Effect of temperature on perceived work environment, symptoms and self-estimated productivity in office work

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ABSTRACT

The aim of the study was to investigate the effects of elevated summer indoor temperatures on perceived comfort, symptoms and subjectively assessed productivity in an office building. The measurements during spring 2002 showed that indoor environment was at the normal Finnish office building level. The mean room temperature during the 2-week measurement period was 22°C. An indoor air questionnaire (MM-40-FIN) including additional questions about work efficiency was presented to the employees during the measurements. The perceived indoor environment was at the normal Finnish office level. During summer 2002, another series of temperature measurements and questionnaires were carried out. When the temperature rose over 25°C, central nervous system symptoms and the dissatisfaction of IAQ increased. Self-estimated work efficiency decreased statistically significantly among the employees, with the temperature. The number of employees reporting reduced work efficiency increased by about 40% when the indoor temperature rose from 24 to 29°C.

INDEX TERMS

Temperature; Ventilation; Thermal comfort; Subjective productive

INTRODUCTION

The effect of moderate heat stress on the performance of reading and multiplication tasks has been studied (Wyon *et al*., 1979). Fisk and Rosenfeld (1997) describe the study of the effect of thermal stress on the learning capacity of university students carried out in 1968. Wyon (1974) has studied the effect of temperature on office work. The typists' level of performance decreased considerably at the temperature of 24°C compared to the temperature of 22°C, although the typists felt comfortable in both temperatures. Furthermore, Wyon (1993) has determined the importance of the possibility to self-adjust the temperature. The productivity of the office workers improved at least 4% when they moved to new workrooms having the possibility to adjust the temperature. In the laboratory, the tests in Denmark have shown that the perception of air freshness improved greatly with decreasing temperature and humidity, and the intensity of fatigue, headache, and difficulty in thinking clearly decreased when subjects worked at slightly lower levels of air temperature and humidity (under 23° and 50% rh) (Fang *et al*., 2002). The recent Finnish studies in a call centre showed that productivity decreased about 2%/°C when the temperature increased above 25° (Niemelä *et al*., 2000). Seppänen *et al.* (2003) have made same conclusion in the literature review. The demand for better indoor environment and the increasing number of office workers have shown that new information on the effect of temperature in offices is needed.

The aim of this cross-sectional study was to investigate the effect of the elevated indoor temperatures in summer on perceived comfort, symptoms and self-estimated productivity.

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METHODS

The cross-sectional study design was applied on two floors of an office building in down town Helsinki, Finland. The building was a typical Finnish seven-floor office building built in the 1970s. It has a concrete structure, the total floor area being 6500 m^2 (69 970 sq. feet). The building has double-glazing and a mechanical ventilation system. The supply air was distributed to the corridors and exhausted from the office rooms through the hollow core slab. The design value for the exhaust airflow was 2 L/s m^2.

The baseline indoor environment measurements (temperature, CO_2, TVOC, dust composition, noise) were carried out during spring 2002. The room air temperature and carbon dioxide measurements (8 a.m. to 5 p.m.) were conducted for 2 weeks with the data-loggers. Total volatile organic compounds (TVOC) samples were collected with stainless steel tubes (Part No L4270123, Perkin Elmer, Beaconsfield England) packed with 150 mg Tenax TA 35/60 mesh (Art 706216, Macherey-Nagel, Dueren). TVOC samples were desorbed in a Perkin-Elmer ATD 400 (Perkin-Elmer Ltd, Beaconsfield, UK) and analysed with a gas chromatograph, equipped with a mass selective detector (Tuomi *et al*., 2000) and the dust composition samples were analysed with scanning electronic microscopy (SEM) (Schneider, 2001). In addition, the exhaust airflows were measured in all rooms through the exhaust air outlets using an electronic hand held rotating vane anemometer. An indoor air questionnaire (MM-40-FIN, FIOH) (Andersson, 1998; Reijula, Sundman-Diegert, 2003) was presented to the employees via the internet. The questionnaire included additional questions about work efficiency.

The work efficiency was estimated using the following scale:

1 = clearly under the average efficiency,
2 = below the average efficiency,
3 = at the average efficiency,
4 = above the average efficiency,
5 = clearly above the average efficiency.

In addition, the temperature measurements were carried out during a 2-month summer period, from June to August 2002. A short questionnaire inquiring into the symptom intensity and perceived indoor environment at the particular moment was presented to the occupants on 5 days during the summer. The temperatures informed were measured during the same working days when the questionnaires were answered.

RESULTS

The baseline indoor environment measurements (temperature, CO_2, VOC, suspended particulate matter, and noise) during spring 2002 showed that the indoor environment was at the normal Finnish office building level (Table 1). Some man-made-mineral fibres (MMMF) were found in three rooms. The average room indoor air temperature during the two-week measurement period was 22°C. The highest temperatures during spring occurred in rooms facing south and being somewhat higher on the 3rd floor than the 4th floor (Table 2). The average exhaust airflow was 2.13 L/s m² and the standard deviation as much as 45% of the average value. The exhaust airflows ranged from 0.0 L/s m² to 5.8 L/s m². An indoor air questionnaire (MM-40-FIN, FIOH) was presented to the occupants during the baseline measurements. The response rate to the questionnaire was 63%. The questionnaire data indicated that more than 40% of the occupants reported that the indoor air is stuffy (44%) and dry (41%). The prevalence of fatigue (25%) was the highest of all the work-related symptoms reported. This is typical in the work community answers where occupational stress is reported

more than on average Finnish office environments. The questionnaire included additional questions about work efficiency. During the baseline measurements 21% of the occupants (n = 118) reported work below their average efficiency.

Table 1 The mean and range of carbon dioxide (CO_2), total of the volatile organic compounds (TVOC) and noise level during baseline measurements

	All rooms		3rd floor		4th floor		Target levels[a]
	Mean	Range	Mean	Range	Mean	Range	
CO_2, ppm (n = 12)	473	419–553	473	419–553	479	451–506	700 ppm
TVOC, µg/m^3 (n = 10)	40	19–81	47	26–81	33	19–44	200
Noise L_{Aeq}, dB (n = 20)	37	33–41	35	33–38	39	34–41	30 dB(A)[b]

[a]Target levels in the highest indoor climate category S1, FISIAQ, 2001.
[b]Target level of the noise level from the heating and ventilation equipment.

Table 2 The mean and standard deviation of the room temperature during spring (n = 48) and summer (n = 49)

	All rooms; spring/summer		3rd Floor; spring/summer		4th Floor; spring/summer	
	Mean	SD	Mean	SD	Mean	SD
All rooms	22.0/25.1	0.9/1.6	22.1/25.2	1.0/1.7	21.8/25.0	0.8/1.6
North	21.8/24.1	0.8/1.4	22.0/24.3	0.7/1.4	21.4/23.9	0.7/1.2
East	21.6/25.7	0.8/1.4	21.5/25.6	0.9/1.4	22.0/25.7	0.7/1.3
West	22.2/25.4	0.9/1.5	22.7/26.0	0.5/1.4	21.7/25.2	0.8/1.5
South	22.5/25.5	0.9/1.6	22.9/25.6	0.9/1.7	22.1/25.2	0.6/1.5

In Finland, summer 2002 was unusually warm, the average outdoor temperature was 2.5–3.5°C warmer than the long-term average. The indoor temperature ranged from 17 to 37°C (mean 25°C, RH 26–67%) (Table 2).

When the temperature rose over 25°C, the percentage of respondents reporting symptom intensity from fairly strong to very strong increased to 34–54% for head feels ‘heavy’, 33–49% for fatigue and 25–36% for difficulties in concentrating (Figure 1). During the baseline questionnaire the corresponding prevalences were 16%, 25% and 10% respectively at the indoor temperature of 22°C. The figure shows how the prevalence of the symptoms (n = number of the occupants who answered the questionnaire) depended on the temperature (measured during five different workdays).

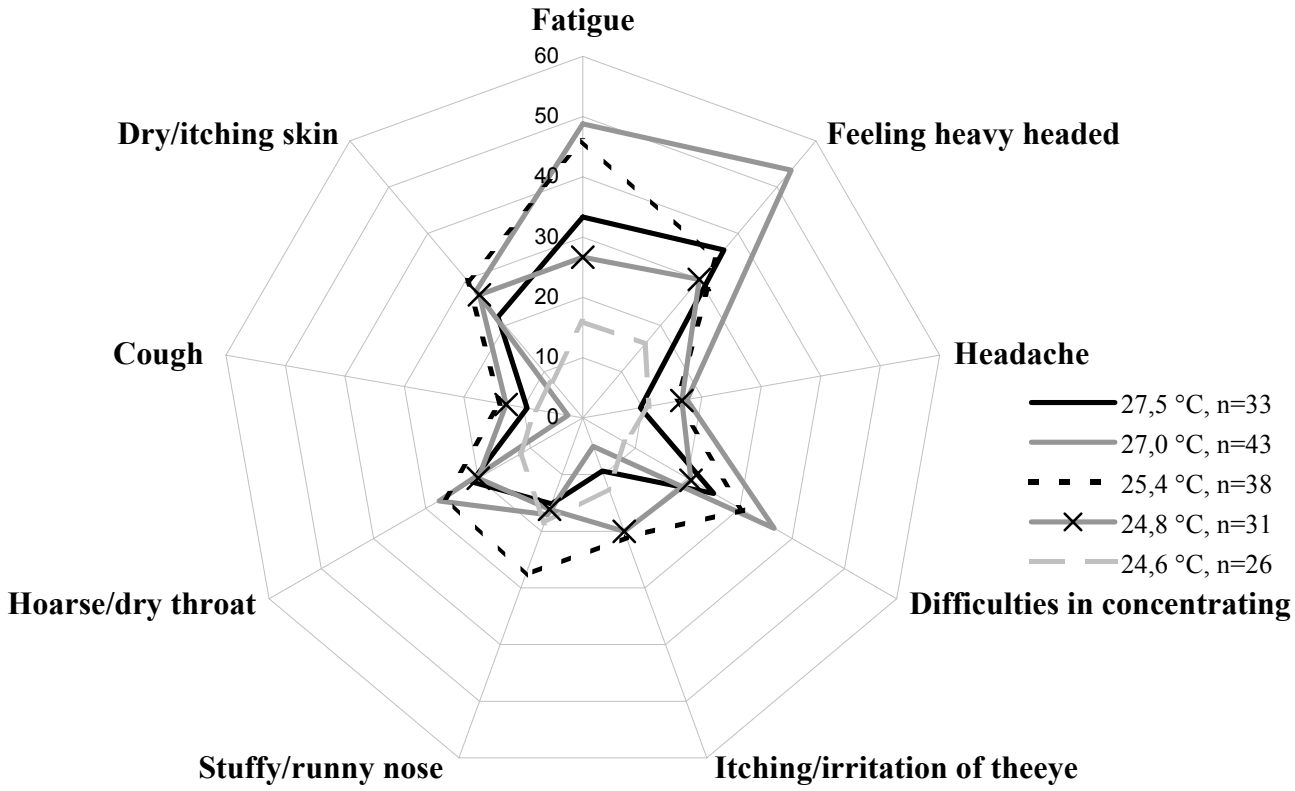


Figure 1 Summary of the prevalence of SBS symptoms (intensity rating fairly strong to very strong) in the single person offices (*n* = number of the occupants who answered the questionnaire) depending on the room temperature during summer (measured during five different workdays).

Over 40% of the employees reported dissatisfaction of indoor air quality and room temperature when the temperature rose over 25°C. The portion of the dissatisfied employees increased up to 60% when the temperature rose over 27°C. Additionally, about 40% of the employees estimated their work efficiency to decrease below average when the temperature rose over 25°. When the temperature rose over 27°C, 60% of the employees reported decreasing work efficiency (Figure 2).

Figure 2 The percentage of employees reporting dissatisfaction with IAQ and room temperature during five different work days, and those reported working with the efficiency below average during summer measurements (n = 171).

When the room temperature rose over 24°C, the employees estimated the work efficiency to decrease (Figure 3). The correlation between the temperature and the estimated work efficiency was $r = -0.51$ ($p < 0.0001$, n = 214). The response rate during summertime questionnaires ranged from 25 to 43% (n = 26–43).

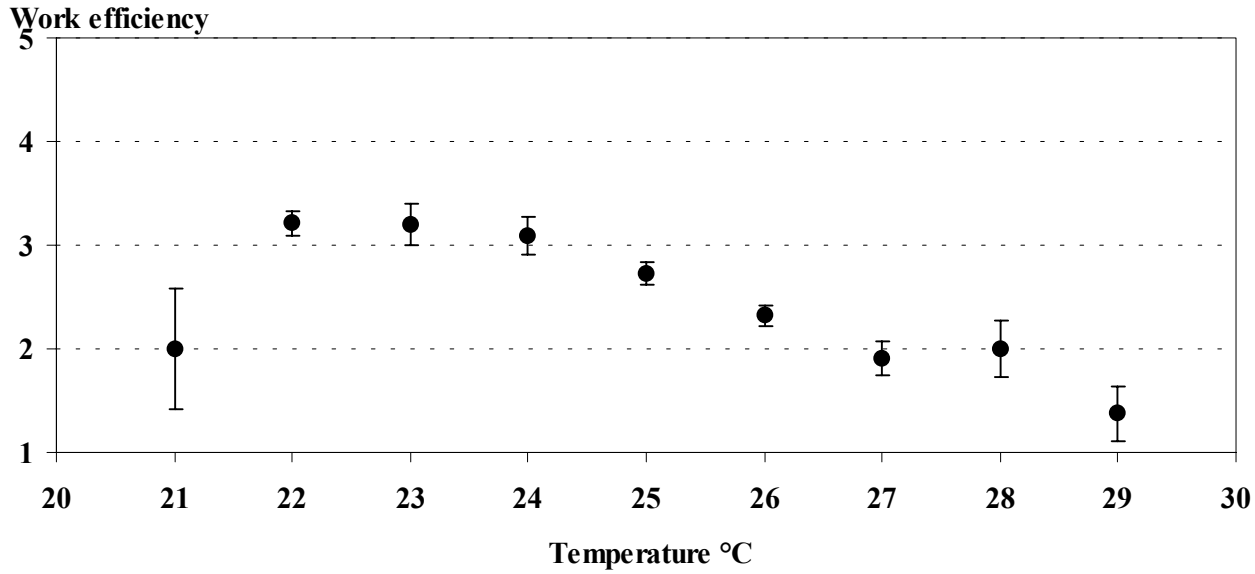
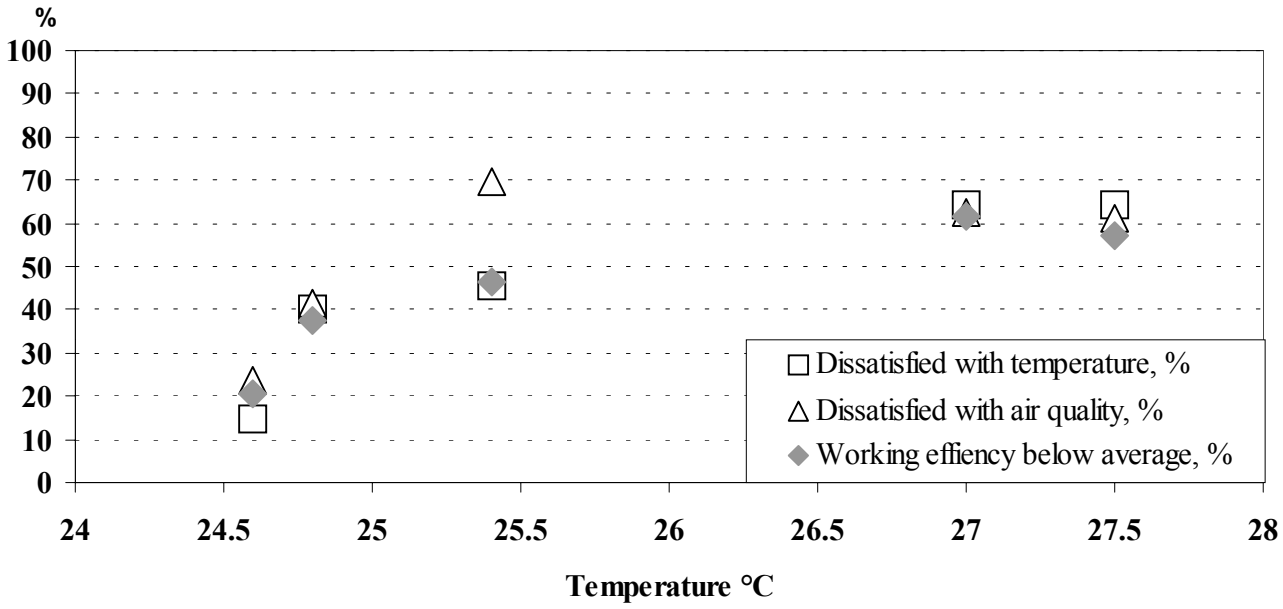


Figure 3 Self-estimated work efficiency at the room temperatures measured during spring and summertime (n = 214).



DISCUSSION

In Finland, long-term temperatures over 25°C are not common, and office workers do not get used to high temperatures. Typically, the indoor temperatures are a few degrees higher than outdoor temperatures due to internal heat loads if the building is not air conditioned This study shows that the temperatures over 25°C elevated the prevalence and the intensity of typical central nervous system symptoms: head feels 'heavy', fatigue and difficulty in concentrating. The summary of an indoor air questionnaire study among Finnish office workers (n = 11 154) reported the corresponding percentages to be 9%, 16% and 3% (Reijula and Sundman-Diegert, 2003). The reduction of the self-estimated work efficiency was statistically significant when temperatures rose over 25°. Temperatures above 24° have been reported to affect productivity (Wyon, 1974; Niemelä *et al*., 2000). The results of the questions (Figure 2) about the dissatisfaction with indoor air quality, dissatisfaction with room temperature and the self-estimated work efficiency are similar. This result may demonstrate the quality of the used questions.

CONCLUSIONS AND IMPLICATIONS

The warm summer period in Finland during 2002 increased indoor temperature up to 37°C. When the temperature rose over 25°, the intensity of central nervous system symptoms and the dissatisfaction with IAQ increased. The self-estimated work efficiency decreased among the employees. The effect of temperature on the reduction of the self-estimated work efficiency was statistically significant. The number of employees reporting reduced work efficiency increased by about 40% when the room temperature rose from 24 to 29°C. In northern Europe, the variation of the outdoor temperature is large and the variation may happen periodically quite quickly. Acclimatization does not take place in a short time. With proper facility management, indoor temperatures can be more effectively controlled. This will decrease the dissatisfaction and SBS symptoms, and at the same time improve productivity.

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