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Analysis on the Age of Air and the Air Change Effectiveness of the Personal Environmental Module System in Intelligent Buildings

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Abstract

An interesting of desktop air-conditioning system is the Personal Environmental Module(PEM) System. The PEM system allows the occupant to choose the desired temperature, air volume and direction of the discharged air. In this study, the measurements on the age of air and the air change effectiveness, using the tracer gas method, are carried out to analyze the ventilation performance for provision of fresh air near the breathing zone by the PEM. The relations between the PEM for optimal control and other factors related to indoor air quality, and the ventilation for the PEM are examined. Also, three different supply diffuser types(desktop, floor and ceiling) are compared in view of their ability to distribute supply air to the workstation breathing zone. The desktop diffuser type could deliver air directly to the occupants breathing zone with a high degree of effectiveness. The minimum local age of air was measured in the breathing zone, which is directly supplied with air from the PEM diffusers, and the measured local air change effectiveness of the desktop diffuser in the breathing zone was about 1.13 to 1.23 times greater than that of the ceiling and floor diffusers. When the minimum outside air change rate as specified using ASHRAE Standard 62R is supplied with a desktop diffuser type, the volume of outside air can be reduced 13 to 23%, resulting in a commensurate in ventilation energy use.

Keywords: age of air, air change effectiveness, Indoor air quality, personal environmental module system, intelligent building, DVR

1. INTRODUCTION

Over the past several decades, many strategies have been developed in an effort to reduce energy consumption in buildings. This has often resulted in very airtight buildings with very little natural ventilation and increased levels of indoor air pollutants (Grieve, 1991).

A factor contributing to this increase is the use of construction materials and furnishings which off-gas volatile compounds. This makes ventilation techniques for removing indoor air pollution and providing fresh outside air in buildings more important than ever. However, many ventilation systems do not perform as well as they should. Often, the air supplied to the space does not reach the occupants because of poor air delivery and circulation (Cho, Ries and Mahdavi, 1998). The building occupants cannot easily determine whether the air supplied is re-circulated or fresh outside air. For human health, we must be concerned with both the quantity and the quality of outside air introduced into indoor space.

One of the techniques for providing ventilation air is an occupant-based system, the Personal Environmental Module (PEM) (Cho, 1998). The PEM has the advantage that it introduces air directly to the occupant's breathing zone. The PEM system allows the occupant to choose the desired volume (fan speed control) and direction (diffuser rotation and louver angle) of the discharged air. The control of the PEM is in the hands of the people who occupy individual workstations.

In this study, measurements of the age of air are carried out to evaluate the effects of directly delivered ventilation air to occupants and to estimate the ventilation performance of the PEM system. The age of air and air change effectiveness for three supply diffuser locations is compared. Finally, estimated energy savings of improved ventilation effectiveness, user based controls and occupancy sensors are calculated.

2. MEASUREMENT METHOD AND CONDITION

2.1 Measuring age of air and air change effectiveness

The ability of the ventilation system to provide fresh air to the breathing zone depends on the fresh air intake rate and the distribution of the flow by the system. Age of air and air change effectiveness measurements can be used to evaluate ventilation systems in buildings. The age of air is the length of time that some quantity of outside air has been in a building zone or space (ASHRAE, 1997a). The zone average or nominal age of air can be determined by tracer gas concentration measurements. By taking concentration measurements in the exhaust air and at any desired point in a space, such as at an individual desktop workstation, the local age of air can be determined. Air change effectiveness is an air distribution system's ability to deliver ventilation air to a building, zone or space (ASHRAE, 1997a). The nominal air change effectiveness is the effectiveness of outside air delivery to the entire building, zone or space, and the local air change effectiveness is the effectiveness of outside air delivery to a specific point in a space. The principal advantage of the age of air method is that measurements can be made for individual points in a room. Using tracer gas sampling instruments with the tracer gas concentration decay method is the most common way to determine age of air.

In a concentration decay test, the space being tested is assumed to be at a uniform tracer gas concentration, C_0, at time $t=0$. The tracer gas concentration in the space then decreases toward the outdoor concentration, assumed to equal zero, at a rate that depends on the air change rate of the space and the location within the space. The age of air at a point i in the space is given by:

$$A_i = (1/C_0) \int C_i \, \delta t. \qquad \text{(Eq. 1)}$$

In ASHRAE Standard 129-1997 "Measuring Air Change Effectiveness", the age of air from a tracer gas decay test can be calculated from the following equation:

$$A_i = (T_{stop} - T_{start})\, C_{avg} \;/\; C(T_{start}). \qquad \text{(Eq. 2)}$$

where

A_i = the age of air at location i

T_{stop} = the time of the final tracer gas measurement at location i during the tracer gas decay or, with time-integrated sampling at location i, the time when sampling is terminated

T_{start} = the time when outdoor air flow is started or tracer injection is stopped at the beginning of a tracer gas decay

C_{avg} = the time-averaged tracer gas concentration at location i between time T_{start} and T_{stop}

$C(T_{start})$ = the tracer gas concentration at location i at time T_{start}.

Also, the nominal time constant is calculated using the following equation:

$$\tau_n = \Sigma(Q_{ex}\; A_{ex}) / (\Sigma Q_{ex}). \qquad \text{(Eq. 3)}$$

where

τ_n = the nominal time constant

Q_{ex} = the rate of airflow in the exhaust air stream

A_{ex} = the age of air in the exhaust air stream.

The air change effectiveness is calculated from the equation:

$$E = \tau_n / A_{avg}. \qquad \text{(Eq. 4)}$$

where

E = the air change effectiveness

A_{avg} = the arithmetic average of the ages of air measured at the breathing level within the test space.

2.2 The test space and experiment conditions

The tests to measure the ventilation performance of the desktop PEM in a workstation were conducted in one bay of the south zone of the Intelligent Workplace (Cho, Ries and Mahdavi, 1998) at Carnegie-Mellon University. The bay was isolated from the rest of the Intelligent Workplace using plastic sheeting. As shown in Fig. 1 and Fig. 2, the dimensions of one bay are 4.8m by 9.8m by 4.8m. Six workstations with PEMs were set up for the measurements. The B & K multi-gas monitoring equipment (B & K photo-acoustic multi-gas monitor 1312 and multi-point sampler and doser 1303) was used for sampling and measurement of tracer gas concentrations and air temperature at the sampling points. Tracer gas samplers were installed at a total of 6 locations (breathing zone, standing zone, return duct (top, bottom), center of bay and supply diffuser of the PEM) within the bay as specified in Fig. 3 and Table 1. The concentration decay method according to ASTM 1993 (Cho, 1998) was used for measuring the age of air and air change effectiveness in the bay. A thermal comfort meter (B & K 1221) was used for air speed and operative temperature measurements as well as thermal comfort indices at the breathing zone.

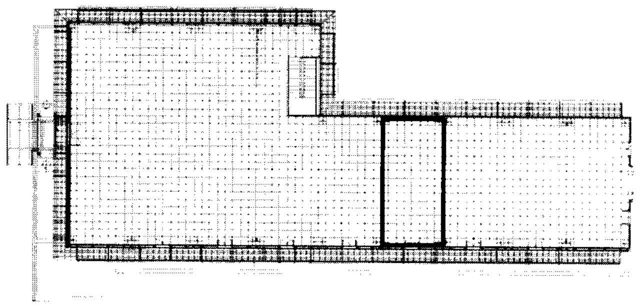


Figure 1. The floor plan of the Intelligent Workplace

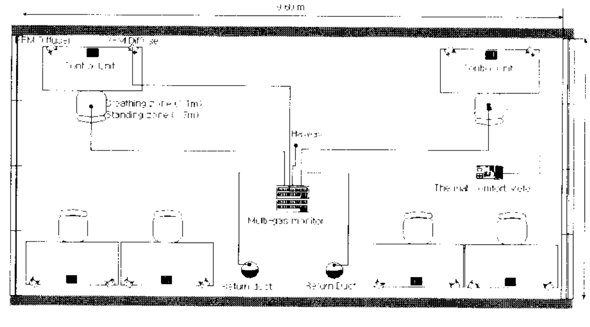


Figure 2. The test space and multi-gas monitoring equipment

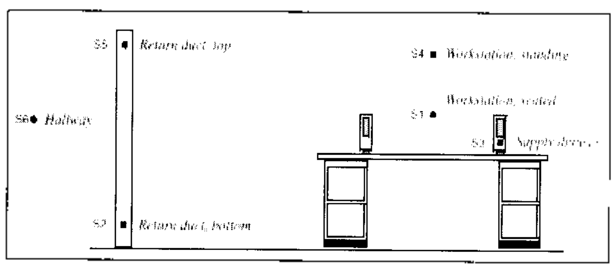


Figure 3. Locations of tracer gas samples

The data related to the HVAC system was acquired from the main control system and the measures for outdoor conditions (temperature, wind speed and direction) were acquired from the weather station(Met one Instruments Model 907) located on the roof of the Intelligent Workplace.

For the tests, the outside air damper was set to introduce 100% outside air to the PEM diffuser through the makeup air handling unit(MAU). SF_6 is used as the tracer gas. While the mechanical system is temporarily shut down, SF_6 is rapidly released in the measurement space until a suitable concentration level is reached. Electric fans were used for mixing the SF_6 in the test bay to a uniform concentration. After a uniform distribution of tracer gas was achieved, the mechanical system was started and the concentration measurement for the local age of air at all locations began. The measurements were continued until the concentration in the return duct decreased by 95%.

The concentration measurements from the six sampler locations are used to calculate the local age of air at each sampler location in the bay. The mean age of air for the bay is calculated based on the concentrations measured in the return duct. The B & K 1312 used for sampling in the age of air test takes 3 minutes to analyze each of the six sampling points once. Linear interpolation was used on the concentration values of the six samplers to calculate the concentrations at common start and end times. To minimize the measurement error from outdoor environmental conditions, a set of related measurements were carried out in the same day. Also, to capture the changes in the infiltration air change rate (also dependent on outdoor weather conditions), the infiltration test is repeated every measurement day. Table 2 summarizes the default measurement settings and conditions.

Table 1 Default sampler location

Sampler	Sampler location
Sampler 1	Breathing zone (1.1m height above floor level)
Sampler 2	Return duct (0.2m height above floor level)
Sampler 3	Inside of supply diffuser
Sampler 4	Standing level (1.7m height above floor level)
Sampler 5	Return duct (top level)
Sampler 6	Hallway in the middle of the bay (1.1m height above floor level)

Table 2. Default measurement settings and conditions

Condition	Item
Diffuser speed	Maximum mode
Air flow direction	Toward occupant
Return duct	Both open
Ratio of outside air	100 %
Re-circulating duct of PEM	Close

3. AGE OF AIR AND AIR CHANGE EFFECTIVENESS OF THE PEM

3.1 Scenario I - All workstations are occupied

The Personal Environmental Module (PEM) system is an easy-to-use desktop control unit that gives each person the flexibility to adjust the characteristics of the air flow as often as necessary to maintain personal comfort levels. The supply air depends on the supply fan speed of the PEM, which can be selected from the maximum to off mode, and on the static pressure of the supply plenum. Under the premise that all workstations are occupied, three experiments are conducted according to the supply fan speed (maximum, medium and off modes). The experiment results (the age of air and air change effectiveness) are listed in Table 3. The experiment conditions are summarized in Table 4.

Table 3. Measurement results (age of air and ventilation effectiveness) for Scenario I

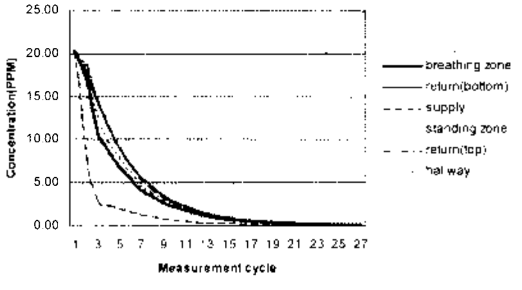
Control mode	Maximum mode		Medium mode		Off mode	
Item	*Ai*	*Ei*	*Ai*	*Ei*	*Ai*	*Ei*
Breathing zone	14.42	1.20	16.75	1.16	20.77	1.14
Return duct (bottom)	17.28	1.00	19.50	1.00	23.65	1.00
Supply diffuser	7.32	-	7.72	-	6.03	-
Standing zone	16.15	1.07	17.80	1.10	23.08	1.02
Return duct (top)	17.10	1.01	19.50	1.00	24.43	0.97
Hallway	17.35	0.99	19.62	0.99	23.95	0.99

Table 4. Measurement conditions of Scenario I

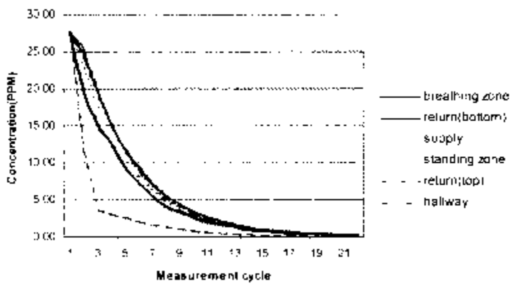
Control mode		Maximum mode	Medium mode	Off mode
Indoor condition	Operative t	21.5 C	20.8 C	20.8 C
	Indoor t	22.7 C	21.9 C	22.4 C
	Air speed	1.18m/s	0.64m/s	0.44m/s
MAU Condition	Discharge t	20.9 C	20.6 C	21.2 C
	Return t	22.8 C	22.8 C	22.8 C
Outdoor condition	Outdoor t	10.6 C	10.4 C	10.3 C
	Wind speed	1.3m/s	1.4m/s	3.4m/s
	Wind direction	204 °	84 °	265 °

The local ages of air vary from a minimum of 14.4 minutes to a maximum 24.0 minutes according to the sampler location and supply fan speed. The minimum local age of air was measured in the breathing zone, which is directly supplied with air from the PEM diffusers. The longest local age of air is measured in the hallway at the center of the bay, which is a stagnant area. The local age of air in a breathing zone varies between 14.4 and 20.8 minutes. The local age of air in the hallway varies between 17.4 and 24.0 minutes according to the supply fan speed. The maximum difference in the age of air of 9.6 minutes between the sampler locations is a result of the supply fan speed.

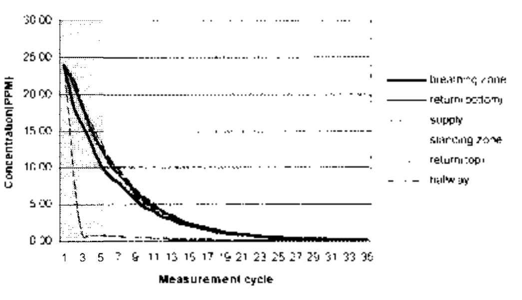
In all cases, the age of air in the breathing zone is shorter than in other locations due to the significant amount of outside air directly supplied through the supply diffuser to the breathing zone. In maximum and medium fan speed mode, the ages of air in the return ducts (bottom and top) are similar. In the off mode, the age of air in the top of the return duct is shorter than that in the bottom of the return duct.



(a) Maximum mode



(b) medium mode



(c) off mode

Figure 4. Tracer gas concentrations during Scenario I tests

In the maximum and medium fan speed mode, the concentration of SF_6 in the supply diffuser is higher than that in the off mode, as shown in Fig. 4. This indicates that indoor air is re-circulated into the PEM unit through leakage due to the negative air pressure in the PEM caused by the supply fan.

The air change effectiveness in the breathing zone is in the range of 1.14 to 1.20, the air change effectiveness in the standing zone is in the range of 1.02 to 1.07.

3.2 Scenario II: One workstation is occupied in the test bay

The PEM units are integrated with a sensor that turns off all functions when the workstation is unoccupied for more than 10 to 15 minutes. If a workstation is not occupied, the supply fan will be automatically changed to off mode and will supply minimum outside air. Table 5 shows the results of age of air measurements when one workstation is occupied and 5 workstations are unoccupied (PEM fans are in off mode) in the test bay. The experiment conditions are summarized in Table 6.

In the maximum and medium fan speed modes, most of the values for age of air are 3 to 4 minutes longer than that of Scenario I, because the total amount of air flow supplied to the bay has been decreased. In all cases, the age of air in the breathing zone is in the same range for all fan speed modes. The air change effectiveness in the breathing zone is also in the same range and has a relatively high value. The air change effectiveness in return duct-top and hallway is lower than that of Scenario I.

Table 5. Measurement results of Scenario II

Control mode	Maximum mode		Medium mode		Off mode	
Item	*Ai*	*Ei*	*Ai*	*Ei*	*Ai*	*Ei*
Breathing zone	17.98	1.18	18.23	1.18	18.83	1.18
Return duct (bottom)	21.20	1.00	21.48	1.00	22.15	1.00
Supply diffuser	9.17	-	6.12	-	7.02	-
Standing zone	20.00	1.06	20.88	1.03	21.32	1.04
Return duct (top)	22.07	0.96	22.95	0.94	23.83	0.93
Hallway	23.27	0.91	22.93	0.94	23.92	0.93

Table 6. Measurement conditions of Scenario II

Control mode		Maximum mode	Medium mode	Off mode
Indoor condition	Operative t	25.7 C	25.6 C	24.7 C
	Indoor t	26.7 C	26.7 C	26.2 C
	Air speed	1.24 m/s	0.57m/s	0.46 m/s
MAU condition	Discharge t	25.6 C	25.7 C	25.3 C
	Return t	25.9 C	26.3 C	25.8 C
Outdoor condition	Outdoor t	18.7 C	19.3 C	17.8 C
	Wind speed	1.7m/s	2.3m/s	1.2m/s
	Wind direction	296 °	283 °	63 °

3.3 Age of air for two supply diffuser directions

To control air flow direction, the occupant can rotate the PEM diffusers, changing the horizontal direction or adjust the diffuser vanes to control the vertical air flow, as shown in Fig. 5. In this measurement, the variation in the age of air according to the horizontal direction of the supply diffusers is examined. For these tests, the fan speed was set to the medium mode. Table 7 shows the local age of air and local air change effectiveness according to the direction of the supply diffuser. Table 8 summarizes the pertinent experimental conditions. When the direction of the supply diffuser is oriented parallel to the desk, the age of air in the breathing zone is 4 minutes longer and the age of air in 1.7 m level is 2 minutes longer than that if the direction is directly toward the occupant. This quantifies the effect of the supply diffuser direction on the age of the occupant's breathing air. The local air change effectiveness in the breathing zone shows a difference of about 20% between the two supply diffuser directions. The local ages of air in other locations within the test bay are in the same range.

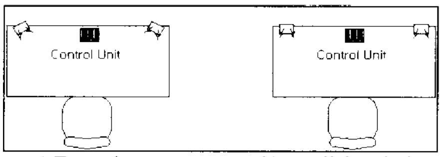


Figure 5. Two supply diffuser directions

Table 7. Results of Age of air according to direction of supply diffuser

Diffuser direction	Toward occupant		Parallel to desk	
Measurement item	*Ai*	*Ei*	*Ai*	*Ei*
Breathing zone	18.23	1.18	22.18	0.98
Return duct(bottom)	21.48	1.00	21.77	1.00
Supply diffuser	6.12	-	7.17	-
Standing zone	20.88	1.03	22.33	0.98
Return duct(top)	22.95	0.94	22.67	0.96
Hallway	22.93	0.94	23.43	0.93

Table 8. Condition of measurement results according to direction of supply diffuser

Diffuser direction		Toward occupant	Parallel to desk
Indoor condition	Operative t	25.6 C	23.9 C
	Indoor t	26.7 C	25.7 C
	Air speed	0.57m/s	0.23m/s
MAU condition	Discharge t	25.7 C	24.1 C
	Return t	26.3 C	25.3 C
Outdoor condition	Outdoor t	19.3 C	14.6 C
	Wind speed	2.3m/s	1.6m/s
	Wind direction	283 °	204 °

3.4 Age of air according to the height of the return duct

Table 9 shows the local age of air according to the height of the return duct. Table 10 summarizes the pertinent experimental conditions. For these tests, the fan speed was set to maximum. No difference was found in the age of air between the two return duct heights.

However, the local age of air was slightly older throughout the test bay when only one inlet of the return duct was open versus when both return duct inlets were open.

Table 9. Measurement results according to height of return duct

Condition of return duct	Top : open Bottom : open		Top : open Bottom : closed		Top : closed Bottom : open	
Item	*Ai*	*Ei*	*Ai*	*Ei*	*Ai*	*Ei*
Breathing zone	14.42	1.20	14.98	1.26	14.78	1.24
Return duct (bottom)	17.28	1.00	-	Close	18.33	1.00
Supply diffuser	7.32	-	8.23	-	8.15	-
Standing zone	16.15	1.07	16.57	1.14	16.35	1.12
Return duct (top)	17.10	1.01	18.83	1.00	-	Close
Hallway	17.35	0.99	18.87	1.00	18.50	0.99

Table 10. Condition of measurement results according to height of return duct

Height of return duct		Top : open Bottom : open	Top : open Bottom : close	Top : close Bottom : open
Indoor condition	Operative t	21.5 C	23.2 C	24.7 C
	Indoor t	22.7 C	24.4 C	26.0 C
	Air speed	1.18m/s	1.52m/s	1.41m/s
MAU condition	Discharge t	20.9 C	23.6 C	25.3 C
	Return t	22.8 C	25.1 C	26.3 C
Outdoor condition	Outdoor t	10.6 C	17.5 C	19.6 C
	Wind speed	1.3m/s	3.5m/s	3.0 m/s
	Wind direction	204 °	282 °	294 °

4. COMPARISON OF THE AGE OF AIR BETWEEN SUPPLY DIFFUSER LOCATIONS

4.1 Measurement summary

In this study, three different diffuser locations (desktop, floor and ceiling) are compared in view of their ability to distribute the supply air to the workstation breathing zone. The standard PEM diffuser location, the desktop, was compared to two other diffuser locations as shown in Fig. 6. The first comparative location was the floor level.

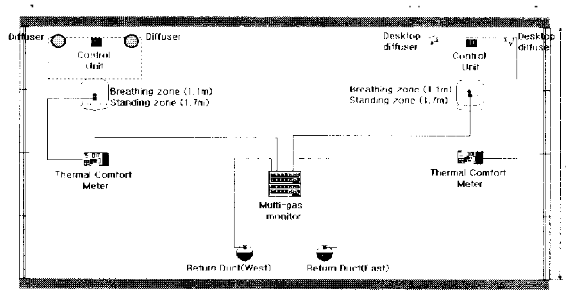


Figure 6. Test space for comparison of the age of air between supply diffuser locations

This was achieved by relocating the two PEM diffuser supply ducts to the floor level and attaching floor diffusers to the ends of the supply ducts. In a similar way, the second locations (ceiling diffusers) were supplied by rerouting the PEM supply ducts to the ceiling above the workstation. The standard PEM diffusers were used at the supply duct outlets.

4.2 Comparison of the age of air between the desktop diffuser and the floor diffuser

The results of the age of air comparison between the PEM desktop diffusers and the floor diffusers are summarized in Table 11. Measurement conditions are shown in Table 12. The ages of air of the PEM diffuser in the breathing zone are, on average, 4 to 5 minutes shorter than that of the floor diffuser in the breathing zone. The ages of air of the PEM diffuser and the floor diffuser are similar in the standing zone, even though the floor diffuser is located lower than the PEM at floor level.

The difference in the air change effectiveness between the PEM diffuser and the floor diffuser is in the range of 0.13 - 0.17. The air change effectiveness of the PEM diffuser and floor diffuser in the standing zone are similar - approximately 0.9.

Table 11. Measurement results of the PEM desktop diffuser and the floor diffuser

Control mode		Maximum mode		Medium Mode		Off Mode	
Item		*Ai*	*Ei*	*Ai*	*Ei*	*Ai*	*Ei*
Breathing zone	PEM	22.18	1.09	25.90	1.08	28.12	1.02
	Under Floor	26.02	0.93	30.75	0.91	32.22	0.89
Standing zone	PEM	26.05	0.93	30.63	0.91	31.45	0.91
	Under Floor	25.90	0.93	31.18	0.90	31.88	0.90
Return duct(average)		24.19	1.00	27.98	1.00	28.70	1.00

Table 12. Measurement conditions for tests of the PEM desktop diffuser and the floor diffuser tests

Control mode		Maximum mode	Medium mode	Off Mode
MAU condition	Discharge t	22.7 C	22.1 C	22.2 C
	Return t	23.1 C	23.0 C	23.1 C
Outdoor condition	Outdoor t	7.6 C	7.2 C	6.4 C
	Wind speed	2.2m/s	2.1m/s	2.7m/s
	Wind direction	168 °	84 °	63 °

4.3 Comparison of the age of air between the desktop and the ceiling diffuser

The results of the age of air comparison between the PEM desktop diffusers and the ceiling diffusers are summarized in Table 13. Measurement conditions are shown in Table 14. The tests show that the local ages of air of the PEM desktop diffuser are, on average, 4 to 6 minutes shorter than that of the ceiling diffuser in the breathing zone. The local ages of air of the PEM desktop diffuser are 2 to 4 minutes shorter than that of the ceiling diffuser in the standing zone. The differences in air change effectiveness between the PEM desktop diffuser and the ceiling diffuser are approximately 0.16 to 0.23 in the breathing zone. The difference in local air change effectiveness between the PEM diffuser and the ceiling diffuser was 0.07 - 0.17 in the standing zone in these tests. On average, the ceiling diffuser displays the longest age of air in the occupied zone of the supply diffuser locations tested. The local air change effectiveness of the ceiling diffuser in both the breathing and standing zones is around 0.9. Apparently, a significant amount of the airflow from the ceiling diffusers short circuits to the return ducts without mixing with the air in the occupied zone.

Table 13. Measurement results of the PEM desktop diffuser and the ceiling diffuser

Control mode		Maximum mode		Medium Mode		Off Mode	
Item		*Ai*	*Ei*	*Ai*	*Ei*	*Ai*	*Ei*
Breathing zone	PEM	23.60	1.08	25.10	1.13	27.72	1.08
	Ceiling	27.72	0.92	31.48	0.90	32.88	0.91
Standing zone	PEM	25.78	0.99	27.47	1.03	29.43	1.02
	Ceiling	27.80	0.92	31.72	0.90	32.77	0.92
Return duct(average)		25.58	1.00	28.40	1.00	29.99	1.00

Table 14. Measurement conditions for tests of the PEM desktop diffuser and the ceiling diffuser

Control mode		Maximum mode	Medium mode	Off Mode
MAU condition	Discharge t	22.7 C	22.3 C	22.5 C
	Return t	23.1 C	22.9 C	22.8 C
Outdoor condition	Outdoor t	12.5 C	13.3 C	13.7 C
	Wind speed	1.4m/s	1.4m/s	2.1m/s
	Wind direction	256 °	244	290 °

4.4 Energy Considerations

The PEM system can potentially save energy in two ways. The PEM delivers air directly to the occupant's breathing zone with a high degree of effectiveness. This may result in a reduction in the total intake of outside air by the ventilation system. Secondly, the PEM controls are integrated with a sensor that turns the fan off when the workstation is unoccupied for more than 10 to 15 minutes. This will reduce the amount of conditioned air supplied to the space to the minimum required for ambient conditioning.

The value of air change effectiveness can be used with the Design Ventilation Rates from ANSI/ASHRAE Standard 62-1989R. ASHRAE Standard 62-1989R describes the determination of the Design Ventilation Rate (DVR62) for a ventilated space based on the space type and occupancy and an analysis of contaminant sources. ASHRAE Standard 62-1989R also requires that the total amount of supply air (outside and recirculated) must be at least 7.5 L/s per person, and requires a minimum ventilation rate per person and a minimum ventilation rate per square meter floor. The two ventilation rates are added (Olesen, 1997). The DVR62 is the minimum recommended amount of outdoor air that must be delivered to the occupied portion of a space in order to comply with the ventilation requirements of Standard 62. The calculation of DVR62 is based on the assumption that the indoor air is well mixed. Indoor airflow patterns that are distinct from perfect mixing within the ventilated space may result in a difference between the effective outdoor air delivery rate to the occupied space and the DVR62 of the space.

The air change effectiveness, E, determined with ASHRAE Standard 129-1997 can be used to relate CDVR and DVR62 with the following relationship:

$$CDVR = DVR\,62 / E. \quad \text{(Eq. 5)}$$

If, for some reason, a significant amount of the supply airflow from the diffusers flows directly into the return vents without mixing with the room air, then the effective rate of outdoor airflow to the occupied portion of the space will be less than the total outdoor airflow rate into the space. An air change effectiveness measurement according to Standard 129-1997 will yield a value of E that is significantly less than 1. This indicates that the ventilation system will be less effective in delivering outdoor air to the occupied portion of the space than it would be under conditions of perfect mixing ($E = 1$). The outdoor airflow rate provided to the space (CDVR) should be increased above DVR62 to account for this short-circuiting.

Some ventilation systems are designed so that the ventilation air is delivered within the occupied portion of the space and sweeps through the space to the return vents with little mixing of the ventilation air with the room air. Such systems are more effective in delivering outdoor air to the occupied portion of the space than systems that offer perfect mixing with the same outdoor airflow rate to the space. An air change effectiveness measurement conducted in accordance with Standard 129-1997 can yield a value of E that is greater than 1. The outdoor airflow rate to the space (CDVR) can therefore be decreased below the value of DVR62 based on the above equation.

The measured local air change effectiveness of the PEM in the breathing zone was usually 1.13 to 1.23

higher than that of ceiling and floor diffusers. If the minimum outside air change rate (as specified using Standard 62-1989) is supplied with a PEM system, the volume of outside air can be reduced 13 to 23%, resulting in a commensurate reduction in ventilation energy use.

5. CONCLUSION

In this study, measurements on the age of air and the air change effectiveness using the tracer gas method are obtained out to analyze the ventilation performance for the provision of fresh air near the breathing zone by the personal environmental module system. The relation between the personal environmental module system for optimal control and other factors related to indoor air quality and ventilation of the personal environmental module system is examined. Also, three different supply diffuser types (desktop, floor and ceiling diffuser) are compared in view of their ability to distribute the supply air to the workstation breathing zone. Finally, estimated energy savings are calculated of improved ventilation effectiveness, user based controls and occupancy sensors. The tests to measure the ventilation performance were conducted in 6 workstations of the south zone of the Intelligent Workplace.

It was evaluated that the desktop personal environmental module system can deliver air directly to the occupants breathing zone with a high degree of effectiveness. In the measurement results, the local ages of air in the test bay vary from a minimum of 14.4 minutes to maximum 24.0 minutes according to the measurement location and supply fan speed. The minimum local age of air was measured in the breathing zone, which is directly supplied with air from the personal environmental module diffusers. The air change effectiveness in the breathing zone was in the range of 1.14 to 1.20, the air change effectiveness in the standing zone was in the range of 1.02 to 1.07. In the results of the air change effectiveness comparison between different diffuser types, the measured local air change effectiveness of the desktop diffuser in the breathing zone was usually 1.13 to 1.23 times greater than that of ceiling and floor diffusers. When the minimum outside air change rate as specified using ASHRAE Standard 62R is supplied with a desktop diffuser type, the volume of outside air can be reduced 13 to 23%, resulting in a commensurate reduction in ventilation energy use.

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