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OCCUPANT BODY MOVEMENT AND SEAT OCCUPANCY RATE FOR DESIGN OF DESK MICRO-ENVIRONMENT

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Abstract

Occupant's body movement and seat occupancy rate are some of the factors important for optimal design of desk micro-environment, including personalized ventilation. A system for identification and recording occupant's presence and body movement at the desk was designed. The detection system consisted of set of five infrared detectors and a non-contact laser distance meter. The system was used in an office building. In total 11 occupants participated in the survey. Each occupant was monitored during one standard working day. Occupants spent approximately 70 % of the working time at the desk. In average occupants left the desk 4.6 times during the day and stayed away in average for 20 min. The average distance between the PC monitor and the occupant body was 0.63 m and changed mainly from 0.48 m to 0.72 m. 78% of the time the length of occupants' body movement to the left/right direction was less than 0.225 m, with maximum span of the whole interval up to 0.75 m. In average the frequency of body position change was 4.9 times per minute, with minimum frequency of 0.6 times per minute and maximum frequency of 11.9 times per minute. The collected data are discussed and requirements for optimal design of desk micro-environment are suggested.

Keywords: personalized ventilation, body movement and posture, occupant density, field survey

1 Introduction

Indoor environment affects occupants' health, comfort and performance. Yet, in many public buildings indoor environment is mediocre. Energy used for heating, cooling and ventilating in buildings is substantial. Ventilation aims at providing occupants with clean air for breathing. Breathing clean air improves perceived air quality and reduces complaints from sick building syndrome (SBS) symptoms (headache, fatigue, etc.), risk of airborne cross infection, illness and sick leave days (ASHRAE 2011, REHVA 2007). Often clean air supplied to spaces is conditioned in order to maintain air temperature and humidity in comfortable ranges (ISO 7730 2005, EN15251 2007, ASHRAE 55 2010). Thus the distribution of heat and air in spaces is of major importance. At present total volume ventilation, based on dilution of polluted and warm room air with clean and conditioned air, is used (Müller et al. 2013). The strategy of total volume ventilation is inefficient. Some of the reasons are: the clean and conditioned air is supplied far from occupants and is mixed with the warm and polluted room air (can carry germs exhaled by sick people) when it reaches the occupants; cleaning, conditioning and transportation of huge amount of supply air increases the energy use; large air handling units and bulky duct systems that take space and increase initial costs are used; flexibility in space use is curtailed, etc. (Melikov 2011). The energy saving strategy adopted recently in buildings based on reduction of ventilation air is dangerous because it will affect negatively occupants' health and will decrease their work performance in rooms with total volume ventilation.

Personalized Ventilation (PV) aims at supplying clean and cool air at low velocity and turbulence intensity directly at workstations. The supplied clean air should reach the breathing zone as less as possible mixed with the polluted room air. PV provides user with control of local velocity (flow rate) and direction and temperature of the supplied personalized flow (Melikov 2014). Several studies have shown the capacity of a PV system to decrease the room air pollution in inhaled air (Melikov et al. 2002, Bolashikov et al. 2003), to reduce the transport of contaminants between occupants (Cermak and Melikov 2007) and to improve the perceived air quality and thermal comfort (Kaczmarczyk et al. 2004, 2006, Melikov and Knudsen 2007). PV system has the potential to save energy as well (Schiavon et al. 2010, Lelong et al. 2013, Lybenova et al. 2011).

PV supplies air in a small zone at occupant´s desk. Therefore, the inhaled air quality depends on occupant´s location in the room and at the desk. Melikov and Hlavaty (2007) introduced three indices to define the relative time an occupant stays in the room, at the desk and is exposed to the personalized flow. Field survey in rooms with occupants performing different type of office work revealed substantial differences in the indices: some occupants spend most of the time at the desk, other occupants spend more time in the office but not at their desks, and some spend most of the time out of the office. This variability in occupants' activity should be taken into account for the implementation of the PV in practice.

For the optimal performance of PV the design of the air supply diffuser is important. As already stated an important requirement is that the supplied personalized flow mixes as less as possible with the polluted surrounding room air, i.e. the generated flow should be with low turbulence intensity. In this way the clean personalized air will be inhaled by the occupant. Another important requirement for the optimal performance of PV is the size of the target area of the personalized flow at the location of the occupant. The occupant will be located in the personalized flow and will breathe clean air when the target area is large. Typically the personalized flow is a free jet and its characteristics depend on the initial conditions at the air supply diffuser. In order to increase the size of the target area large air supply diffuser has to be used. However, this will lead to increase of the supplied flow rate in order to obtain target area of clean air with high enough target velocity (needed for penetration of the free convection flow that exists around human body). The shape of the air supply diffuser, the uniformity of the initial supply velocity profile and its turbulence intensity also can be used to change the size of the target area. All these parameters can be used to design diffuser that generates personalized flow with optimal size of the target area and needed minimum velocity. The size of the target area has to be large enough to accommodate the occupant's movement while he/she performs work at the desk. However, this information is not available.

The objective of this study was to identify occupants' body movement while performing work at the desk. The focus was to identify typical range of occupants' distance from PC monitor as well as the span of left/right body movement. The results can be used for design of personalized ventilation.

2 Method

2.1 System for identification of body movement

A set of five infrared presence detectors (AIR30, Bircher) were used to detect left/right body movement. The detectors were fixed in a raw on a metal support that was placed above the PC monitor (Figure 1). The operating principle of AIR30 detector is optoelectronic, based on reflection of a light beam. The infrared light beam is emitted by transmitter, then reflected by any object (occupant's body) and finally captured by a receiver. If no object is present in the scanning area, no signal is captured by the receiver. AIR30 detector has separate optical units (transmitter and receiver) installed in a shared housing. The actual location of the occupant´s head is determined by the position of the sensor(s) that detect presence in its scanning range.

The distance between the five detectors was chosen to be 15 cm, corresponds to the average width of the head (14.5 cm is in average the width of the human head in eye region without taking into account the ears, Lee et al., 2006). The scanning area was adjustable and the maximum detection distance from the detector was 2.5 m. The minimum detecting distance was 0.1 m. The scanning range was approximately 0.5 m. The scanning area of the detectors was tuned separately of each occupant because of different height of the used chair. Software was used to analyse the signals from the detectors and to define the position of occupant´s body to the left/right from the vertical plane where the middle of the five detectors was located. An example of three detected positions of occupant's head is shown in Figure 2. When the head is in central position (Figure 2a), only the middle detector detects presence (D) and is active. The rest of the detectors are inactive (N). When the occupant leans a little to the left, the sensor on the left form the central one will be active as well (D) (Figure 2b). When the occupant leans more to the left only the detector placed on left from the central one will detect the presence (D) (Figure 2c). Taking into consideration that the width of the head is 15 cm its position may be defined. The left/right position of the head in the terms of real measurements is listed in Table 1. The whole scanning range of occupant´s head movement is 75 cm, i.e. 37.5 cm to the left and 37.5 cm to the right. Occupants may lean more than 37.5 cm to the one side. This posture is detected but the leaning distance is not quantified. However, as it will be discussed later the relative time occupant´s movement is outside of the scanned area was rather low.

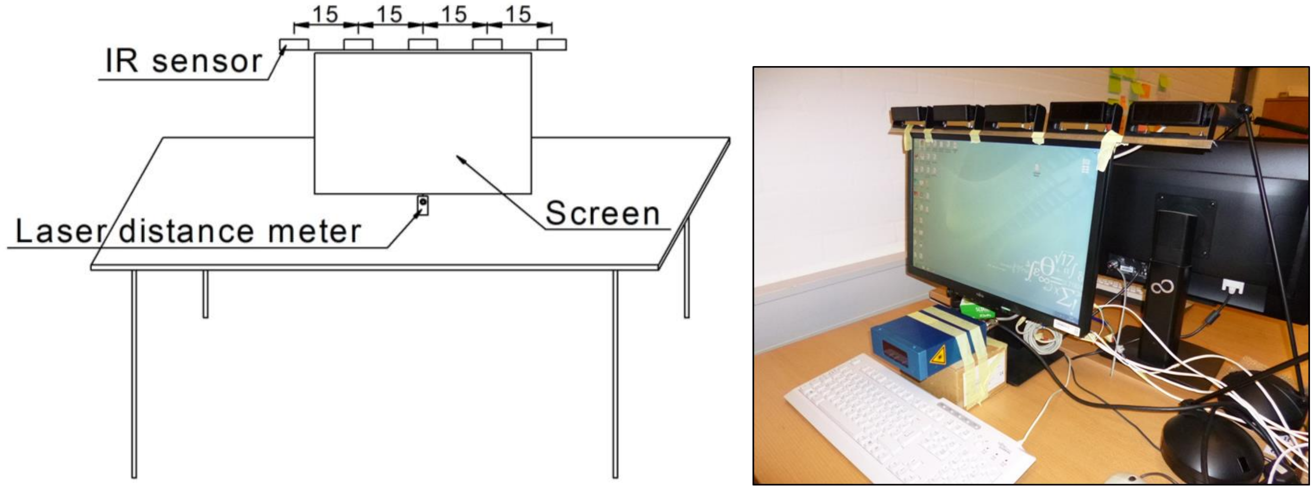
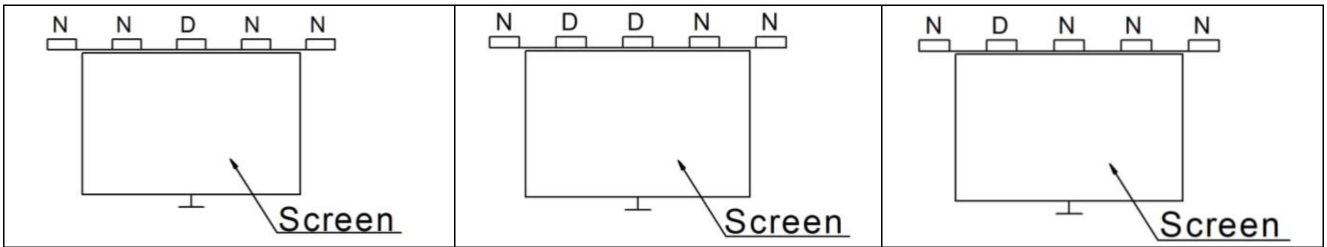


Figure 1.Sketch and photo of the five detectors that were used to defined left/right head movement



a: Central head position | b: Left head position | c: Left+ head position

Figure 2. Example of head position

Table 1: *Detectable ranges of occupant's head position left/right from the middle of the PC monitor*

Name of the Position	Value or Interval (cm)
Center	(-7.5 ; 7.5)
Left	-7.5
Left +	(-22.5 ; -7.5)
Left ++	-22.5
Left +++	(-37.5 ; -22.5)
Right	7.5
Right +	(22.5 ; 7.5)
Right ++	22.5
Right +++	(37.5 ; 22.5)

Occupant´s distance from the screen was measured by non-contact laser distance meter ODS Blue-Line (Danish Sensor Engineering). The principle of this laser distance meter is based on triangulation technique which measures accurate distance. A red laser beam is emitted by a transmitter then it is reflected back by the object. Then the reflected beam is focused by a lens. The distance to the object is determined by the position of the focused beam on the receiver. Movement in the range of 0.4 m is measured, e.g. from 0.15 – 0.55 m. During this study the sensor was placed on the desk near the PC monitor. Since the layout of the occupants' desk varied the laser meter was placed at different distance from the screen. The distance between the sensor and the PC monitor (the screen) was measured and was added to the value measured by the sensor. In this way the distance between the chest of the person and the PC monitor was determined. The response time of the laser meter is less than 0.1 s and measurement uncertainty less than 10^{-5} m. Software provided by the manufacturer was used to analyze the collected data.

2.2 The survey

A study was designed and performed 1) to test the performance of the developed system for monitoring occupants´ movements and 2) to identify occupants´ movement while working at the desk. Measurements in an office building were performed. In total movement of 11 occupants performing PC work, reading, talking on phone or with colleagues, etc. was monitored. Each of the occupants was monitored for one working day. One day of monitoring and the limited number of surveyed occupants may not be quite representative but this was the time available. Nevertheless the measurements were sufficient to test the performance of the method and to obtain good impression on occupants' body movement.

2.3 Data analyses

The collected data were analyzed to determine the following parameters: a) Time each occupant spent at the desk; b) How often and for how long time each occupant left the desk; c) Range of movements left/right; d) Range of body movement forward and backward; e) Frequency of change of head position per minute, named "Frequency of Head Position Change" and referred as f-index:

$$f = \left(\frac{HPCH}{T_M - T_{OD}}\right) * 60 \quad [min^{-1}], \tag{3}$$

where: *HPCH* is Total Number of Head Position Changes; T_m is Total Monitoring Time in seconds T_{OD} is Total Time Out of the Desk in seconds.

3 Results

In the following only some of the obtained results are presented. The monitoring system was switched on when the occupant started his/her working day and was switched off at end of the working day. Table 2 shows total monitoring time and time that occupants did not spend at the desk. The occupants stayed in the office for different time. However, the results in the table reveal that the percentage of the time that the occupants spent at the desk is quite similar. In average approximately 30 % of the time occupants spent a part of the desk. It is not clear whether during this time they were at the desk out of the scanning range, in the office or out of the office.

Table 2 shows the number and the length of time intervals when occupants left the desk (only intervals longer than 1 minute were counted). The average interval, minimum and maximum interval are listed in the table. The average number of the time intervals is 4.6, though for 8 persons (73%) it is 4 or lower. The average length of time intervals when occupants were not at the desk is 20 min.

Table 2: *Total monitoring time and time occupants was not at the desk (hours, minutes and seconds are listed).*

	Total Monitoring Time	Not at the desk	Percent of time not at desk	Number of Time Intervals not at desk	Average Time Interval not at desk	Minimum Time Interval not at desk	Maximum Time Interval not at desk
Subject 1	04:23:36	00:26:43	10,13%	4	00:02:40	00:00:59	00:05:36
Subject 2	07:59:24	02:43:31	34,11%	8	00:08:52	00:01:00	00:29:59
Subject 3	03:06:38	01:06:31	35,64%	4	00:13:39	00:02:00	00:37:38
Subject 4	07:13:02	02:08:51	29,76%	3	00:43:39	00:14:59	01:22:59
Subject 5	05:58:25	02:13:43	37,31%	2	00:44:42	00:02:59	01:26:25
Subject 6	06:08:27	01:54:41	31,12%	7	00:15:50	00:00:59	01:12:59
Subject 7	03:57:21	00:39:19	16,56%	3	00:04:59	00:00:59	00:08:00
Subject 8	06:20:50	02:20:51	36,99%	10	00:13:59	00:00:59	01:51:59
Subject 9	02:44:20	00:45:01	27,40%	4	00:09:29	00:01:59	00:25:59
Subject 10	04:30:47	01:36:21	35,58%	3	00:22:39	00:03:59	00:49:59
Subject 11	06:26:00	01:56:59	30,31%	3	00:29:59	00:03:59	01:18:59
Average				**4.6**	**00:19:08**	**00:03:10**	**00:53:41**

The distribution in time of left/right movements of occupant's body is listed in Table 3. The values in the table show the percent in time each occupant spent at particular distance left and right from the center of the monitor. The average values are shown in Figure 3. Values lower than 2 % are neglected in the analysis because they are relatively small. Eight occupants (73 %) stayed more than 75 % of the time in one (central) position. Occupant named "Subject 2" has the highest body movement interval of 60 cm, spending 4 % (20 minutes) of the time in the both marginal areas. Nine occupants (82 %) stayed most of the time within the range of 30 cm.

The calculated f-index is listed in Table 3. The average value of the index is 4.9 changes per minute. Big differences between the occupants existed: "Subject 3" changed his/her head position 0.6 times per minute while "Subject 4" 11.9 times per minute.

Table 3: *Percent of time occupants' head was located left/right from the center of the monitor.*

Subject	1	2	3	4	5	6	7	8	9	10	11
(-37.5;-22.5)	0.1	0	0.1	0.2	0	1.2	0.1	6.7	0.2	0.5	0.9
-22.5	0	0	0	0.5	0	0.4	0	0.2	0	0.4	0.2
(-22.5;-7.5)	0.1	**4.4**	0	0.5	1.8	0.6	0.1	0.4	0.1	**39.1**	**4.7**
-7.5	0.1	1.8	0	0.2	1.0	0.7	0.6	0.5	0.5	**21.4**	2.7
(-7.5;7.5)	**76.5**	**46.4**	**99.9**	**97.8**	**80.5**	**72.6**	**99.0**	**89.2**	**79.4**	**36.5**	**77.8**
7.5	**23.0**	**22.0**	0	0.6	3.8	**11.6**	0	0.3	**16.3**	0.2	**7.8**
(7.5;22.5)	0.1	**21.1**	0	0.2	**12.1**	**9.3**	0	2.3	3.3	0.2	**4.9**
22.5	0	0.2	0	0	0.2	0.2	0	0.1	0	0.1	0.1
(22.5;37.5)	0.1	**4.1**	0	0	0.6	3.2	0.1	0.4	0.2	1.7	1.0
f index	2.1	13.8	0.6	2.4	5.2	4.7	2.7	3.6	7.2	9.8	11.9

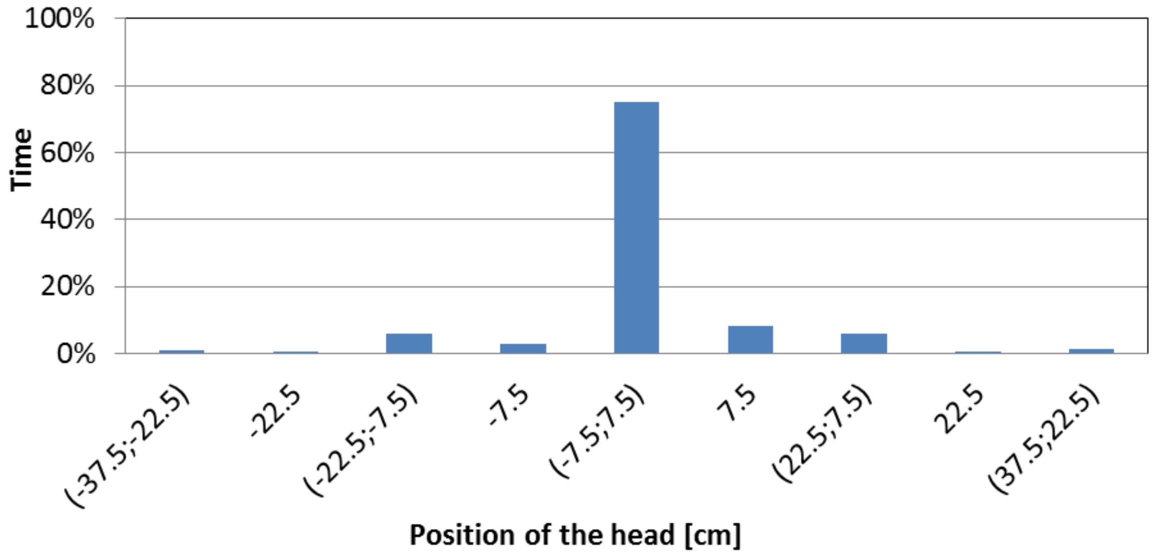


Figure 3. Percent of time occupants' head was left/right from the center of the monitor. Average data for the 11 occupants are presented.

Occupants' movement forward/backward is listed in Table 4. Only distances where occupants spent more than 2 % of the time are counted. The average distance from the screen of all monitored occupants is as high as 62.7 cm and the average length of the range is 10.6 cm. The average distances were found to be little determined by the size of the desk and the workstation layout. The lowest average distance from the screen is 48 cm ("Subject 2"). The highest average distance is 71.4 cm ("Subject 4"). The difference between the lowest and highest average distance is as high as 23.4 cm, i.e. the overall range of occupants' body movement forward/backward is 23.4 cm.

***Table 4:** Ranges of occupants' body movement forward/backward.*

Subject	1	2	3	4	5	6	7	8	9	10	11
Minimum distance (cm)	66	44	58	67	63	62	62	56	56	57	51
Maximum distance (cm)	73	55	64	78	75	74	72	71	65	68	61
Average distance	69	48	61	71	66	66	67	63	60	62	56

4 Discussion

Occupants´ movements at the desk and occupants´ presence in the office have significant impact on PV design. Melikov and Hlavaty (2007) reported on substantial difference in the time occupants spent at their workstation. The results of the present survey reveal that most of the occupants spent at the desk around 70% of their work time, though large deviations were identified as well (Table 2). This result is important when decision for implementation of PV in practice has to be taken. Important information for the design of PV is occupants' movement and position while they perform work at the desk. In this survey most of the occupants (73 %) stayed most of the time (78%) in one position and they did not move left/right much. The span of left/right body movement was mainly in an area with size 45 cm. There were occupants that leaned left/right in wider range. It is reasonable to suggest that in practice PV flow that covers an area with size of 60-75 cm will accommodate left/right body movement for most of the occupants and most of the time.

Another important parameter for optimal design of the PV and providing occupants with clean air for breathing is the distance between the occupant at the desk and the PV air supply diffuser. In the present study this distance was different for the surveyed persons but was in the range 50 – 80 cm. The occupants moved little (approx. 10 cm) forward/backward in time.

Typically the PV flow is a free jet issued from a circular or rectangular opening or a nozzle. The first region of the PV flow known as a core region contains a core of almost nearly unmixed fresh supply air with constant velocity and low turbulence intensity. The highest inhaled air quality can be achieved if this air is inhaled. The length of the core region is typically 4 – 5 times the diameter of the diffuser (in case of circular opening). As already discussed in the introduction section such large target area will require air supply diffuser with large size. According to the results obtained in the present study the diameter of the air supply diffuser should be 20 cm or more in order to have potential core longer than the maximum distance between the occupant and the diffuser (in case the diffuser is placed above the monitor). Apart of the size of the diffuser its design also can be used to change the characteristics of personalized flow (Khalifa et al. 2009, Bolashikov et al. 2013). Another possibility is to apply design that make it possible to rotate the diffuser so that the personalized flow follows occupant's movement, e.g. by sensing body movement and rotating the air supply diffuser by a stepper motor. In average subjects in the present study moved their head 4.9 times per minute, though large differences between the occupants were recorded, from 0.6 to 11.9 times per minute. It was identified in the present study that occupants moved apart of the desks several times during the working hours. It may be expected that due to change in their activity they will need to cool more the body when they come back to the desk. Diffusers with more complicated design, that allow change in the spread of the jet, to be more focused and with elevated velocity at the beginning to cool more the head and more widely spread after the body is cooled initially, can be developed.

In the present study up/down movement of occupants' head was not measured. However, it may be expected that this movement will be smaller than body movement forward/backward.

5 Conclusions

In average occupants spent 30 % of the working time out of the desk and left the desk 4.6 times for 20 min. While at the desk occupants' body movement to the left/right was in an area of 60 cm (most of the time 45 cm), but most of them (73 %) did not move (left/right) much. In average 78 % of the time the occupants spent in the central position, but some moved their body left/right in the whole scanning interval of 75 cm. In average occupants moved their head left/right 4.9 times/min, though large differences in minimum (0.6 time/min) and the maximum (11.9 times/min). The average distance of occupant's body was 62.7 cm (48 – 71.4 cm).

Personalized flow covering an area 70 cm wide and with initial core region with clean air as long as 80 cm has to be aimed. Use of air supply diffusers allowing change in personalized flow characteristics as well as PV designs generating flows that follow occupants movement at the desk may be considered.

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