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Survey—offices
NORWEB headquarters environmental survey

COMBINED PHYSICAL AND SUBJECTIVE SURVEY REVEALS A HIGHLY SUCCESSFUL AIR CONDITIONED OPEN PLAN OFFICE

Don Dickson

This research study conducted by Don Dickson, ERDC, was part of a larger programme into the causes of building sickness and the results of the survey showed that the environmental conditions were exactly as designed, with close control achieved by good operation and maintenance – the building compared favourably with the best naturally ventilated buildings.

Cette étude de recherche menée par Don Dickson, ERDC, était une partie d'un projet plus grand qui examinait les causes de la maladie de constructions et les résultats de l'enquête ont montré que les conditions ecólogiques étaient exactement ce qu'elles étaient projetées, avec le contrôle étroit achevè par le bon fontionnement et l'entretien – le bâtiment avait comparé favourablement avec les bâtiment les plus naturellement ventilés.

Introduction

Open plan offices, in particular air-conditioned ones, have been the subject of some quite harsh criticism over recent years, particularly in relation to the so-called Sick Building Syndrome.

There is no valid reason why a properly designed, commissioned and run air-conditioned office should provide a less comfortable or less healthy environment than a naturally ventilated office; in fact, the internal environment should be better. The implications of this are that unsatisfactory conditions may be the result of shortcomings in operation rather than in concept. This study was designed to identify these failings and also to uncover factors which may contribute to a very successful building.

The recently commissioned NORWEB Headquarters building at Talbot Road, Manchester was surveyed in September 1989. The method was to compare the results of a subjective questionnaire survey with a wide range of physical parameters, measured at the same time.

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The NORWEB Headquarters building

The design aim for the new NORWEB building was to produce a modern all-electric building 'featuring the latest advances in communications, information technology and environmental control to produce productive and energy efficient working conditions'.

The external design is striking in appearance with apparently 100% glazing to all floors (Fig. 1). However this is a clever illusion, the double-glazed solar control glazed area is 21% viewed from outside.

It is a deep plan three-storey building with two wings per floor organized round a central core (Fig. 2). Each floor is smaller than the one below and shaded against solar overheating by overhanging canopies, with balconies for ease of external maintenance.

The structure is of reinforced concrete with structural columns on an 8.4m square grid. The internal floor to ceiling height is 3m. The two ground floor wings have a floor area of approximately 44×35m.

The building was completed in March 1988 and the staff moved in June.

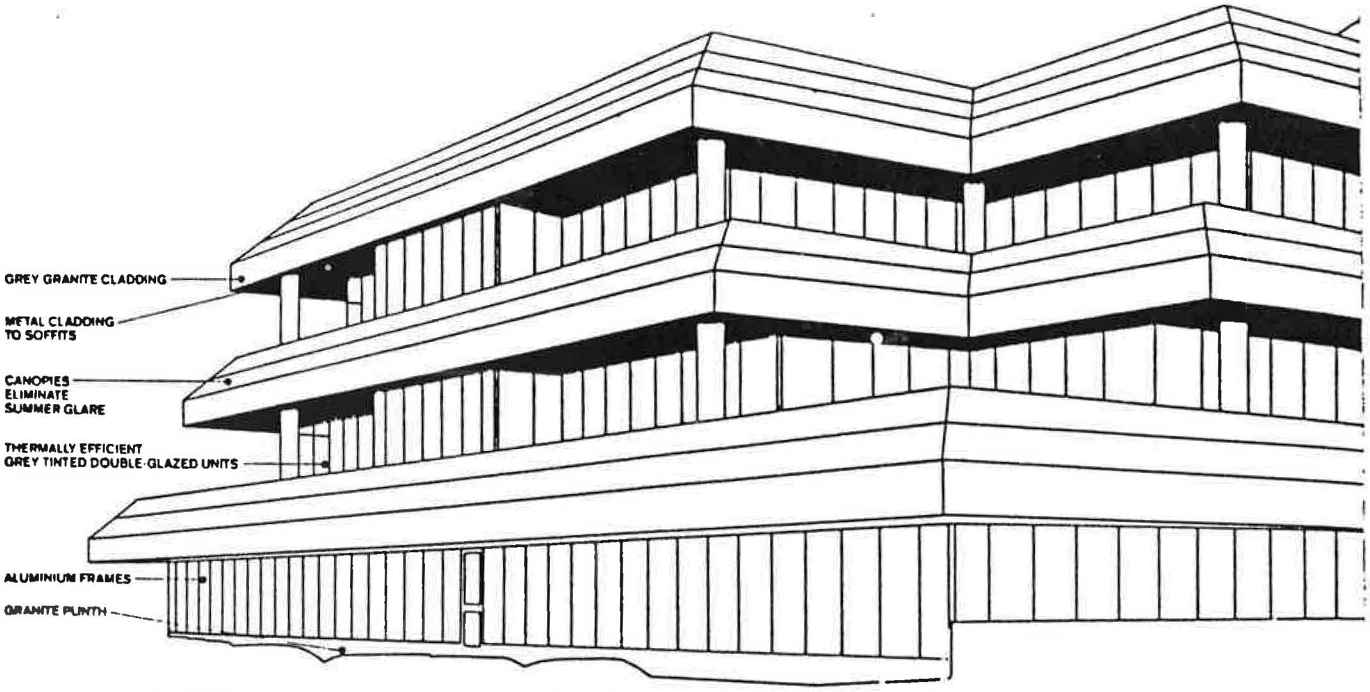


Fig. 1. NORWEB HQ, Talbot Road, Manchester

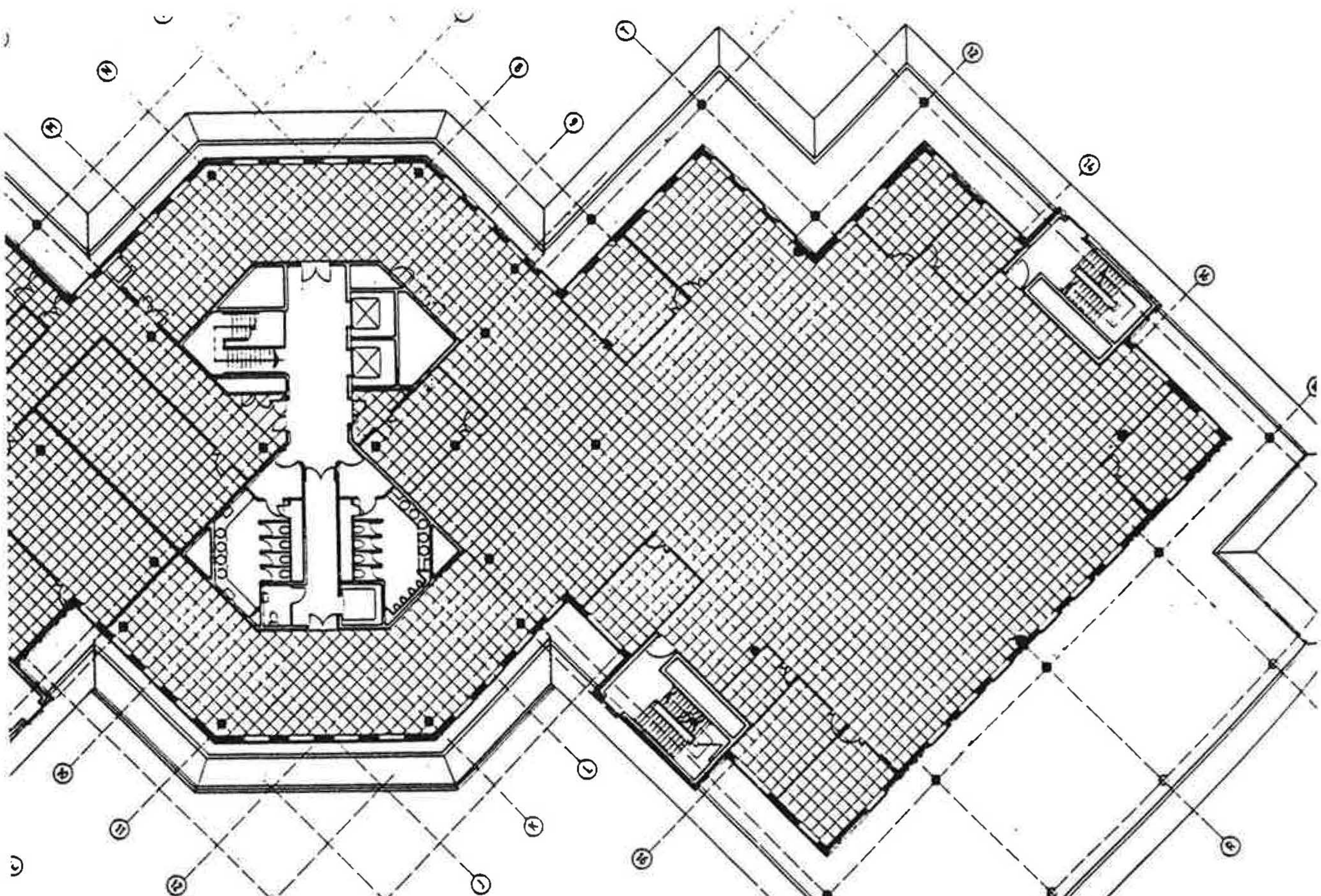


Fig. 2. Floor plan

Fig. 3. Air supply terminal in floor

Environmental control

The office and restaurant areas are air conditioned by eight air handling units in the roof level plant room. The most interesting and unusual feature of the design is the way the conditioned air is supplied to the offices; the space under the floors serves as an air distribution plenum with 'twist' outlet terminals (Fig. 3), flush with the floor every few metres through which the air emerges in a rapidly mixing gentle spiral. The terminals can be placed freely and repositioned to follow organizational changes. They were originally planned three to a desk position, but many desks have been moved without moving the terminals and their locations are now random. Air return is through the light fittings into the ceiling void. The system operates effectively as a displacement ventilation system (ref. 1) since much of the surplus heat from people and machinery is removed by convection without mixing with the incoming cool air. The air supply to the open plan areas is at constant volume with individual heater and cooler batteries to each zone.

Heat recovery from the exhaust air is by heat pumps into the hot water system, with additional off-peak hot water storage. Cooling is provided by chilled water from heat pumps rejecting heat to roof top cooling towers.

Lighting is fluorescent using low loss electronic ballast and low brightness diffusers in air handling fittings. Design illumination is 600–700 lux.

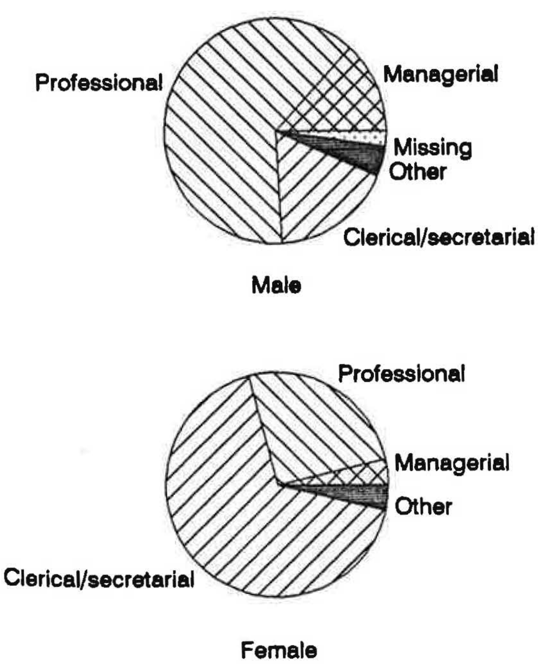


Fig. 4. Sample divided by sex and grade

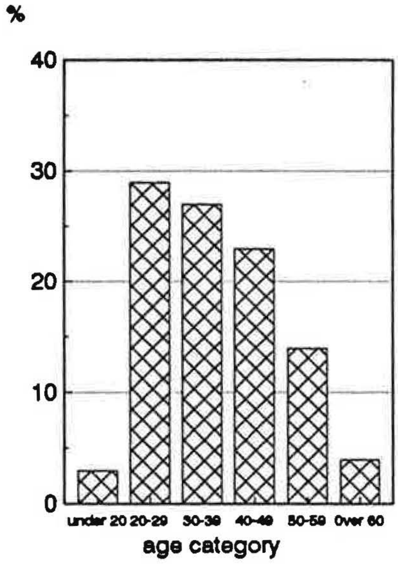


Fig. 5. Age distribution

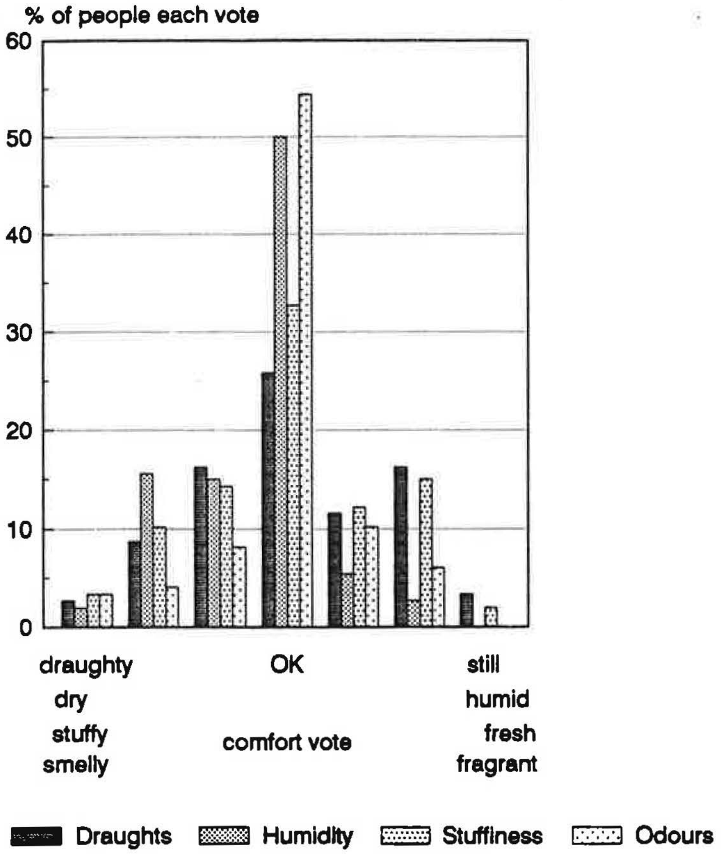


Fig. 12. Ventilation assessment

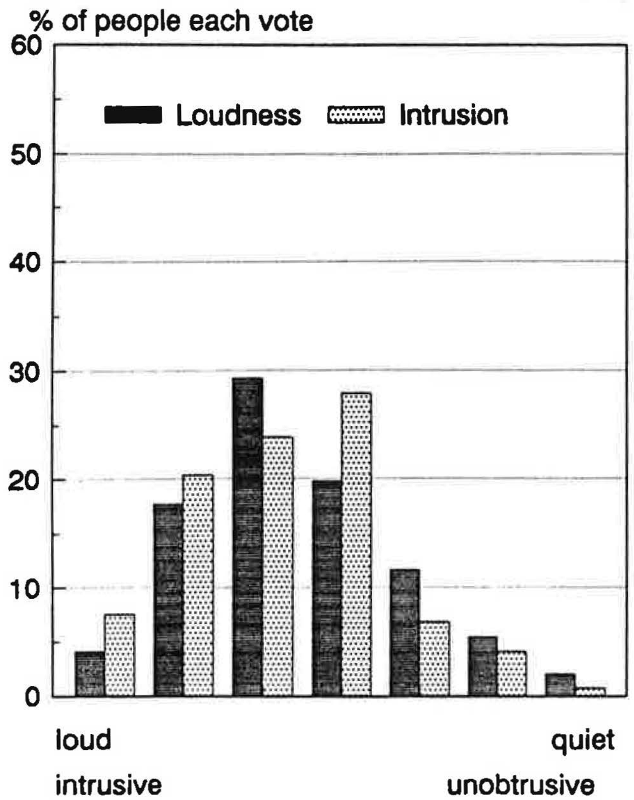


Fig. 13. Perceived noise

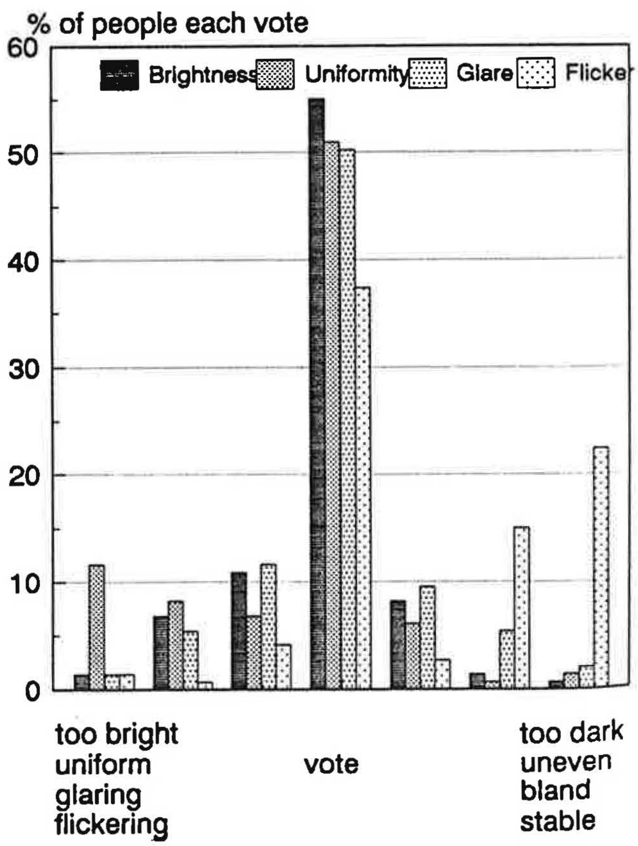


Fig. 14. Perceived lighting

Fig. 15. Perceived degree of privacy

The rank order of symptoms was found to be similar to that found in other buildings, with lethargy being the most common, followed in order by headache, stuffy nose, dry throat, dry eyes, itching eyes. Those who do experience symptoms appear to suffer them frequently (Fig. 9) with about half of those who reported symptoms suffering daily. Fifteen per cent had left work early during the previous month because of these symptoms.

The environmental conditions were voted as being generally satisfactory (Fig.10). The survey results relating to itemized feelings of comfort are shown in Figs 11 to 14. On every item except noise the most frequently occurring vote was the neutral point on the seven point scale, indicated by OK.

The staff overwhelmingly felt that they had no control over the environmental conditions, but this is not reflected in a high building sickness score. Sixty-four percent were to some extent dissatisfied with privacy at their desks (Fig. 15). A majority found their job fairly stressful (Fig. 16). The perceived influence of working conditions on productivity was generally positive or neutral (Fig. 17).

Subjective assessment

The subjective survey results were examined statistically to see which factors related to the number of symptoms people experienced. The factors which had no significant influence on the number of symptoms were: hours spent in the building, at their desk or working at a VDU; smoking habits; job stress; privacy; warmth; draughts; odours; control over the environment.

Conforming to the pattern established in the OES, female and clerical workers experienced more symptoms than male and professional/managerial workers. Although desk position was found to be not significant, having a view was found to be beneficial. Perceptions of decreased productivity were associated with higher numbers of symptoms, as was general dissatisfaction with thermal comfort, ventilation, noise and lighting. The particular items relating to number of symptoms were: dryness, stuffiness, glare and flicker.

The conclusion drawn from the subjective survey is that the occupants are, on the whole, satisfied or neutral about their environmental conditions. However, there are some feelings of lack of privacy, and some dissatisfaction with noise levels.

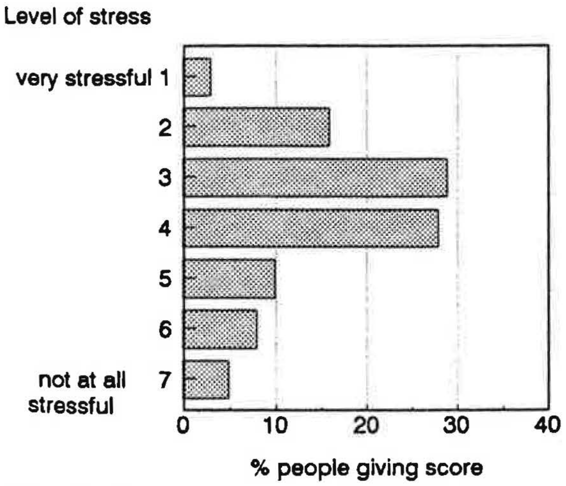


Fig. 16. Perceived job stress

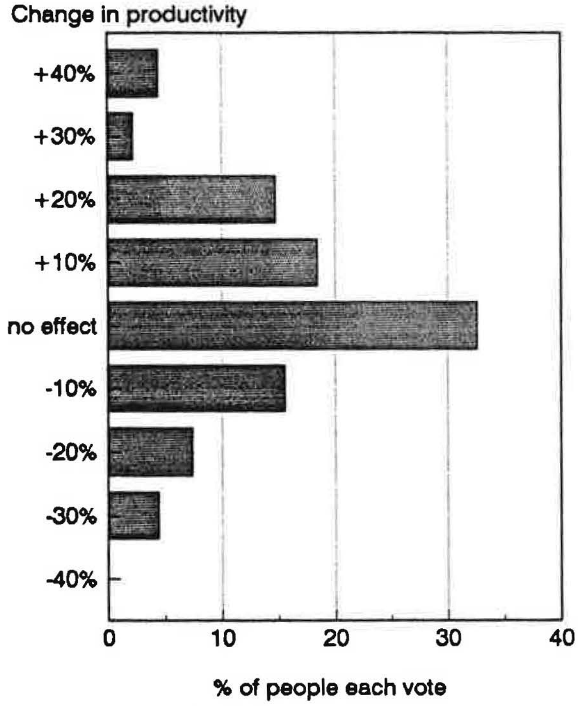


Fig. 17. Perceived influence of working conditions on productivity

Physical measurements

Air temperature

The air temperature in the office during the week 5–12th September 1989 was logged at two locations on each floor chosen to represent a 'core' and a 'perimeter' environment. At each logging station, three platinum resistance thermometers were located at ankle, sitting head height (1.2m) and ceiling height respectively. Temperatures were logged at 10-minute intervals, 24 hours per day. Temperature records were also available from the energy management system for seven locations on the ground floor and two locations on the second floor, for the week 4–12 September 1989 at 20-minute intervals.

All the records show very uniform temperatures in space and time. During the survey week the air temperature at 1.2m was between 22.5 and 23.5°C over 24 hours,

Table 2. Measured fresh air ventilation rates

	Ground floor east office	Ground floor east return air	2nd floor east office	2nd floor east return air
Time on 6.8.89	1300–1400	1300–1400	1500–1630	1500–1630
Office volume (m^3)	4600	4600	3400	3400
Fresh air (ch/hr)	0.91	1.06	1.15	1.2
m^3/hr fresh air	4186	4876	3910	4080
Fresh air l/s	1163	1354	1086	1133
l/s per person	9.3	10.8	8.7	9.1

Table 3. Measured air speeds in office

Height of sensor metres	Mean air speed m/s	RMS air speed m/s	Turbulence %
1.2	0.092	0.041	44
0.6	0.093	0.041	44
ankle	0.087	0.037	42

Table 4. Measured air speeds in office near terminals

Height above floor mm	0 1450	300 1150	600 850	900 550	1200 250	1450 0	←mm from terminal 1 ←mm from terminal 2
1200	0.069	0.078	0.062	0.069	0.076	0.104	m/s mean
	0.033	0.042	0.024	0.026	0.037	0.049	m/s RMS
	48	54	39	38	49	47	% turbulence
600	0.214	0.096	0.084	0.073	0.082	0.221	m/s mean
	0.074	0.046	0.055	0.027	0.053	0.091	m/s RMS
	35	48	65	23	65	41	% turbulence
100	0.524	0.087	0.060	0.069	0.088	0.588	m/s mean
	0.162	0.059	0.031	0.022	0.020	0.184	m/s RMS
	31	68	51	32	23	31	% turbulence

falling to 22°C over the weekend and rising to 24°C on some afternoons. Ankle temperatures were generally up to 0.5°C cooler than at head height. This shows that very effective air mixing is being achieved. Ceiling temperatures were generally up to 1°C warmer than at head height.

Humidity

The relative humidity during the survey week as recorded in the central zone on each floor by the energy management system was 50–55% on the ground floor (falling to 45% at nights and weekends), and 45–50% on the second floor.

Fresh air ventilation

The fresh air ventilation rate in the offices was measured by a tracer decay technique. For this test, 300ml of sulphur hexafluoride–a harmless and odourless tracer gas–was introduced into the fresh air supply of each wing in turn. The initial tracer gas concentration in the office was about 0.01 ppm. The rate at which the tracer concentration decayed was measured in the occupied space and in the return air duct simultaneously using portable gas chromatograph+electron capture detector gas analysers, thus giving the ventilation rate, i.e. the rate of dilution of the indoor air by fresh air, in air changes per hour.

The results are given in Table 2. Assuming an occupancy of 125 people per floor (i.e. equal to the number of desks) the fresh air rate is 9–10 l/s per person which is comfortably above the CIBSE recommended minimum of 8 l/s per person (ref. 3). At the actual occupancy rate of about 80 per floor, the fresh air per person is about 14 l/s.

Air speeds

Air speeds in the office were measured using Dantech omnidirectional low velocity anemometers at three heights: 0.1, 0.6 and 1.2m. The measured mean air speeds at one randomly chosen central location are given in Table 3. Air speeds generally were very low, about 0.1m/s varying in the range 0–2m/s.

The air speeds in the immediate vicinity of the air supply terminals in the floor were measured. The three sensors at the same heights as before were traversed in 300mm steps along the line joining two terminals

1450mm apart. The measured air speeds are given in Table 4. The air speed dropped to the low ambient value of 0.1m/s at 1m or more above the terminal and at all heights 250mm or more to the side of the terminal. Thus the potential draught zone at a terminal is very limited–extending to a radius of 250mm and a height of 0.6m.

Carbon dioxide

The carbon dioxide concentration at head height was recorded at 10-minute intervals during the week 5–11th September 1989, at one location on each floor. The concentration rose rapidly from about 340ppm at 8a.m. to a maximum of about 560ppm at 10am. After a lunch time dip to about 450ppm there was an afternoon peak similar to that of the morning, which decayed slowly after 6p.m.

The rate of decay of CO_2 concentration between 8pm and midnight on Friday evening gave the infiltration rate of fresh air into the building, when the air conditioning plant is off and the building unoccupied, as 0.2 air changes per hour or less.

Over the weekend, the CO_2 level falls to approximate the outside value of 250–300ppm.

Noise

The noise level was measured in dBA on each floor over a period of 40 minutes, during normal working hours.

Table 5. Measured noise levels

Location	time	L 10 dBA	L 50 dBA	L 90 dBA	L eq dBA
Ground floor: centre	1045	56.5	52.0	49.3	54.1
Ground floor: perim.	1130	62.0	55.0	48.8	59.8
2nd floor: centre	1445	62.5	57.5	53.5	59.6
2nd floor: perim.	1530	61.5	57.0	53.5	58.8

Sample time 40 minutes

The measured values are given in Table 5 where L_{10}, L_{50}, L_{90} are the noise levels exceeded for 10%, 50% and 90% of the time period, respectively. L_{eq} is the Equivalent Continuous Sound Level, i.e. the level of steady noise which has the same energy as the actual time varying noise measured.

The recommended noise limit for a landscaped office is given in the CIBSE Guide as NR45 where NR refers to a set of noise rating curves which define noise criteria in a way which takes the frequency content of the noise source and the frequency response of the human ear into account. The limit NR45 is roughly equivalent to 51dBA. NR50, roughly equivalent to 56dBA, would generally be considered noisy by sedentary workers.

Thus, according to the CIBSE criteria the NORWEB office is on the point of being too noisy.

Dust

The dust in the air was measured using a Climet particle counter: this instrument measures particle size distribution over the range 0.2 to 20 microns by an optical scattering technique. Results are given in Table 6, as number of particles per cubic metre in each size range.

The indoor dust is shown in Fig. 18 compared with that in the air outside, on the roof. It is seen that the air in the office is cleaner than outside air.

Lighting

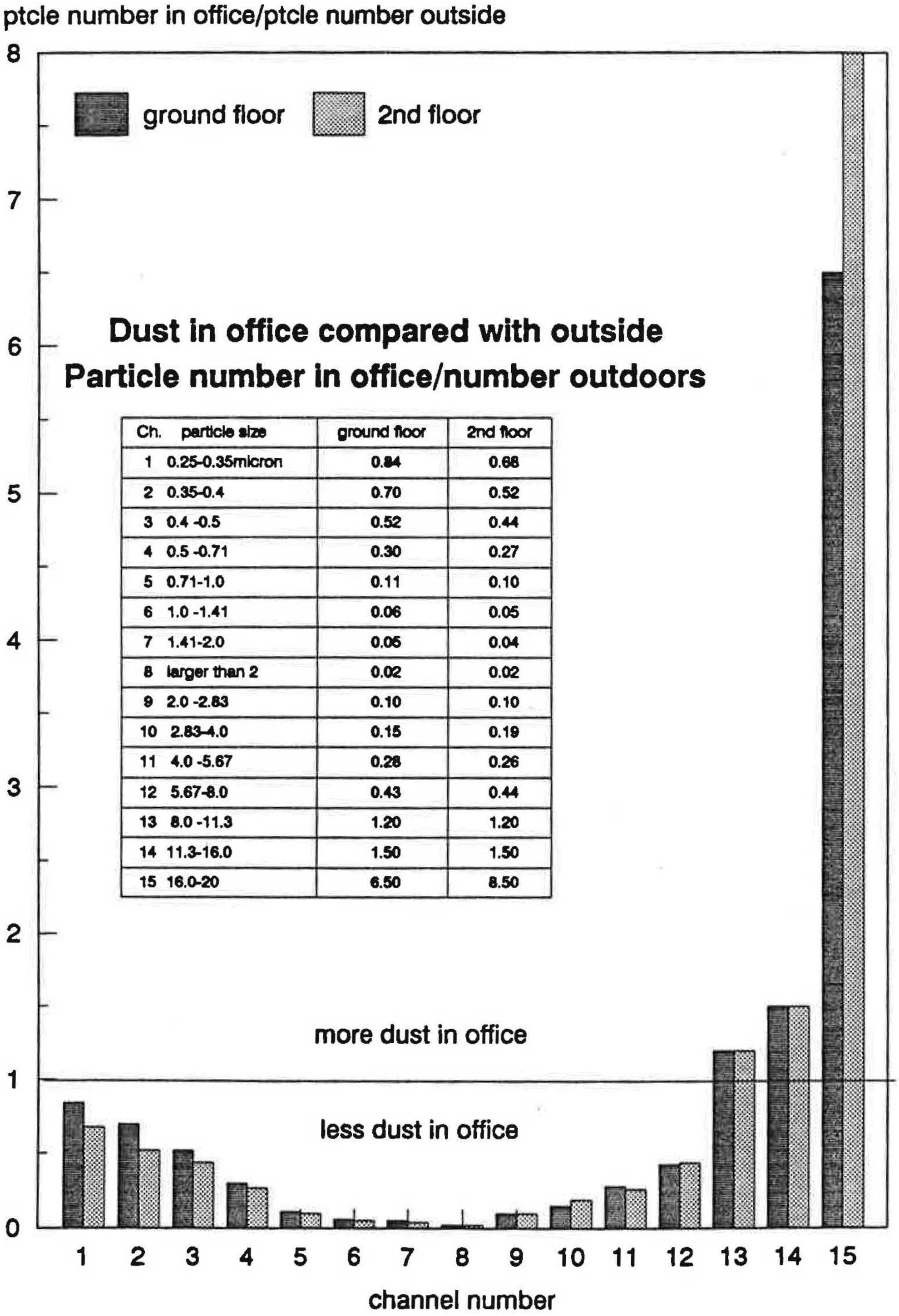
The illuminance was measured on each desk, with a person sitting at the desk. The results are given in Fig. 19. Most values were 400–600 lux, mean 525 lux and standard deviation 100 lux.

Microbiological survey

The microbiological quality of the ambient air and water associated with the building and services were evaluated by an independent specialist.

Table 6. Measured dust Climet particle counter

Ch.	particle size microns	outside particles/m^3	ground floor particles/m^3	2nd floor particles/m^3
1	0.25–0.35	57 000 000	48 000 000	39 000 000
2	0.35–0.40	23 000 000	16 000 000	12 000 000
3	0.40–0.50	10 000 000	5 200 000	4 400 000
4	0.50–0.71	9 600 000	2 900 000	2 600 000
5	0.71–1.00	3 800 000	410 000	380 000
6	1.00–1.41	6 200 000	370 000	310 000
7	1.41–2.00	4 100 000	200 000	160 000
8	>2.0	4 100 000	71 000	63 000
9	2.00–2.83	450 000	43 000	47 000
10	2.83–4.00	140 000	21 000	26 000
11	4.00–5.67	47 000	13 000	12 000
12	5.67–8.00	13 000	5 600	5 700
13	8.00–11.31	2 800	3 400	3 400
14	11.3–16.0	1 100	1 600	2 300
15	16.0–20.0	200	1 300	1 700
16	>20	0	90	90



Ch. particle size	ground floor	2nd floor
1 0.25-0.35micron	0.84	0.68
2 0.35-0.4	0.70	0.52
3 0.4 -0.5	0.52	0.44
4 0.5 -0.71	0.30	0.27
5 0.71-1.0	0.11	0.10
6 1.0 -1.41	0.06	0.05
7 1.41-2.0	0.05	0.04
8 larger than 2	0.02	0.02
9 2.0 -2.83	0.10	0.10
10 2.83-4.0	0.15	0.19
11 4.0 -5.67	0.28	0.26
12 5.67-8.0	0.43	0.44
13 8.0 -11.3	1.20	1.20
14 11.3-16.0	1.50	1.50
15 16.0-20	6.50	8.50

Fig. 18. Dust in office compared with outside

Samples of water were collected from:

mains tap in kitchen,
cold water storage tanks serving cold water services, hot water services, humidifiers,
calorifiers (two) for domestic hot water,
cold water taps in ground and 2nd floor toilet,
cooling tower distribution troughs (two).

Domestic hot water and recirculating cooling water samples were examined for legionellae and total viable bacteria capable of growth at 30°C. Cold water storage tanks were examined for legionellae and bacterial counts at 22°C and 37°C. Mains and cold tap water were examined for potability and overall bacteriological quality. No legionellae were found in any of the water systems.

The total bacteria counts (22° and 37°C incubation) were lower in the cold water storage tanks, and cold taps in the toilets, than in the mains water. The total bacteria counts (30°C incubation) were somewhat higher in the calorifiers (7500 and 55 000 per ml), indicating the need to drain them routinely at least once a year. In the

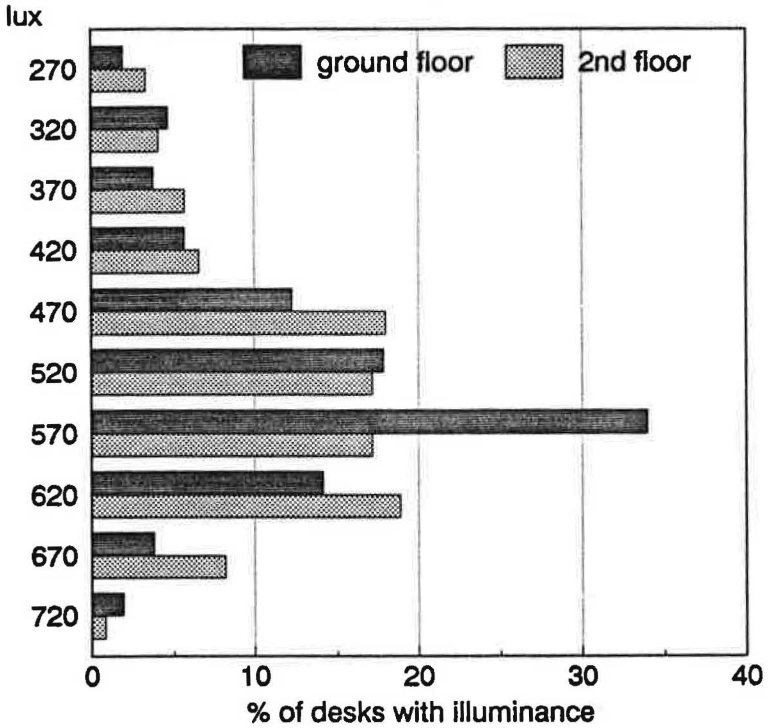


Fig. 19. Measured illuminance

cooling towers the count (>250 000 per ml) was just above the recommended limit of 10^5/ml. The significance of this depends on where in the biocide cycle the sample was taken; further regular sampling would show up any trends.

Air sampling was performed, between noon and 5p.m., using a portable sieve sampler at 18 sites within the building and two external locations. Air samples were analysed for bacteria (48 hours at 30°C on nutrient agar), yeasts and moulds/fungi (5 days at 25°C).

Similar results were obtained at all sites tested: 30 to 300 (mean 125) bacteria per cubic metre of air and 15 to 300 (mean 44) yeasts and moulds per cubic metre. This yeast and mould number was lower than outside where the count was 1200 per cubic metre.

In general, the condition of water and other building services was found to be excellent and very clean.

Water temperatures were found to be 18°C for cold water and 56.5–58.5°C for hot water, which should be effective in minimizing the risk of legionellae multiplication.

Conclusion

The immediate impression of a comfortable, pleasant office is reflected in the low 'Building Sickness Score' of 1.68 (average number of symptoms per person) found in the subjective survey.

The occupants were generally satisfied with the temperature, but there was a very slight tendency to feeling too warm rather than too cold. This might be expected at the measured temperature of 23°C.

Similarly, the humidity was generally acceptable, but with a tendency to feel dry rather than humid. This would not be expected at the measured relative humidity of around 50%. The dry feeling may be associated with being slightly too warm.

The noise level was considered loud and intrusive by just over half of the occupants. The measured noise level was at the limit of the CIBSE recommendations. This merits further investigation to find out what aspect of the noise is annoying.

The ventilation and lighting were both very satisfactory, which would be expected from the physical measurements.

The air in the building was cleaner than outside air with respect to dust and yeasts/moulds.

Although most people found their jobs fairly stressful, 73% felt that the environment had either no effect on, or enhanced, their productivity.

The BSS of 1.68 is extremely low compared with the average of 3.10 found by Building Use Studies in a survey of 46 buildings of all types. This is the most successful air-conditioned building they have surveyed (previous lowest BSS was 2.25), and is comparable with the best naturally ventilated buildings.

Acknowledgements

The cooperation of the staff at the NORWEB HQ Building during the course of this study is gratefully acknowledged.

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