The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work

Abstract Three air temperatures (22/26/30°C) and two acoustic conditions—quiet (35 dBA) or open-plan office noise (55 dBA)—were established in an office. Thirty subjects aged 18–29 years (16 male), clothed for thermal neutrality at 22°C, performed simulated office work for 3 h under all six conditions. Many more (68% vs. 4%) were dissatisfied with noise in the noise condition (P < 0.01). Warmth decreased thermal acceptability (P < 0.001) and perceived air quality (P < 0.01) and increased odour intensity (P < 0.05) and stuffiness (P < 0.01). After 2 h, some forehead sweating was observed on 4, 36 and 76% of subjects (P < 0.001) at 22, 26 and 30°C, while 0, 21 and 65% felt “warm” (P < 0.001). Raised temperature increased eye, nose and throat irritation (P < 0.05), headache intensity (P < 0.05), difficulty in thinking clearly (P < 0.01) and concentrating (P < 0.01), and decreased self-estimated performance (P < 0.001). Noise increased fatigue (P < 0.05) and difficulty in concentrating (P < 0.05) but did not interact with thermal effects on subjective perception. In an addition task, noise decreased workrate by 3% (P < 0.05), subjects who felt warm made 56% more errors (P < 0.05) and there was a noise–temperature interaction (P < 0.01); the effect of warmth on errors was less in the noise condition. Typing speed (P < 0.05) and reading speed (P < 0.05) were higher in noise.

Practical implications This paper demonstrates that open office noise distraction, even at the realistic level of 55 dBA, increases fatigue and has many negative effects on the performance of office work, as does a moderately warm air temperature. These findings may be used to provide economic justification for the provision of private offices and air temperature control in hot weather. The additional finding that noise distraction and heat stress can sometimes counteract each other in the short term is of academic interest only, as they both increase subjective distress and fatigue. In practice, neither should be deliberately introduced to counteract the other.

Introduction

In warm thermal environments, the human body will tend, in the absence of conscious effort to the contrary, to respond adaptively by lowering internal heat production so as to avoid sweating. This may lead to lower arousal and a slower work rate. Several studies have shown that thermal load may negatively affect mental performance (Wyon, 1996). However, optimal work performance may not occur under conditions providing optimal thermal comfort, as was found in an experiment by Pepler and Warner (1968) in which subjects performed mental work at air temperatures in the range 20–30°C. They were normally clothed and performed best at 20°C, although most of them felt uncomfortably cold at this temperature, while they reported exerting the least effort and performed the least work at 26.7°C, at which temperature they were the most thermally comfortable.

In a study of mental performance, subjects clothed for comfort at two different air temperatures performed sedentary work in a climate chamber (Wyon et al., 1975). The subjects rated their effort, arousal and fatigue, together with the freshness of the air, on subjective scales. Self-estimated effort, arousal and fatigue did not differ between the two air temperatures, but subjects perceived the air to be fresher in the cool air/warm clothing condition. Performance did not differ significantly between the two conditions. Later field studies have shown a powerful effect of air...
temperature on the prevalence of SBS symptoms (Jaakkola et al., 1989; Krogh et al., 1991), a mechanism that in turn may reduce productivity by having a negative effect on effort and on performance. In the study by Wyon et al. (1975 op. cit.) each session lasted only 2.5 h and was carried out in a climate chamber with clean air (40 air changes per hour), which may be one reason why no effects on performance were found.

The effects of heat stress on performance seem to be more adverse for males than for females. Wyon et al. (1979) found a multiplication task to be performed significantly more slowly by male subjects at 28°C, in comparison with lower or higher temperatures, while female subjects’ performance on the same task was not affected by heat stress.

Effects of noise on performance have often been interpreted as being due to increased arousal, supplemented by the hypothesis that the field of attention becomes more narrow and selective at higher arousal levels. Parameters that are known to be arousing may counteract the effect of heat on performance. This was shown by Wyon et al. (1978) for the performance of a control task by black South African factory workers. As the subjects were industrial workers and were exposed to noise levels of 50 or 85 dBA, the findings are not necessarily applicable to the office environment.

The stimulating effect of noise will not counteract thermal discomfort, so an even higher complaint rate may be expected in noise, since both level of arousal and the level of general annoyance are higher. Furthermore, any task that involves the use of auditory cues may be negatively affected by noise. Tasks involving short-term memory may be negatively affected because noise masks “inner speech”, a term used to denote one of the thought processes involved (Salamé and Baddeley, 1982, 1987). Sudden changes in the environment may disrupt ongoing activities. This is also the case for onset and offset of noise. Distraction of this or other kinds may be an important reason for the negative effects on performance of variable, intermittent, or meaningful noise. This kind of noise contains more information than continuous noise and is thereby more likely to attract attention. In many work environments complaints about noise often concern irrelevant but clearly audible speech. It seems likely that the information content of speech is the main determinant of its intrusiveness (Kjellberg, 1990).

Johannsson (1983) studied mental performance (learning, reading and multiplication) and writing pressure exerted on the paper by 10-year-old school children under three noise conditions: silence (25 dB), continuous (51 dB) and intermittent (55–78 dB) noise. The intermittent noise level was adjusted to have the same “noy rating” (level of annoyance) as the continuous noise. Children of above-average intelligence solved more units in a multiplication task in continuous noise, compared to the quiet condition, and more in the intermittent noise, compared to the continuous noise. The reverse was found for children of below average intelligence. The latter were also more negatively affected by noise in the reading task. The author suggests that this was because the tasks were too difficult for this group, but too easy without the additional challenge of noise distraction for the children of above average intelligence.

Other studies indicate that noise may lead to a more superficial processing of text when reading and thus to impaired comprehension of the text. Jones and Broadbent (1979) investigated performance of a proof-reading task in two different noise conditions, “soft” (55 dBC) or “loud” (80 dBC) office noise. Subjects read significantly fewer words in the loud noise than in the soft noise. The error detection rate was lower and there were more false positive responses in the loud noise compared to the soft noise condition. The effects of noise on these two measures were not significant when analyzed separately, but when combined, errors were significantly higher in the loud than in the soft noise.

A similar effect was found by Weinstein (1974, 1977). Intermittent noise had no effect on the detection of simple typographical errors in a series of proof-reading experiments, but lowered the detection rate for more complicated errors, which required comprehension of the text for their detection. In a series of noise experiments conducted by Jones et al. (1990), the performance of a proof-reading task was found to be dependent on whether background speech was meaningful, independent of the intensity (in the range 50–70 dBA). Meaningful background speech decreased detection of misspellings but not the detection of grammatical errors or inappropriate words, or reading speed.

The background noise in offices usually consists of noise from the ventilation system, office machinery, occupant’s activities, and perhaps traffic noise entering the office from outdoors. In open-plan offices people often prefer a certain level of background noise to prevent colleagues from hearing what they are saying, for example on the telephone, in other words to create some kind of acoustic privacy. In the USA individual noise generators are now sometimes built into desks and in large open-plan offices where many people work in the same space they are used for this purpose by 40% of the occupants (Kroner et al., 1992; Wyon, 1998). A systematic study of how unwanted acoustic information affects office work thus seems overdue.

Several studies have shown that females report more building-related symptoms than do males (Zweers et al., 1992; Mendell, 1993; Mikatavage et al., 1995; Groes et al., 1996; Sundell, 1996). It has been suggested that this difference is due to women being more aware of their health. However, as noted above, men have been found to be more adversely affected by heat stress.

Moderate heat stress and open-plan office noise distraction

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Both male and female subjects were therefore recruited for the present experiment.

Method

The experiment was carried out as a 3 × 2 repeated-measures design (3 thermal and 2 acoustic conditions) in an office space with a total floor area of 36 m² and a volume of 108 m³ (L × W × H = 6 × 6 × 3 m³). The office space was renovated some 3 years prior to the experiment. The walls are of painted brick and the floor is covered with low-polluting polyolefine tiles. The facade of the office faces east and has two windows with a total glazed area of 6 m² (Fig. 1). The office has previously been used in studies by Wargocki et al. (1999, 2000).

The office was divided into two smaller spaces by a partition made of laminated wooden panels. The height of the partition was about 2 m and circulation fans were used to ensure that air from one space was well mixed with air from the other, while the partition formed a visual barrier between the two spaces. The partition was placed at right angles to the windows, so that both spaces had access to them. One space was used for technical equipment and the other for exposing the subjects (Fig. 1). In the space occupied by subjects, there were six workstations. Each workstation consisted of a table, a table lamp, a chair and a computer monitor connected to a personal computer (PC). The other space was used to accommodate the equipment that was used to control the environmental conditions in the office.

Outdoor air was provided to the office by axial fans created. The partition from the occupied space. In this way the curtain from the wall that was partially concealed by the partition, the partition was placed at right angles to the windows, so that both spaces had access to them. One space was used for technical equipment and the other for exposing the subjects (Fig. 1). In the space occupied by subjects, there were six workstations. Each workstation consisted of a table, a table lamp, a chair and a computer monitor connected to a personal computer (PC). The other space was used to accommodate the equipment that was used to control the environmental conditions in the office.

Outdoor air was provided to the office by axial fans mounted on the visible part of the wall that was partially concealed by the partition, extending across the full width of the office. With the curtain in place, only the curtain was visible above the partition from the occupied space. In this way the illusion of a larger office space divided by a curtain was created.

Test conditions

The experiment included three air temperature levels: 22°C, 26°C, and 30°C. The air temperature of 22°C meets the design criteria for a Category A landscaped office during the heating season (CEN, 1998), while 26°C is just outside the range for Category A during the cooling season. The extreme temperature of 30°C is clearly outside the range, even for a Category C office. It is, however, not unrealistically high for naturally ventilated office environments under summer conditions, even in temperate regions. Subjects dressed for thermal neutrality at 22°C are expected to have a PMV of +1.0 and +1.9 at 26°C and 30°C, respectively (Fanger, 1970). The expected proportion of subjects dissatisfied with the thermal environment at the temperatures of 22°C, 26°C and 30°C are 5%, 26% and 72%, respectively.

The absolute humidity content of the office air was controlled and kept constant at 7.4 g/kg, which corresponds to 45%, 35% and 28% RH, respectively, at the three air temperatures. This was to simulate typical conditions in a building that is naturally or

![Fig. 1 Plan of the experimental office. 1: partition, 2: outdoor air supply fan with damper and silencer, 3: electric heater, 4: air-conditioning unit, 5: electric humidifier, 6: mixing fan, 7: workstation, 8: measuring points for air temperature, relative humidity and concentration of tracer gas and CO₂, 9: ventilation exhaust](image-url)
mechanically ventilated by outdoor air without humidification or dehumidification.

During the experiment the office was ventilated with a constant outdoor air supply of 90 l/s, corresponding to 3.0 air changes per hour. When six subjects at a time occupied the office, the outdoor air supply rate corresponded to 15 l/s/person. The ventilation rate was kept high to ensure that air pollution levels remained low.

Noise conditions

In the unoccupied office, the background noise level was as low as \( \text{Leq, } A = 35 \text{ dB} \). The background noise was caused by the supply fans and fans mixing the air in the office. The background noise level meets the requirements for a Category A landscaped office. This condition served as the reference acoustic environment in the experiments and no recorded noise was played back in this “quiet” condition. Subjects were not allowed to speak to each other during the sessions and the noise level was only slightly increased by the activities of the subjects. During the text-typing task the noise level in the office increased to about 50 dBA.

The 55 dBA noise distraction condition was a high-fidelity simulation of the noise in a typical large open-plan office in which about 50 people are working. A recording of office noise on DAT equipment was played back through a set of loudspeakers placed behind the partition and connected to a high quality amplifier. The recording masked the background of ventilation noise and the total level in the unoccupied office was adjusted to provide an equivalent sound pressure level of 55 dBA, which is typical for open-plan office environments. Each 4-hour recording, long enough to cover a full exposure period, was prepared as follows.

Open-plan office environment recording

The constructed soundscape contained different types of noise recorded at different levels to simulate activities taking place at different locations in a large office environment. The recording levels were selected to simulate activities in three different zones: back zone, mid-zone and front zone of the office, relative to the listener. Furthermore, some recordings of activities were panned to the left or right side, both to simulate activities at different locations and to increase the spatial depth and realism of the stereo recording. The different types of noise and activities in the recording were:

- foot-steps of people walking in the office,
- office machinery being operated (fax: machines, printers, etc.),
- doors to the office being opened and closed,
- drawers in desks and archive cabinets being opened and closed,
- keyboards in use,
- telephone signals with different tones and patterns,
- continuous conversation, incomprehensible and at a low level, but easily identifiable as a conversation going on at the back of the office,
- occasional laughter,
- continuous conversation, both comprehensible and incomprehensible. The conversations were varied in level as if people were moving around in the office,
- clearly comprehensible conversation between two persons, or one-sided telephone conversations.

The recording of background noise was taken from a commercially available audio CD with examples of real-life sound environments (WIDEX, 1995). Recordings of conversations and telephone signals were made in a real open-plan office. These additional recordings were inserted using a digital four-track tape recorder. In order to create a recording that was equally “busy” and equally disturbing at all times, special care was taken so that telephone signals and conversations were equally distributed over the total recording. To avoid a “learning effect” during the session, no conversation appeared more than once on the recording. The voices of four persons (two male + two female) were used. Each person’s voice was always panned left or right to a specific position in the office. The conversations were of varying length (between 6 and 546 s, with a mean of 126 s) and inserted at random intervals, resulting in clearly audible conversations during 53% of the total exposure time.

Measurements

Physical measurements. The following physical parameters of the indoor environment were continuously measured in the office during the experiments: air temperature and relative humidity, operative temperature, air velocity, ozone concentration indoors and outdoors, ventilation rate, CO\(_2\) concentration, noise and lighting level.

Each subject’s finger skin temperature was measured on several occasions during the experimental sessions as an objective indicator of the subject’s thermal state. Subjects picked up a temperature sensor and held it briefly between thumb and index finger when told to do so. At the same time as the finger skin temperature was measured, an experimenter covertly noted whether the subject’s forehead was matt, shiny or had visible drops of sweat on it. This observation was used as an indicator of the extent to which sweating took place under each condition (Andersson et al., 1975).

Based on the CO\(_2\) concentration measured outdoors and in the middle of the occupied space, the average metabolic rate of the subjects was calculated. The
calculations were made for each group separately following the procedure given in ISO8996 (1990), involving CO₂ production and the DuBois body surface area of the subjects, assuming a respiratory quotient of 0.85.

**Subjective measurements.** Subjects rated their thermal sensation, perceptions of the indoor environment and the intensity of a number of SBS symptoms on questionnaires. The scales used for this were identical with the scales used by Wargocki et al. (1999).

**Measurement of performance.** Office work covers a wide range of different tasks. Some of the most common tasks are text-typing, reading, and performing calculations of different kinds. For many office workers, their everyday work also includes some kind of creative thinking. The different tasks require different levels of manual and intellectual skill. The most common tasks were broken up into component skills, which were used to represent the complex set of tasks involved in typical office work.

The tasks used for estimating performance of office work in the present experiment were: text-typing, proof-reading, addition and creative thinking. All tasks were identical to those previously used in the study by Wargocki et al. (2000).

Self-estimated performance was rated on a visual analog scale. On a scale from 0 to 100%, subjects marked to what extent they rated themselves able to work. This type of self-estimated performance scale was previously used by Langkilde et al. (1973) and Wyon et al. (1975).

Different versions of the Tsai-Partington test (described by Ammons, 1955) were used to measure subjects’ level of arousal. The Tsai-Partington test is a diagnostic test of cue-utilization. The task is to draw a line from the labeled ‘start’ position to each of different numbers located at random on the page. In the test versions reviewed by Ammons, the sequence of links was given by numbers, letters or alternate numbers and letters. Wyon (1969) introduced a new version in which approximately 25 numbers are linked by ranking. The numbers ascend from 00 to 99 in steps of random size. The score is given by the number of (correct) links made. Eysenck and Willet (1965) have shown that performance of this test is reduced by increased arousal and motivation to do well. In the versions used in the present experiment, 30 numbers printed on an A4-size paper were to be connected in ranked order. Subjects worked on the task for exactly 40 s.

**Subjects**

Fourteen female and 16 male subjects aged 18–29 were recruited for the experiment. The inclusion criteria were: familiar with the use of a computer, non-smoker, currently healthy and not suffering from any chronic diseases, asthma, allergy or hay-fever. Subjects were screened for normal olfactory sense and hearing and none was excluded on these grounds. Subjects were randomly assigned to experimental groups of six.

**Procedure**

Subjects were initially trained in the performance tasks and in the subjective reporting procedure. Each experimental group was then exposed on the same day of the week for 6 successive weeks, meeting a different experimental condition each week in randomized order (as shown in Table 4). Reporting each day at 13.30, they assembled in a meeting room maintained at 22°C, close to the experimental office, where they adjusted their clothing for comfort while performing a multiplication task for 20 min, reporting thermal comfort sensation and thermal acceptability before and after this period. Finger temperature was measured. They then entered the experimental office at 14.00 for an exposure period of 3 h, during which they were allowed to adjust their clothing only during those sessions when the air temperature was 22°C. On three occasions during the session, each subject performed a step-climbing exercise to simulate normal activity, walking up to and over a two-step up, two-step down staircase, then back to their desk. Finger temperature was measured at intervals. The timing of performance tests and subjective ratings is given in Fig. 2. Subjects returned to the office after leaving it and breathing fresh air for 2 min, in order to record perceived air quality as visitors to an office in which bio-effluents were present.

In the statistical analyses, the subjective responses and performance data were tested for Normality using...
the Shapiro-Wilks’ $W$-test. The non-parametric Friedman Two-Way Analysis of Variance by ranks was applied to variables that appeared not to be Normally distributed (Siegel, 1956). Conventional ANOVA was used for variables that were at an interval level of measurement and Normally distributed. The non-parametric Page $L$-test (Siegel and Castellan, 1988) was applied to test directional hypotheses.

**Results**

Table 1 shows the physical measurements obtained during the exposures. The measurements show that the environment in the office varied systematically as intended.

The measured relative humidity was slightly above the intended level on average. The difference was small (max. 9% RH), the actual level being higher than intended under all conditions.

Based on the CO$_2$ concentration measured outdoors and in the middle of the occupied space, calculations indicate that the metabolic rate may have increased significantly at higher temperatures (ANOVA: $P < 0.001$). A Newman–Keuls test indicates that estimated metabolic rates at the three temperatures differed significantly from each other ($P < 0.05$). The metabolic rate was highest in the condition 30°C with office noise. Note that the measured average CO$_2$ concentration was not highest for this condition, as a greater number of subjects were absent. Estimated metabolic rate did not differ significantly between the noise conditions.

Finger temperature measured during the pre-exposure did not differ significantly between conditions, while finger temperature measured during occupation of the experimental office increased significantly with air temperature (Friedman ANOVA: $P < 0.001$). At 22°C most of the subjects’ foreheads were observed to be “matt”, while most became “shiny” at the elevated temperatures. At 30°C “visible drops of sweat” were observed on a few subjects’ forehead, while none were observed at 26°C or 22°C. No differences were found for the two acoustic conditions. Table 2 shows the number and percentage of subjects whose forehead was “matt”, “shiny” or with “visible drops of sweat” in each temperature condition (average of the last two hours of exposure). Noise conditions are pooled, since the effect of noise on estimated metabolic rate was not significant.

Office noise was rated on two occasions during the exposure: upon entering and after 120 min. At both assessments, the acceptability of the noise level was affected significantly by whether the recording was being played (ANOVA: $P < 0.01$). The levels of acceptability reported by the subjects indicate that only 4% of a random sample of the population would be dissatisfied with the noise in the quiet office, while 68% would be dissatisfied in the open-plan office condition. No adaptation to noise was found under either acoustic condition.

Figure 3 (top and middle) shows the subjects’ thermal sensation and the reported level of thermal acceptability at the different temperatures. Both thermal sensation and thermal acceptability were significantly affected by the increased temperature, on both occasions (ANOVA: $P < 0.001$). Noise had no significant effect on either assessment.

Upon entering the office, 0%, 2% and 22% of the subjects experienced a thermal sensation of PMV $\leq -2$ at 22°C, 26°C and 30°C, respectively, equal to feeling “warm” or warmer. After 120 min of occupation, the

<table>
<thead>
<tr>
<th>Condition of forehead</th>
<th>22°C</th>
<th>26°C</th>
<th>30°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matt</td>
<td>51 (96%)</td>
<td>38 (64%)</td>
<td>13 (24%)</td>
</tr>
<tr>
<td>Shiny</td>
<td>2 (4%)</td>
<td>21 (36%)</td>
<td>38 (71%)</td>
</tr>
<tr>
<td>Visible sweat drops</td>
<td>0</td>
<td>0</td>
<td>3 (5%)</td>
</tr>
<tr>
<td>No. of observations</td>
<td>53</td>
<td>59</td>
<td>55</td>
</tr>
</tbody>
</table>

![Table 2](image)

Fig. 3 Subjects’ thermal sensation, thermal acceptability and overall acceptability at the different conditions
The performance of typical office tasks was significantly reduced upon entering and re-entering the office (ANOVA: \( P < 0.05 \)). In a test of the directional hypothesis that temperature increases the irritation of mucous membranes, the Page L-test showed a significant effect of temperature for all irritation indices, both upon entering and re-entering the office (\( P < 0.05 \)). Neither odor intensity nor irritation of mucous membranes was affected by noise.

The intensity of several SBS symptoms increased with noise and/or temperature. \( P \)-values for the significant effects obtained are tabulated in Table 3, which also contains the group average symptom intensity values for all six conditions on a scale from 0 to 100. The end-labels of the visual-analog scales corresponding to 0 and 100 are given in the Table.

Self-estimated performance was significantly reduced at elevated temperatures. The effect was most pronounced after 120 min of exposure (ANOVA: \( P < 0.001 \)) but was also significant at the beginning of the session (ANOVA: \( P < 0.05 \)). No effect of noise on self-estimated performance was found.

The performance of typical office tasks was significantly affected by the experimental conditions. The group average values obtained in each test of performance in each of the six conditions are tabulated in Table 3, together with the significant \( P \)-values. In an addition task, office noise decreased the rate of performance by 3% (ANOVA: \( P < 0.05 \)) and subjects who felt too warm made 56% more errors (Newman–Keuls test: \( P < 0.05 \)). There was a noise–temperature interaction on performance of the addition task (ANOVA: \( P < 0.01 \)); the effect of warmth on errors was less in noise. There were no significant main effects of noise or temperature, and no significant interaction between them, on the Tsai–Partington test of cue-utilization or the creative thinking task. Applying the Page L-test in each noise condition separately to test the hypothesis that raised temperatures decrease arousal (and thus increase cue-utilization as measured by the Tsai–Partington test) yielded a significant result in the office noise condition only (\( P < 0.05 \)). In the open-ended creative thinking task, performance as measured by the normalized C-score appeared to be higher at the intermediate temperature of 26°C in the quiet, as expected, and also to be lower at 30°C in the office noise condition, but only the latter tendency yielded an apparently significant effect of temperature in noise (ANOVA: \( P < 0.05 \)). Typing speed (ANOVA: \( P < 0.05 \)) and reading speed in a proof-reading task (ANOVA: \( P < 0.05 \)) were higher in the office noise condition than in the quiet. No thermal effects on these tasks could be demonstrated.

**Discussion**

The hypotheses of the present experiment were that increased thermal load would increase SBS symptom intensity and decrease the performance of office tasks. Exposure to the office noise distraction condition was expected to decrease the performance of office tasks. Noise was expected to counteract the under-arousing effect of moderately warm thermal discomfort, but not the effect of warmth on symptom intensity. The negative effect of very warm thermal discomfort on performance was expected to be intensified by noise.

Raised temperatures affected thermal comfort and thermal acceptability as expected, while noise did not, but overall acceptability was affected by both factors. What was not expected was that CO\(_2\) measurement indicates that raised temperatures appear to have progressively increased metabolic rate. In order to reduce sweating, subjects were expected to respond to moderately increased temperatures by reducing their metabolic rate, leading to decreased arousal. Some evidence for this expected effect of raised temperatures on arousal is provided by the significant interaction between noise and temperature in their combined effect on the performance of the addition task: it is generally assumed that noise has an arousing effect, so if raised temperatures counteract the effect of noise, they would appear to be behaviorally under-arousing.

The effect of raised temperatures on estimated metabolic rate was unexpectedly large: +9% at 26°C and +31% at 30°C. The proportion of subjects in
Table 3. Group average symptom intensity and performance values

<table>
<thead>
<tr>
<th>Perception</th>
<th>Time</th>
<th>22°C, 35dBA</th>
<th>26°C, 35dBA</th>
<th>30°C, 35dBA</th>
<th>22°C, 55dBA</th>
<th>26°C, 55dBA</th>
<th>30°C, 55dBA</th>
<th>Main effect</th>
<th>Interaction effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air quality acceptability</td>
<td>0 min</td>
<td>0.54 0.02</td>
<td>−0.38</td>
<td>0.51</td>
<td>0.16</td>
<td>−0.45</td>
<td>T: P &lt; 0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>125 min</td>
<td>0.63 0.15</td>
<td>−0.38</td>
<td>0.56</td>
<td>0.06</td>
<td>−0.47</td>
<td>T: P &lt; 0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>re-enter</td>
<td>0.39 0.11</td>
<td>−0.41</td>
<td>0.43</td>
<td>−0.05</td>
<td>−0.59</td>
<td>T: P &lt; 0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odor intensity</td>
<td>0 min</td>
<td>0.65 1.06</td>
<td>1.22</td>
<td>0.74</td>
<td>1.01</td>
<td>1.38</td>
<td>T: P &lt; 0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>125 min</td>
<td>0.38 0.65</td>
<td>1.17</td>
<td>0.53</td>
<td>0.76</td>
<td>1.17</td>
<td>T: P &lt; 0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>re-enter</td>
<td>1.02 1.03</td>
<td>1.16</td>
<td>0.80</td>
<td>1.11</td>
<td>1.68</td>
<td>T: P &lt; 0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye irritation</td>
<td>0 min</td>
<td>0.24 0.43</td>
<td>0.54</td>
<td>0.35</td>
<td>0.29</td>
<td>0.65</td>
<td>T: P &lt; 0.05*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>125 min</td>
<td>0.50 0.69</td>
<td>0.80</td>
<td>0.53</td>
<td>0.84</td>
<td>1.08</td>
<td>T: P &lt; 0.05*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>re-enter</td>
<td>0.43 0.55</td>
<td>0.59</td>
<td>0.17</td>
<td>0.78</td>
<td>0.96</td>
<td>T: P &lt; 0.05*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throat irritation</td>
<td>0 min</td>
<td>0.27 0.73</td>
<td>0.67</td>
<td>0.36</td>
<td>0.40</td>
<td>0.96</td>
<td>T: P &lt; 0.05*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>125 min</td>
<td>0.34 0.59</td>
<td>0.88</td>
<td>0.21</td>
<td>0.34</td>
<td>0.83</td>
<td>T: P &lt; 0.05*</td>
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<td>41 49</td>
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Moderate heat stress and open-plan office noise distraction
which some forehead sweating was observed increased almost linearly from 4% at 22°C to 76% at 30°C, but even at 30°C only 65% of subjects reported feeling warm even though their clothing insulation had been optimized for 22°C. No reports of temperature effects on metabolic rate this close to the thermal comfort range were found in the literature. The Q10 effect describing the dependence of biochemical reactions in the body on skin temperature (Benzinger et al., 1963; Werner and Buse, 1988) would predict an increase of only 4% at 26°C and 8% at 30°C, estimating skin temperatures from a theoretical model of human heat balance (Huizenga, C., pers. commun., 2001). Conzolazio et al. (1963) reported that a temperature of 29°C did not result in any measurable increase in metabolic rate, as estimated from expired CO₂, in comparison with a temperature of 21°C, but that a temperature of 38°C increased metabolic rate by 11% when subjects were resting and by 13% during moderate activity. The sweat rate measured for these subjects was doubled at 29°C and tripled at 38°C, in comparison with 21°C. No information on clothing insulation or thermal sensation was provided. The question of whether and by how much metabolic rate is affected by exposure to temperatures close to thermal comfort merits further study.

The acceptability of the acoustic environment was reported to be much lower in the simulated open-plan office noise condition. No adaptation over time was observed. Overall acceptability of the combined conditions was significantly lower in the open-plan office.
noise condition, at all temperatures, although thermal conditions had a much larger effect than that of the noise conditions on overall acceptability. Similar findings have been reported by Alm et al. (1999) in a study of the acceptability of ventilation noise levels of 45, 48 and 51 dBA at operative temperatures of 26, 27.6 and 29.6°C. In the present study, reported fatigue and difficulty in concentrating were significantly higher in the open-plan office noise condition, but did not interact with any thermal effects on subjective perception. The performance of an addition task, and of an open-ended creative thinking task, was significantly lower in the noise condition. Typing speed and reading speed, both well-practiced and routine skills, were observed to be higher in noise condition, which may indicate that subjects were stimulated by the additional noise distraction. This interpretation is consistent with the finding that the negative effect of warmth on errors in the addition task was absent in the noise condition. Subjects who reported feeling too warm made 56% more errors in the addition task, while the diagnostic Tsai–Partington test of cue-utilization was performed better (indicating that arousal was decreased) with increasing temperature in the office noise condition, as found by Wyon (1969).

The results provide support for the hypothesis that increasing temperatures increase the intensity of a wide range of SBS symptoms and decrease the performance of office tasks; that the noise distraction of an open-plan office decreases performance of office tasks requiring concentration while stimulating the rate at which simple well-practiced tasks are performed, increasing fatigue and decreasing the ability to concentrate without affecting more specific SBS symptoms; and that moderate heat stress reduces arousal. The suggested mechanism for this last-mentioned effect, that metabolic rate is adaptively reduced at raised temperatures, was not supported; indeed, some indication of the opposite effect was obtained, requiring further study.

Conclusions
Raised temperatures in the range 22–30°C and the noise conditions that occur in open-plan offices, when reproduced at 55 dBA, both had negative effects on the performance of office work. Self-estimated performance was decreased by exposure to raised temperatures but not by exposure to open-plan office noise. The overall acceptability of working conditions was lower during exposure to either factor, with no apparent interaction between them. Raised temperatures had negative effects on a wide range of SBS symptoms, while open-office noise did not, although reported fatigue was higher and ability to concentrate was lower at 55 dBA than in the quiet 35 dBA private office noise condition. It is clear that while subjects in a relatively brief experiment may exert some conscious effort to counteract noise distraction, becoming more fatigued as a result, office work may generally be performed considerably less well in open offices than in enclosed offices, and less well at subjectively warm air temperatures than at cooler temperatures.

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Financial support for the project was provided in the form of the Rockwool 1999 research prize that was awarded to one of us (D.P.W.) for the study of noise and temperature effects on office work. The experiment was carried out during Autumn 2000.

References
Witterseh et al.


