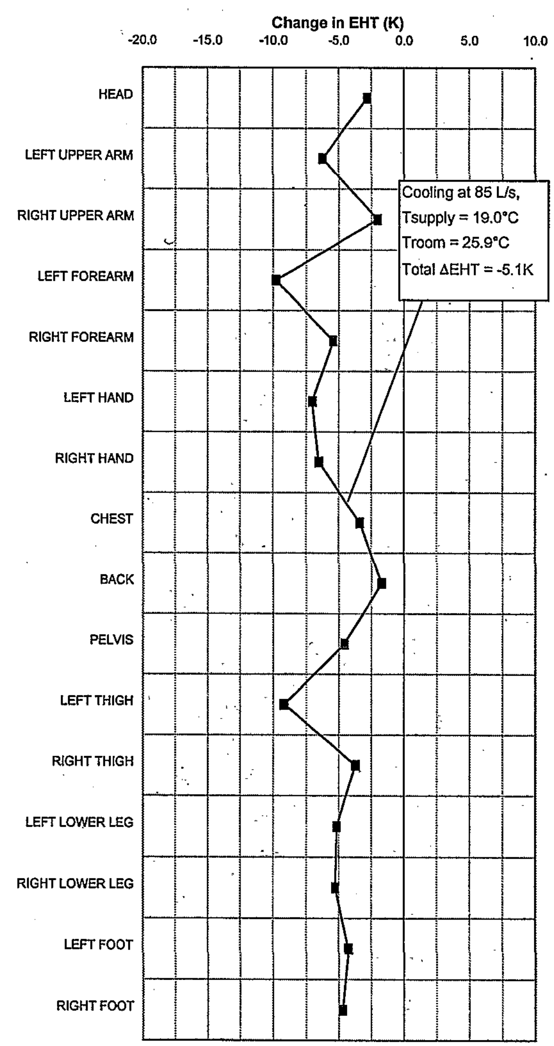

Figure 3. Mannequin profile diagram for TAM: Change in EHT from reference conditions

Since all three TAC units deliver air that impacts only certain parts of the human body, some amount of thermal asymmetry does occur. The sectional results for the mannequin display the magnitude of this asymmetry, which is largest for the maximum cooling rates obtained for PEM. In fact, some of the individual body parts directly exposed to the high velocity supply air (head, chest, right upper arm, right forearm [Fig. 1]) experience EHTs that are below 16°C, which is taken here as a practical lower limit for long-term exposure (health regulations in many countries mandate at least 16°C for homes and sedentary work, as that temperature requires for thermal neutrality a clothing insulation of 1.5 clo, i.e., 50% above normal indoor clothing, which is difficult to exceed without adding blankets or items of outdoor clothing). The EHT measured under reference (still air) conditions in the nominally 25 °C room was actually closer to 26 °C, so all values of delta EHT greater than 10K would be below 16 °C. The next highest cooling rate obtained for PEM at the 50% flow rate of 35.4 L/s did not produce any individual sectional EHT values below 16°C and can therefore be considered as acceptable for long-term exposure. The maximum whole-body cooling in comparison to reference conditions for PEM at the 50% flow rate was 4.0-4.5K. The maximum cooling rate for TAM, although obtained at a higher flow rate of 85 L/s, produced some individual sectional EHT values that were very close to but not below 16°C. The whole-body cooling for the TAM at this maximum condition was 5.0-5.5K below reference, suggesting that 5K of cooling is a good estimate for the maximum cooling rate suitable for long-term exposures. For short-term cooling, of course, the maximum cooling rate of 7K for PEM can be used.

Both PEM and CDESK provide individual control of heating, while TAM does not. Figures 1 and 2 show the different effects that the heating panels for PEM and CDESK have on the mannequin. The PEM heater was placed on the floor to the right of the mannequin producing the largest increases in EHT for the right thigh, lower leg, and foot. The CDESK heater was under the desk and had the largest effect on both thighs and the pelvic region. Although the radiant heating panels for PEM and CDESK are located in different orientations, they both provided about 2K of heating, in terms of the change in room air temperature that would have affected whole-body heat loss equivalently. Therefore, the total range of equivalent whole-body temperature control (heating plus cooling) provided by each device was PEM: 9K, TAM: 5K, and CDESK: 3K.

At its lowest flow rate, 9.4 L/s, PEM focused still provided a 1-2K whole-body cooling effect, similar in magnitude to that provided by CDESK at its maximum flow rate, 7.1 L/s. While these cooling rates may not be high enough to satisfy the needs of a warm occupant wanting to recover quickly to equilibrium with the environment, they may be satisfactory for a majority of situations in which the occupant requires only minor adjustment of the local thermal environment. In ventilation effectiveness experiments carried out in parallel [7], significant improvements in air change effectiveness and pollutant removal efficiency were measured when 100% outside air was provided to PEM or CDESK at these same low flow rates. Future TAC systems should therefore include the possibility of using quite low air supply volumes.

PEM and TAM were also tested with a "defocused" flow direction in which the supply air was directed away from the mannequin in such a way as to maximize air circulation within the partitioned workstation. Under these conditions, PEM provided up to 2-3K whole-body cooling effect, while TAM provided almost no measurable cooling. The stronger influence of PEM is due to the horizontal flow direction of the desk-mounted nozzles, which is more easily contained by the partition configuration. In comparison, TAM supplies air at a 40-degree upward angle, making it more difficult for the partitions to contain the air movement.

When the partitions were removed, PEM defocused provided approximately 1K of whole-body cooling, while TAM provided no cooling at all.

The wet mannequin tests determined the rate of evaporative (latent) cooling provided by these TAC units when the mannequin had a fully wetted surface. The evaporative cooling rate was very large in comparison to the sensibly cooled (dry) mannequin results. At 0.20 skin wettedness, the maximum fraction of the skin that can be wet and be perceived as comfortable, the combined evaporative and sensible cooling would for most of the tests have more than doubled the total whole-body cooling rate measured with the dry surface.

CONCLUSIONS

TACs are capable of delegating considerable control of heat balance to the individual occupant. Among the three TACs tested, the change in room temperature that would have affected whole-body heat loss equivalently (ΔEHT) ranged from 3-9K. Although thermal control is somewhat reduced at lower flow rates, significant improvements in ventilation effectiveness are observed when 100% outside air is supplied through the desk-mounted TAC units, making this operating condition an important feature of future TACs.

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