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IMPLEMENTATION OF DISPLACEMENT VENTILATION SYSTEM BY USING A WALL-MOUNTED AIR CONDITIONER

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ABSTRACT

Wall-mounted air conditioning systems including window-type and split-type air conditioners are widely used in Asian countries. However, these systems blow cold air directly into the working space perpendicular to the mounted wall and may make people affected by these air conditioners experience discomforts such as draught and uneven temperature distribution. Now a wall-mounted air conditioning system is expected to effectively implement the displacement ventilation system for space cooling and cold draught avoiding. Computer simulation method and experimental measurement were used to justify this new system design. Thermal comfort indices (PMV & PPD) as well as temperature and velocity patterns were reported in this paper. The results show that the displacement ventilation system, which was designed for a centralized air conditioning system in the past, can now be implemented in a rather small-scaled residential air conditioning system.

KEY WORDS

Displacement ventilation system, Wall-mounted air conditioning system, Thermal manikin, Thermal comfort, Draught, CFD

INTRODUCTION

Displacement ventilation systems have been widely used in European countries for many years. These systems have been viewed as a more efficient ventilation method, particularly, in providing a higher order of indoor air quality. In these systems, low velocity air is supplied from a low-level supply device directly into the working space at a temperature slightly cooler than the design room air temperature, while warm air is extracted at high-level. The driving force in displacement ventilation is therefore the internal heat source. The free convection from these heat sources creates a vertical air movement in the room. The momentum flux from the supply air terminal is very slow with no significant importance to the general room air movement. In recent years, many applications of displacement ventilation have been implemented. In 1998, F. Alamdari used the CFD method to study the advantage of cooled ceilings combine with displacement ventilation. M.G.L.C. Loomans used experimental and CFD method to investigate the improved desk displacement ventilation concept.

This paper demonstrates a new wall-mounted air conditioning system, which can effectively implement the displacement ventilation system for space cooling. In this new system, cooled air is distributed though the four outlets pointing at four evenly spaced planar directions parallel to the mounted wall. At first, air ejected from these outlets moves closely along the wall. When it reaches the working zone, the air speed has been greatly reduced to avoid cold draught.

To justify the performance of this new system, experimental measurement was used to analysis the influence on the thermal sensation as well as the skin surface temperature and dry heat loss of a thermal manikin caused by the operation of a wall-mounted displacement ventilation system and a split-type air conditioner. The temperature field was measured by using 480 T-type thermocouple sensors. The CFD software-FLOVENT was utilized to study the velocity distribution around the human body to compensate the restriction of experimental measurement. The numerical model of FLOVENT is based upon the "Finite Volume Method". In 1998, Dr. Kato et al. used the 3-D CFD method to investigate the flow, temperature and moisture fields around a human body. They have done an in-depth study on this. The purpose of this paper is to justify that the new wall-mounted air conditioner can effectively implement the displacement ventilation system and produce more comfortable indoor environment than a split-type air conditioner. So the simplified model was applied for the CFD simulation to save a lot of time. The simulation results were also compared with the experimental results to verify the credibility of this assumption.

THERMAL COMFORT MEASUREMENT

The real thermal environment is non-uniform, so the thermal sensation of each human body part is different. To express the real thermal sensation of a thermal manikin, the so-called manikin-based equivalent temperature t_{eq} was used. Manikin-based equivalent temperature t_{eq} is defined as the temperature of a uniform enclosure in which a thermal manikin with realistic skin surface temperature would lose heat at the same rate as it would in the actual environment. The equation of t_{eq} can be written as:

$$t_{eq} = t_s - 0.155\ I_t \cdot Q_t \qquad (1)$$

$$I_t = (t_s - t_o) / 0.155\ Q_t \qquad (2)$$

In this study, the thermal sensation of a thermal manikin was measured in the indoor unit of the Indoor Environment Research Laboratory at ITRI. The indoor unit has two rooms (A & B) with the same size of 4.8m (length)×3.7m (with)×2.7m (height) as shown in Figure 1 and 2. A new wall-mounted displacement ventilation system was installed on the left wall at 1.6m above floor in room A and a split-type air conditioner was installed on the right wall at 2.2m above floor in room B. The temperature of the outdoor unit was controlled at 30°C. The cooling capacity of both air conditioners was 2500 kcal/hr. The supply air temperature was 18°C for both air conditioners.

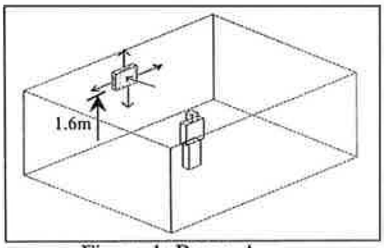

Figure 1: Room A

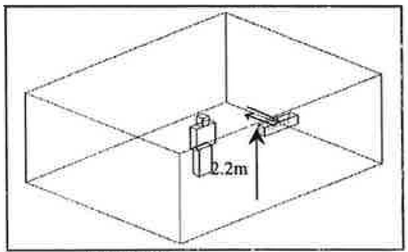

Figure 2: Room B

Figure 3 shows the dressing and the posture of the thermal manikin. Figure 4 shows the changes of skin surface temperature of the thermal manikin with the operation time of air conditioners. Figure 5 shows the equivalent temperature based on the thermal manikin as the skin surface temperature approaching the steady state.

Figure 3: Picture of thermal manikin

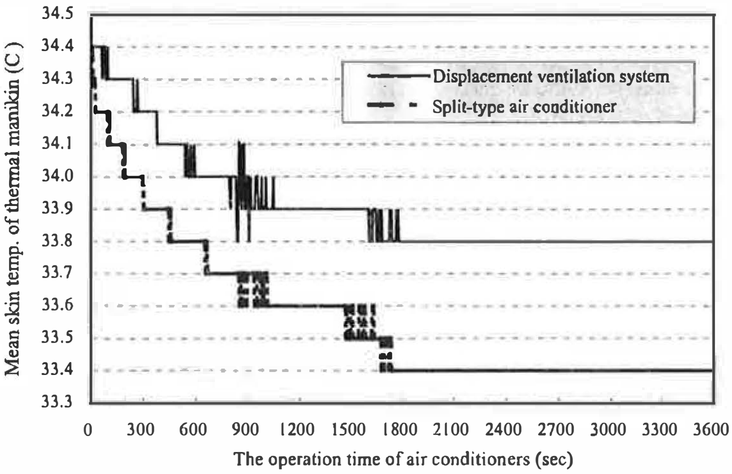

Figure 4: T_{skin} of thermal manikin V.S. the operation time of air conditioners

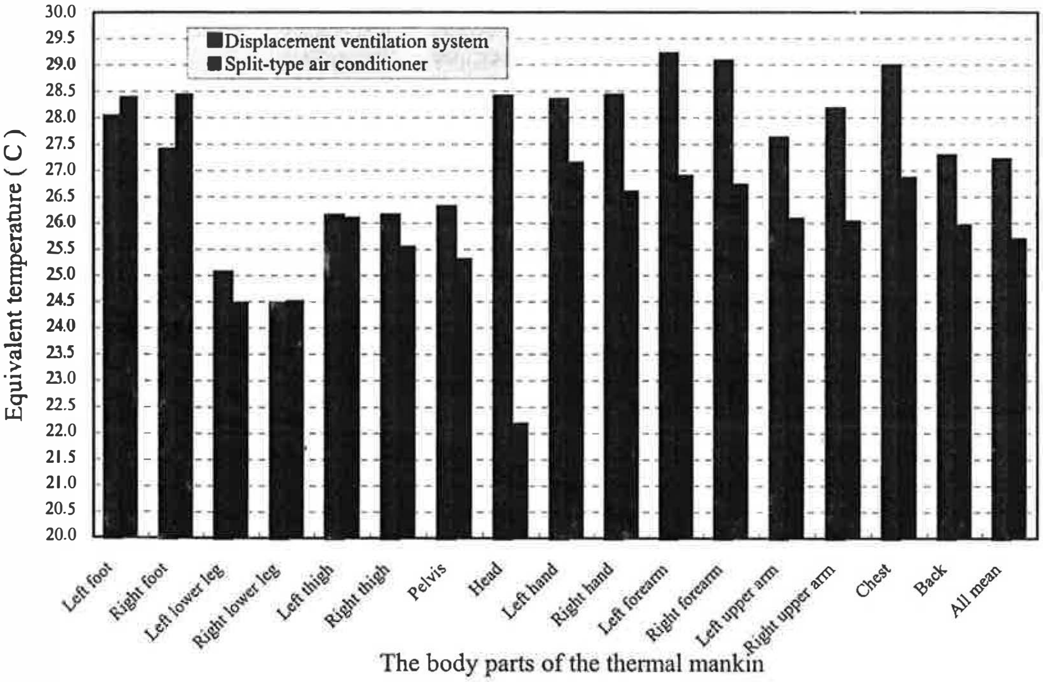

Figure 5: The equivalent temperature based on thermal manikin

As shown in Figure 4 and 5, when using the wall-mounted displacement ventilation system for space cooling, it took about 30 minutes for the mean skin surface temperature of the thermal manikin to become stable and the final mean skin surface temperature was 33.8°C. Using the split-type air conditioner took about 28 minutes to be stable and the final mean skin surface temperature was 33.4°C. There is no significant difference in the cooling pull-down time between these two air conditioners. But the final skin surface temperature of the thermal manikin shows that the split-type air conditioner, which blew cold air directly to the thermal manikin, produced lower but comparatively non-uniform manikin-based equivalent temperature.

Thermal comfort indices (PMV & PPD) may be easily calculated based on thermal manikin measurement. Since t_{eq} is defined as being under uniform conditions, PMV is calculated by inserting t_{eq} into the air temperature and mean radiant temperature of the program. The mean air speed was obtained by averaging omni-directional air speed measurements taken between 0.1 and 1.6m above the floor close to the manikin. The mean air speed was 0.13m/s in room A and 0.55m/s in room B. Relative humidity was 45% in both rooms as the original control set-up. The clothing of the thermal manikin was 0.4Clo and the metabolism rate was 1.2Met. In room A, PMV was 0.44 (PPD = 9%) and the thermal sensation was comfortable. In room B, PMV was –0.71 (PPD = 16%) and the thermal sensation was slightly cool.

SIMULATION RESULTS

Using the measurement data as the boundary conditions. In room A, the supply air temperature was set at 18°C and the velocity was 3.5m/s. In room B, the same supply air temperature was used but the velocity was 6.0m/s. The skin surface temperature of the human body was set at 33.8°C and the heat loss was 70W/m ^{2} according to experimental measurement. The temperature of external walls was set at 30°C.

Figure 6 and 7 are the temperature fields of CFD simulation results. As shown in Figure 6, a stratified temperature field in room A is observed to have the same pattern for a conventional displacement ventilation system. As shown in Figure 7, the head location is directly blew by cold air from the split-type air conditioner and people in this room may feel local thermal discomfort caused by the draught.

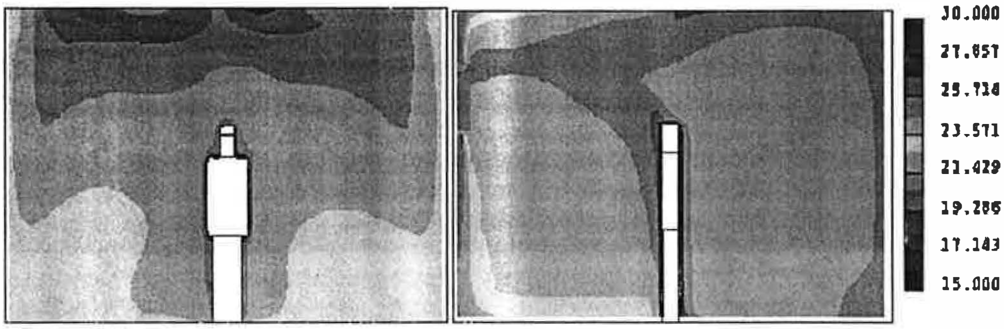

Figure 6: Temperature field in room A

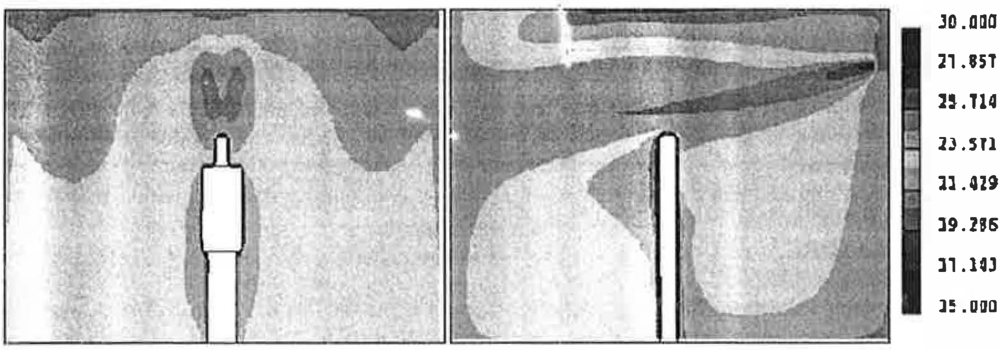

Figure 7: Temperature field in room B

To make a comparison between the temperature field of CFD simulation results and that of experimental results, as shown in Table 1, the CFD simulation results are similar to the experimental results and have a deviation smaller than 10%. So the CFD model is creditable and the velocity field around the human body can be representable by CFD simulation. Also in Table 1 the room temperatures measured in room A show average 0.3°C ~ 0.7°C higher than those in room B. This is because more heat is brought into the space by the enhanced convection heat transfer on the building envelopes. However, the consumption of more energy in turn is compensated by more comfortable indoor environment for the new wall-mounted air conditioner using the displacement ventilation concept. As shown in Figure 8 and 9, the mean air velocity experienced by people in room A is about 0.1m/s and there is no problem about cold draught. But in room B, the cold supply air directly blew to the head and may cause local thermal discomfort such as draught.

TABLE 1
TEMPERATURE COMPARISON BETWEEN CFD AND EXPERIMENTAL RESULTS

	Location(x,y,z)m	(0.3,1.9,1.1)	(1.2,1.9,1.1)	(2.6,1.9,1.1)	(3.5,1.9,1.1)	(4.5,1.9,1.1)	(2.1,1.9,0.1)	(2.1,1.9,0.6)	(2.1,1.9,1.1)	(2.1,1.9,1.6)	(2.1,1.9,2.1)	mean
New-type	-Experiment	24.9	24.7	24.8	24.5	24.3	23.1	24.7	24.7	25.1	25.6	24.6
air conditioner	-CFD	23.9	23.6	24.0	23.6	23.8	23.9	24.2	24.3	24.3	24.6	24.0
Traditional	-Experiment	23.8	24.4	24.7	24.6	24.3	24.2	24.3	24.7	23.5	24.2	24.3
air conditioner	-CFD	23.3	23.2	23.9	23.3	23.3	23.6	23.9	24.1	22.5	21.9	23.3

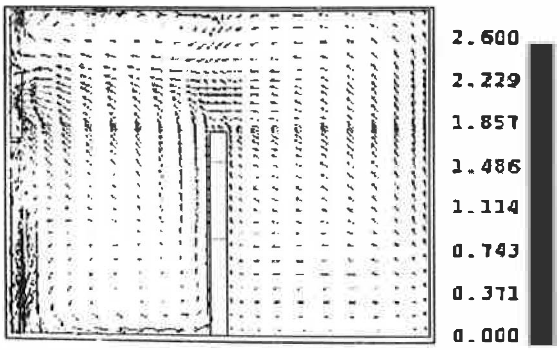

Figure 8: Velocity field in room A

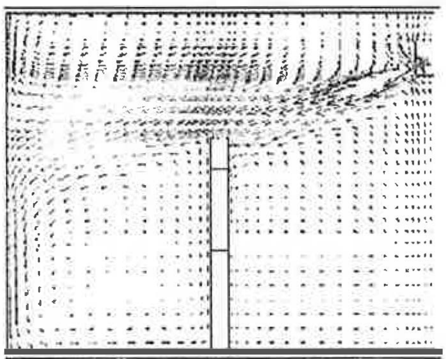

Figure 9: Velocity field in room B

CONCLUSIONS

To integrate the experimental and CFD simulation results, it shows that the new wall-mounted displacement ventilation system produces more comfortable indoor environment than a traditional air conditioner. The displacement ventilation system, which was designed for a centralized air conditioning system in the past, can now be implemented in a rather small-scaled residential air conditioning system.

NOMENCLATURE

I_t • Total clothing insulation (Clo)

Q_t • Sensible heat loss from skin surface (W/m^2)

t_{eq} • Equivalent temperature based on thermal manikin (°C)

t_s • Skin surface temperature of thermal manikin (°C)

t_o • Operative temperature (°C)

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