PRODUCTIVITY IS AFFECTED BY THE AIR QUALITY IN OFFICES

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ABSTRACT

The results of three independent studies involving 90 subjects, and using similar procedures and blind exposures have shown that increasing air quality (by decreasing the pollution load or by increasing the ventilation rate, with otherwise constant indoor climate conditions) can improve the performance of simulated office work (text typing, addition and proof-reading). An analysis of the combined data from these studies is presented to establish the relationship between air quality and performance in offices. It confirms that good air quality improves the performance of text typing (P=0.0002), and a similar tendency is seen for addition (P=0.056) and proof-reading (P=0.087). A positive correlation between the air quality, as it is perceived by occupants, and the performance of typing (R^2=0.82, P=0.005), addition (R^2=0.52, P=0.07) and proof-reading (R^2=0.70, P=0.08) indicates that performance will increase on average by 1.5% when the proportion dissatisfied with the air quality is decreased by 10% in the range of air quality levels causing 25-70% to be dissatisfied. The results imply that doubling the outdoor air supply rate at constant pollution load, or a two-fold decrease of pollution load at constant ventilation rate, can increase overall performance by 1.9%. The present results document the economic benefits of providing good indoor air quality and indicate that providing indoor air of a higher quality than the minimum prescribed by the present ventilation standards will increase productivity.

KEYWORDS: air quality; productivity; office building; ventilation rate; source control

INTRODUCTION

The results of three independent experiments show that the performance of simulated office work improves when the air quality is increased [1,2,3]. To simulate office work, text typing, proof-reading and addition were used, all being typical office tasks requiring concentration. Air quality was altered either by decreasing the pollution load, i.e. by removing a pollution source at constant ventilation rate [1,2], or by increasing the outdoor air supply rate from 3 to 10 or to 30 L/s per person (0.6, 2 and 6 h^{-1} respectively) while the same pollution source was always present [3]. The pollution source in all 3 studies was the same 20-year old carpet (taken from an office building with a history of SBS symptoms [4]), of a size corresponding to the floor area of the office where each exposure took place. Temperature, relative humidity, air velocity and noise level were constant. Ninety female subjects (18-33 years old, all but 3 non-atopic) were exposed to different levels of air quality, 30 in each study. In all three studies similar procedures were used: the subjects performed simulated office work during 4.5-hour exposures to different air quality levels and assessed the perceived air quality and the intensity of any SBS symptoms, in a repeated-measures design balanced for order of presentation. They could not see whether the source was present or perceive changes in noise level or air velocity when the ventilation rate was changed, and they remained thermally neutral by adjusting their clothing. The aim of the present paper is to determine the relationship between air quality and the performance of office tasks by combining the results of these studies.

METHODS

To estimate the effects of air quality on productivity in offices, data on sensory assessments of air quality and corresponding data on performance of simulated office work from three independent studies [1,2,3] were analyzed by combining the statistical significance (P-values) of the effects obtained separately in each study [5], regarding each experiment as an independent test of the same hypothesis (that poor indoor air quality affects performance negatively), and by regression analysis.

Sensory assessments of the acceptability of air quality were used to estimate air quality levels. They were made using a continuous scale coded as follows: 1=clearly acceptable, 0=just acceptable/just not acceptable, -1=clearly not acceptable [1]. Average sensory ratings of the quality of air polluted by building materials and bioeffluents (assessments made immediately after exposure in the original studies) were used in the analysis. They reflect the actual air quality levels when the performance of simulated office work was measured.

The performance of simulated office work including text typing, addition and proof-reading, was used to estimate productivity. Average number of characters typed per minute, average number of correctly completed arithmetical calculations (units) per hour (i.e., excluding units with errors) and average number of lines that were correctly proof-read per minute (i.e., excluding the lines with missed errors or false positives) were used for analysis after each had been individually normalized. In the original studies there was at least an indication ($P<0.10$) that they were affected when the air quality was changed. Normalization was adopted because performance was measured in three independent studies with different subjects and could have been influenced by group differences in the subjects' experience, intellectual skills and level of practice. The normalization factors (which were different for each study) were the ratios between the mean of performance at all air quality levels in all three studies to the means of performance at all air quality levels in each individual study. To estimate the overall performance of simulated office work, the performance index was calculated by dividing normalized performance at a specific level of air quality by the mean of normalized performance of a specific task at all air quality levels.

RESULTS

The effects and P-values of the individual interventions investigated by the 3 studies [1,2,3] and the combined effect of all interventions on perceived air quality and performance are summarized in Tables 1 and 2 respectively. The results show that removing a pollution source or increasing the ventilation rate significantly improved perceived air quality ($P<0.0001$) and the performance of typing ($P=0.0002$), and tended to improve the performance of the addition ($P=0.056$) and proof-reading ($P=0.087$) tasks.

A positive correlation was found between the acceptability of air quality and performance. It was significant in the case of typing ($R^2=0.82$; $P=0.005$), and approached significance for addition ($R^2=0.51$; $P=0.07$) and proof-reading ($R^2=0.70$; $P=0.077$). Regression lines with data points are plotted in Figure 1, after the linear regression lines against ratings of acceptability have been transformed into the corresponding relationship with percentages dissatisfied with the air quality [6]. The results indicate that every 10% decrease in the proportion dissatisfied with the air quality below the air quality level causing 70% to be dissatisfied can improve the performance of typing by 1.4%, of addition by 1.1% and of proof-reading by 2.3%.

Figure 2 shows log-linear regression lines describing the relationship between performance and ventilation rate (outdoor air supply rate) calculated as the reciprocal of the perceived air quality expressed in pol [7]. The relationship implies that for every two-fold increase of ventilation rate, the performance of typing would be expected to increase by 1.8%, of addition by 1.5% and of proof-reading by 2.8%.

Table 1. Effects of the interventions on perceived air quality (2-tailed P values)

Study	Intervention	Perceived air quality			Effect of intervention
		acceptability	% dissatisfied	decipol	
[1]	source present	-0.18	68	11.7	P<0.0001
	source absent	0.18	25	1.9	
[2]	source present	-0.12	61	9.2	P=0.062
	source absent	0.04	40	4.1	
[3]	3 L/s per person	-0.09	58	8.2	P=0.010
	10 L/s per person	0.14	29	2.4	
	30 L/s per person	0.14	29	2.4	
Combined effect (all interventions) (1-tailed P): P<0.0001 (χ^2=33.23, df=6)					

Table 2. Effects of the interventions on performance (1-tailed P-values)

Study	Intervention	Performance		Effect of intervention
		not normalized	normalized	
Text typing (performance = characters typed per min)				
[1]	source present	136.1	139.6	P=0.002
	source absent	145.5	149.2	
[2]	source present	135.2	143.3	P=0.019
	source absent	137.3	145.5	
[3]	3 L/s per person	149.5	141.8	P=0.077
	10 L/s per person	152.5	144.6	
	30 L/s per person	154.9	146.9	
Combined effect (all interventions): P=0.0002 (χ^2=25.95, df=6)				
Addition (performance = units completed per h)				
[1]	source present	227.9	229.1	P=0.245
	source absent	231.4	232.6	
[2]	source present	204.5	227.8	P=0.139
	source absent	210.0	233.9	
[3]	3 L/s per person	238.0	222.1	P=0.063
	10 L/s per person	249.6	232.9	
	30 L/s per person	254.8	237.7	
Combined effect (all interventions): P=0.056 (χ^2=12.30, df=6)				
Proof-reading (performance = lines read per min)				
[1]	not measured			
[2]	source present	3.62	5.08	P=0.245
	source absent	3.85	5.41	
[3]	3 L/s per person	6.02	5.05	P=0.070
	10 L/s per person	6.29	5.28	
	30 L/s per person	6.45	5.41	
Combined effect (all interventions) P=0.087 (χ^2=8.12, df=4)				

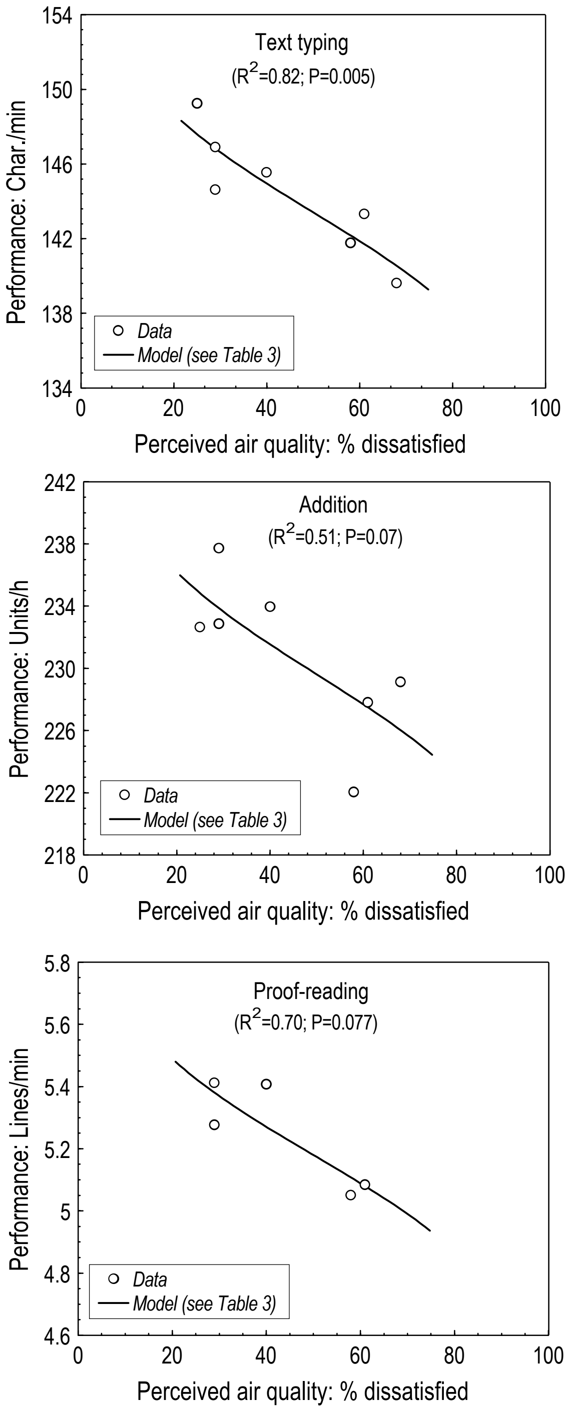

Figure 1. Performance of text typing, addition and proof-reading as a function of the air quality (% dissatisfied with the air quality)

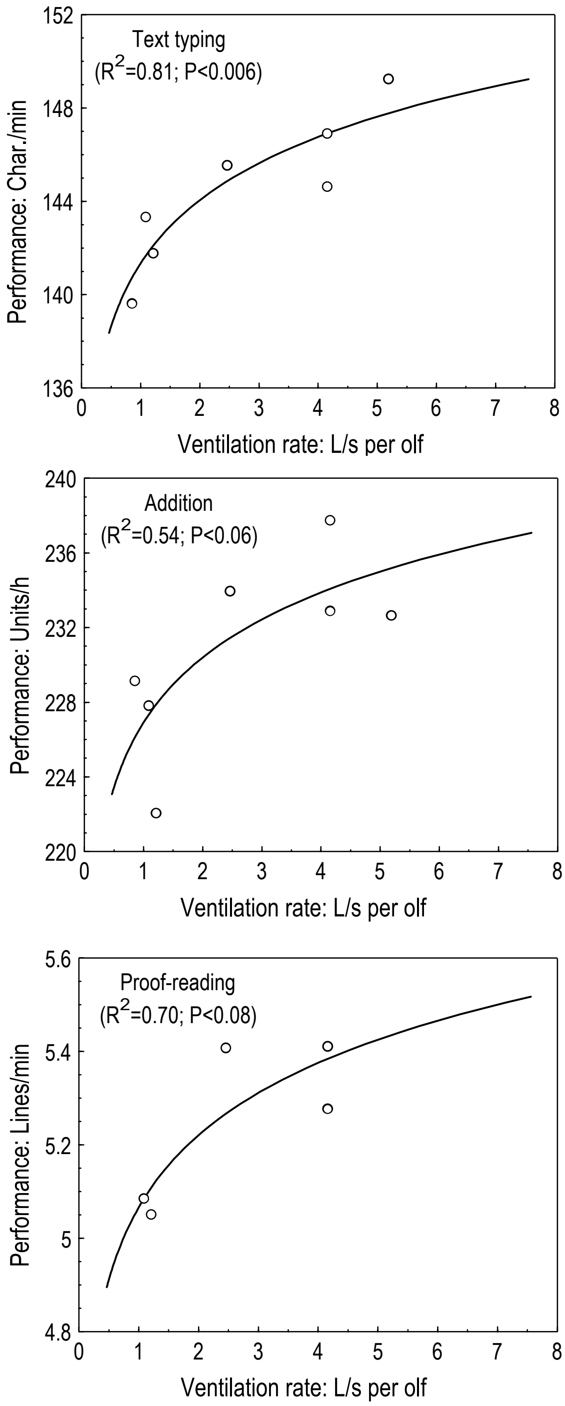

Figure 2. Performance of text typing, addition and proof-reading as a function of the ventilation rate (outdoor air supply rate)

Figure 3 shows log-linear lines describing the relationship between overall performance of simulated office work at different ventilation rates (outdoor air supply rates) and sensory pollution load calculated using the comfort model [7]. The relationship implies that doubling the outdoor air supply rate at constant pollution load or a two-fold decrease of pollution load at constant ventilation rate can increase performance by 1.9%; the equivalence of effects stems from the linear relationship between ventilation rate and sensory pollution load assumed in the comfort model [7].

DISCUSSION

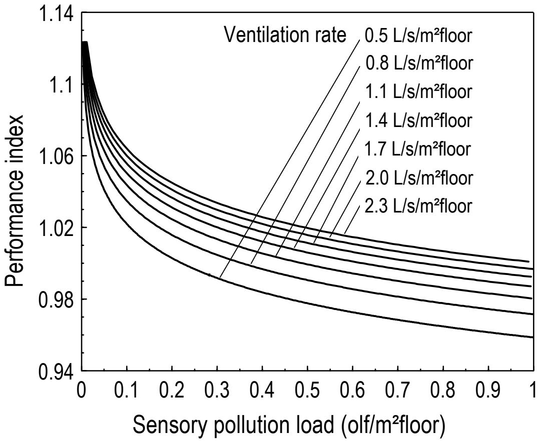

Figure 3. Overall performance of simulated office work as a function of sensory pollution load and ventilation rate (outdoor air supply rate)

Wyon [8] has shown that thermal conditions within the thermal comfort zone can reduce performance by 5% to 15% and has suggested that similar effects may be expected as regards the impact of poor air quality, although at that time there was little information on the latter issue. The present data support this suggestion and show that performance is affected by air quality. They indicate that even a moderate increase of air quality corresponding to 10% fewer people dissatisfied with air quality, can improve the performance of typical office work by an average of 1.5%. The present results thus provide a strong economic incentive to improve indoor air quality. Moreover, they indicate that improving air quality in offices above minimum standards will also improve productivity. This is illustrated in Table 3, where the predicted increase in the performance of typing, addition and proof-reading is shown, assuming that air quality is upgraded from Category C to Category A and B according to European guidelines for ventilation CEN CR 1752 [9].

Table 3. Relative increase in performance of office work by upgrading to a higher category of air quality in an office

Air quality (CEN CR 1752 [9])		% increase in performance relative to category C		
Category	% dissatisfied	text typing	addition	proof-reading
C	30	—	—	—
B	20	1.4	1.1	2.3
A	15	2.1	1.6	3.4

Three strategies are usually used to improve indoor air quality: ventilation, reduction of indoor pollution sources and cleaning, the first two being applied in the studies [1,2,3] from which the present data were obtained. Figure 2 shows the effect of ventilation. Figure 3 predicts the simultaneous impact of the reduction of indoor pollution sources and ventilation on overall performance of office work (i.e., office productivity). It provides a strong economic incentive for the selection of low-polluting materials, as recommended by CEN CR 1752 [9]. This need not involve any extra costs if applied at the building design stage. Increased ventilation rates will incur extra costs which may, however, be reduced by application of proper energy recovery systems. Reduction of indoor pollution sources and ventilation were investigated separately in the present studies and to support the prediction of Figure 3 they should in future be studied in the same experiment.

The interventions applied in the present studies were shown to significantly affect perceived air quality, and it is a reasonable assumption that they also affected actual levels of air pollution. Chemical measurements were carried out in 2 of the studies [1,3] and showed only slightly elevated levels of some pollutants when the pollution source was present or when ventilation rate was decreased. It is obvious that human olfactory and chemical senses are superior to chemical analysis, especially at low concentrations of pollutants encountered indoors, despite considerable progress in analytical chemistry. The air quality caused 25% to 70% to be dissatisfied. It is recommended that this range be extended below 25% in future investigations to validate the predictions in Table 3.

Productivity was estimated by measuring the performance of standardized tests of typing, addition and proof-reading, all being typical office tasks requiring concentration. Performance was measured in an office environment and although every effort was made to make this environment as natural and as typical of normal offices as possible, the conditions for the subjects may still have been perceived as different from that of their normal workplace. It would therefore be useful to validate the effects found of air quality on productivity in real offices.

CONCLUSIONS

- Air quality affects productivity in offices. The performance of simulated office work is estimated to increase on average by 1.5% for every 10% decrease in the percentage of persons dissatisfied with the air quality.
- The overall performance of office tasks is estimated to increase by 1.9% for every two-fold increase in the ventilation rate at constant pollution load or for every two-fold decrease of the pollution load at constant ventilation rate.
- The present data document the economic benefits of providing indoor air of a higher quality than the minimum prescribed by the present ventilation standards.

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