Call-centre operator performance with new and used filters at two outdoor air supply rates

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ABSTRACT
A 2×2 replicated field intervention experiment was conducted in a call-centre providing a national public telephone directory service: outdoor air supply rate was adjusted to be 8 or 80% of the total airflow of 430 l/s (3.5 h^{-1}); and the supply air filters were either new or had been in place for 6 months. One of these independent variables was changed each week for 8 weeks. The 26 operators were blind to conditions. Room temperature and relative humidity averaged 24°C and 27%, respectively. Outdoor O_3 concentration was fairly constant throughout, averaging 28 ppb. Increasing outside air supply rate caused performance to increase as indicated by reduced average talk-time ($P < 0.055$) with a new filter and to decrease ($P < 0.05$) with a used filter, so that talk-time was about 10% lower with a new filter than with a used filter at high outdoor air supply rate ($P < 0.01$). The present results provide field confirmation that increasing outdoor air supply rate and replacing filters can improve employee performance.

INDEX TERMS
Productivity; Air filter; Ventilation rate; Office building; Office work

INTRODUCTION
Field measurements of the effects of indoor environment on office productivity are scarce. The main reason is that it is difficult to reliably quantify the performance of real office tasks. So far, three metrics of productivity appear to have been used to investigate indoor environmental effects in the field: embedded neurobehavioral tests (Nunes *et al.*, 1993); short-term sick leave (Milton *et al.*, 2000); and the performance of operators in a call-centre (Federspiel *et al.*, 2002; Fisk *et al.*, 2002; Niemelä *et al.*, 2002). The last metric is an especially promising measure of office performance because operators repeatedly perform the same type of work, making it possible to obtain a large amount of data. Automated telephone exchange systems routinely record the number of calls, their average duration (talk-time), the number and duration of any breaks, number of operators on duty, etc. Although the call-centre operator task is only one type among an array of different office tasks, it requires concentration, verbal communication, logical thinking under time pressure, visual attention and usually, the use of sophisticated computer software. These skills are common to most office tasks, so if call-centre performance were affected by changes in the indoor environment, it would suggest that other office tasks are similarly affected.

Previous field studies in call-centres showed that high temperature can negatively affect the performance of operators, but no effects were seen when outdoor air supply rates were increased. A small cross-sectional study in a telecommunication call-centre showed that temperatures below 25°C improved operator performance by 5–7% by reducing average talk-time (Niemelä *et al.*, 2002). Temperatures above 25.4°C caused qualified nurses providing medical advice in a call-centre to work 16% more slowly when writing up their reports after the call was over (i.e. 'wrap-up time' increased) and intermediate outdoor air supply rates were significantly associated with increased talk-time (Federspiel *et al.*, 2002). When the same data were used to derive a multi-factorial mathematical model predicting productivity (Fisk *et al.*, 2002), it could be shown that very high ventilation rates, indicated by carbon dioxide (CO_2) levels less than 75 ppm above the concentration in outdoor air, tended to reduce average handling time (a productivity measure combining talk-time and wrap-up time) by about 2% compared with lower ventilation rates.

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Wargocki *et al.* (2002a) reported how perceived air quality and SBS symptoms were affected in an experiment in which outdoor air supply rate and filter condition were independently manipulated. They showed that increasing the outdoor air supply rate with a new filter in place significantly alleviated many symptoms, as did changing from used to new supply air filters at a very low outdoor air supply rate, while filter condition appeared to have little effect on these subjective variables at the high outdoor air supply rate. The present paper reports the concomitant effects on operator performance in the same experiment.

METHODS

A field intervention experiment was carried out in a call-centre with a floor area of 154 m^2 and a volume of 447 m^3, located in a penthouse on a three-storey building. There are 24 workstations equipped with PCs, all with connections to telephone lines and to the Internet. The call-centre is served by a mechanical ventilation system with recirculation and cooling but there is no humidity control and the system shuts down from 23:00 to 06:00 each night. A synthetic-fibre coarse bag filter class G3, 80% by weight filter efficiency, is situated downstream of where the return and outdoor air streams are mixed. No fine filters are present. The system provides a total supply air flow of 430 l/s, according to tracer gas measurements made with either used or new filter in place, which corresponds to an air change rate of 3.5 h^{-1} (without infiltration), in which the proportion of outdoor air varies in order to keep the supply air temperature at ca. 23°C and thus varies with outdoor conditions when the system is operated normally.

The following reversible interventions were applied: (1) New vs. used filter (a filter that had been in place for 6 months). (2) Constant outdoor air supply rate 8 vs. 80% of total supply air flow (i.e. 34 or 344 l/s) or ca. 2.5 and 25 l/s per person with 14–15 operators working at the same time in the call-centre during periods when high call volume is expected. The experiment was carried out as a repeated-measures 2×2 design, in which all combinations of the two interventions new/used filter, low/high outdoor air supply rate occurred in each of two successive 4-week periods, each combination being maintained for one week at a time. The changes between conditions were 'blind' to operators and implemented on Friday evenings. The interventions did not alter total supply air flow rate, so ventilation noise, draught and supply air temperature, the latter controlled by a heating/cooling coil, remained the same throughout the experiment. Other experimental details are reported elsewhere (Wargocki *et al.*, 2002a). Operators were able to open windows, so micro-switches with event recorders were attached to each window to monitor this possibly compensatory behaviour.

A total of 26 operators answer directory enquiry calls from anywhere in Denmark, working in shifts. The number of operators on duty varies with the time of day depending on the expected call volume. Number of calls and talk-time is automatically registered for each operator by an automated telephone exchange system every 30 min. As a measure of operator performance the average talk-time in each 30-min period was calculated by dividing total talk-time in that period by the number of calls answered. This outcome variable has a direct impact on profitability, as for a given call volume an increase in average talk-time makes it necessary to ensure that more operators are on duty, and it may thus be regarded as an index of operator productivity.

RESULTS

Several analyses were carried out to observe the impact of a change in outdoor air supply rate and a change of filter condition on the average talk-time. These analyses were carried out by pooling all available values of 30-min average talk-time for each operator. Beside variables depicting the main interventions, i.e. the filter condition and the outdoor air supply rate, the analyses included other variables which could influence the results: a coded operator ID; number of calls received by an operator; number of operators working concurrently in the call-centre; weekday; the time of day; and the number of hours the operator had been at work. The analyses revealed that independently of the interventions the average talk-time depended on the number of calls received by the operator ($P < 0.0001$) (Figure 1); that the number of calls depended on time of a day ($P < 0.0001$) but were independent of weekday (Figure 2); and that the number of operators working concurrently in the call-centre varied during the day ($P < 0.0001$) and between days ($P < 0.0001$) (Figure 3). The expected increase in average talk-time with hours worked was significant ($P < 0.02$) only in the first 3–4 h of work (Figure 4).

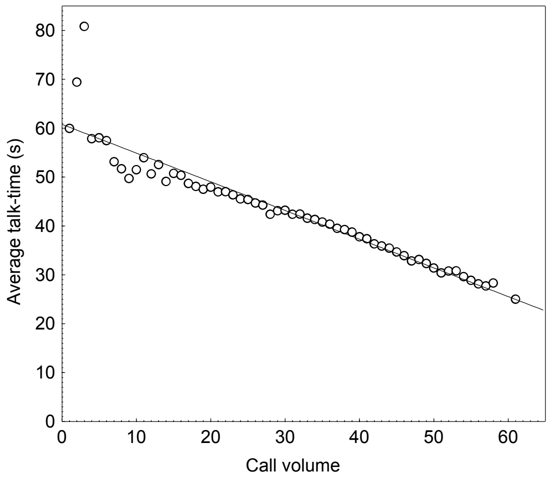

Figure 1 Average talk-time as a function of call volume.

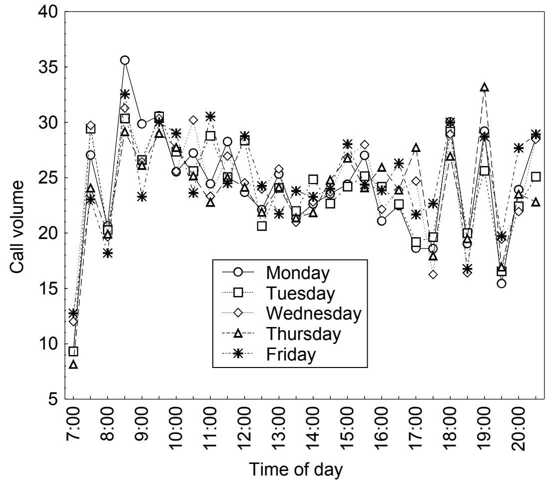

Figure 2 Call volume as a function of time of day and weekday.

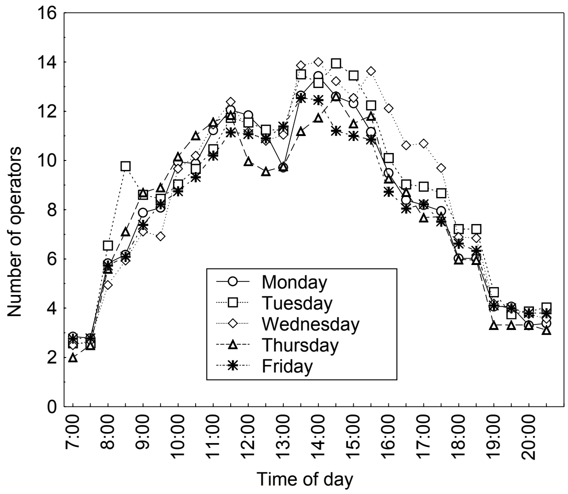

Figure 3 Number of operators working concurrently in the call-centre as a function of time of day and weekday.

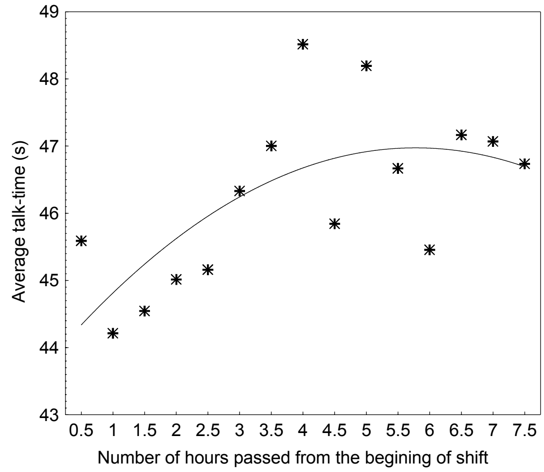

Figure 4 Average talk-time as a function of time elapsed from the beginning of shift.

Because the systematic variability in the data described above obviously contributes to the variance, an attempt was made to minimise this effect by carrying out analyses using pooled 30-min average talk-time for each operator in the periods when the variability in the data was as small as possible. This approach was unsuccessful as there were extensive missing data as a consequence of shifting work schedules. It was thus decided to calculate the overall average talk-time for each operator in each of the four conditions, separately for each replication, i.e. from a total of 2×5 working days in each condition, using only data from periods when call volume was fairly constant during each day, i.e. from 09:00 to 17:00, and similarly excluding data obtained in the first 3 h of work on any given day. The data for three operators were excluded entirely: one operator was absent for 2 weeks within the same condition, one was absent during the first 4 weeks of the experiment and one was absent for more than two-thirds of the time throughout the experiments. Analysis of variance indicates that the interaction between outdoor air supply rate and filter condition was significant ($P < 0.022$) (Figure 5). Pairwise comparisons using the least significant difference method showed that increased outdoor air supply rate decreased average talk-time ($P < 0.055$, one-tail) as expected with a new filter in place, that replacing the new filter with a used filter at high outdoor air supply rate increased average talk-time ($P < 0.01$, one-tail) as expected, and that reducing outdoor air supply rate with a used filter in place unexpectedly decreased average talk-time ($P < 0.05$, two-tail). No significant effect was seen when a used filter was replaced with a new one at the low outdoor air supply rate.

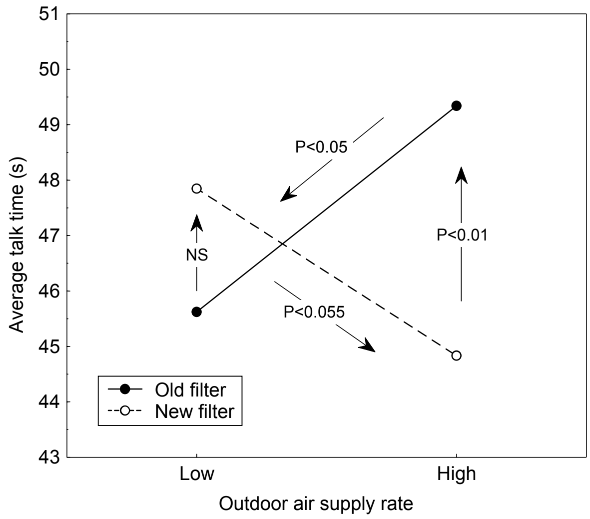

Figure 5 Average talk-time as a function of outdoor air supply rate and filter age; arrows indicate the direction of the intervention, where the first condition studied was the new filter at the low outdoor air supply rate.

Supplementary analyses of variance were also carried out when weekly average talk-time for each operator was calculated using data for all periods, for periods when large variations in call volume were seen, i.e. before 09:00 and after 17:00 and for the period when the average talk-time changed systematically with number of hours at work, i.e. up to 3 h from starting work. The result of the analysis using all available data show an interaction effect similar to what is depicted in Figure 5 ($P < 0.038$) but for other periods no significant differences were observed. An analysis of window opening behaviour revealed no significant differences between conditions. Windows were routinely opened by cleaners while they worked in the early morning and late evening hours, but were open for only 4% of the time period in which a significant effect on talk-time has been demonstrated (from 09:00 to 17:00). This can have had no more than a negligible effect on average air quality.

DISCUSSION

The results of the present experiment show that outdoor air supply rate and filter condition are important determinants of office work performance. They may be summarized as follows:

1. With a new filter in place, performance was better with 80% outside air than with 8% outside air, as expected.
2. With a used filter in place, performance was worse with 80% outside air than with 8% outside air, contrary to expectation.
3. Performance with 80% outside air was better with a new filter than with a used filter, as expected.
4. Changing the filter did not significantly affect performance with 8% outside air.

The positive effect of increased ventilation on performance noted at (1) is compatible with earlier studies showing that increased outdoor air supply rate improves the performance of typical office tasks (Wargocki *et al.*, 2000a) and reduces short-term sick leave (Milton *et al.*, 2000).

The negative effect of ventilation rate on performance noted at (2) seems at first counter-intuitive. However, the effect could be due to the fact that ventilation systems and especially used ventilation filters can be a substantial source of pollution (Clausen *et al.*, 2002; Wargocki *et al.*, 2002b). Moreover, taking into account that the pollution source strength of a used filter increases with operating time (Pejtersen, 1996) and with the amount of outside air passing through it (Alm *et al.*, 2000; Strøm-Tejsen *et al.*, 2003), increasing the outside air supply rate may have led to an increased concentration of some indoor air pollutants due to increased emission of pollutants accumulated on the surface area of the dust particles retained by the filter, a process which can be further amplified by oxidation (Bekö *et al.*, 2003) and night shut-off of the ventilation system (Mysen *et al.*, 2003).

The positive effect of changing the filter noted at (3) is a direct consequence of the effects implied in (1) and (2).

That no effect of changing the filter was noted at (4) could be a result of the low rate at which outdoor air was supplied by the ventilation system (0.25 h^{-1}). It seems likely that at the low outdoor air supply rate the air infiltration rate through the building envelope, which is normally above 0.5 h^{-1}, was the principal determinant of the concentration of air pollutants indoors. Air infiltration does not pass through the ventilation filters. When the new filters were installed, the reduction in total pollution load was probably quite small, due to the low outdoor air flow rate through the ventilation system and the consequentially low emission rate from the used filter (Alm *et al.*, 2000; Strøm-Tejsen *et al.*, 2003).

Performance effects 1 and 3 are compatible with the SBS results reported earlier by Wargocki *et al.* (2002a). Performance effects 2 and 4 are not. The SBS results were reported in terms of the significance of the changes that took place in response to each intervention, and do not reflect the absolute level of subjective distress over time, which is likely to be more closely related to performance. This discrepancy could cause the observed differences. It may well be that not all the pollutants causing SBS are the same as those reducing performance.

The present results constitute field validation of laboratory experiments without filters and with recruited subjects performing simulated office work (Wargocki *et al.*, 2000b). The size of the effect on performance in this study (5–10%) is similar to that observed in the laboratory simulation experiments. This experiment extends the applicability of previous findings to actual workplaces in which normal office workers perform real work.

CONCLUSIONS AND IMPLICATIONS

- Increasing the outside air supply rate through a new filter increased the productivity of operators in a call centre, but decreased productivity when a used filter was in place. No effect of changing the filter at low outdoor air supply rate was observed.
- The present results provide field validation of earlier laboratory findings showing a positive effect of improved indoor air quality on the performance of office work.
- Changing to a new filter is a more effective and more energy-efficient way of improving IAQ and productivity than increasing the outside air supply rate with used filters in place.

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